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Cognition in Action: Testing a Model of Limb Apraxia

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Assessment of limb apraxia is still suffering from Liepmann's legacy and performance in gesture-processing tests is generally rendered by classifying patients' profile according to the classic clinical labels of ideomotor and ideational apraxia. At odds with other cognitive functions, interpretation of apraxia has suffered from a lack of a reliable model which does justice to its complexity. Recently such a model has been proposed (Rothi et al., 1991, 1997). In this article a modified version of this model is presented and predictions are made according to its functional architecture. Five different patterns of impairment of gesture processing are postulated. To validate the predicted performance profiles, 19 left-hemisphere-damaged patients were assessed by means of an ad hoc battery of four praxis tests. Four of the five predicted apraxia patterns were observed, the fifth being more equivocal. These results support the need to overcome the simplistic dichotomous view of apraxia and confirm the fruitfulness of a model of normal gesture processing in order to understand dissociations in apraxia. © 2000 Academic Press

Key Words: limb apraxia; gesture imitation; object utilisation; brain lesion.

INTRODUCTION

Limb apraxia is generally understood as covering all those disorders of purposive movements resulting from neurological dysfunction which cannot be explained by elementary motor or sensory defects, by task-comprehension problems, or by object-recognition deficits (De Renzi & Faglioni, 1999; Kertesz, 1979; Rothi et al., 1994; Liepmann, 1905; Rogers, 1996). Therefore apraxia is usually conceived as a deficit of gesture production and is defined

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by default. Clinical studies demonstrate that limb apraxia is generally associated with a lesion in the left hemisphere (Rothi & Heilman, 1997) and that it may be independent from aphasia (De Renzi & Faglioni, 1999).

Though the term was coined by Steinthal (1871), it was Liepmann (1900) who firstly formally investigated apraxia. He proposed a theory of gesture production distinguishing between the formulation of a motor program (the idea of a gesture) and the implementation of the planned spatio-temporal sequence (Faglioni & Basso, 1985). A deficit of formulation would give rise to ideational apraxia; a deficit of execution to ideomotor apraxia. This seminal dichotomy, which has gained the status of a dogma, challenged experimenters and clinicians for several decades to devise tools to enable them to set apart the two classic kinds of apraxia. Ideational and ideomotor apraxia have been identified by deficits of transitive (with the use of an object) or intransitive gestures (Morlaas, 1928) and by deficits on verbal command or imitation tests (De Renzi, 1985) respectively. Both these clinical definitions encompass the idea of limb apraxia as a deficit of gesture confined solely to its production. However, apraxics also show impairments in tasks which do not require the performance of a gesture. Examples of such impairments abound in the literature, ranging from errors in matching the drawing of an object with the associated typical gesture (Gainotti & Lemmo, 1976; Seron et al., 1979; Ferro et al., 1980; Rothi et al., 1985), to difficulty in ordering series of pictures depicting the action sequences required when using related objects to fulfill a task (Lehmkuhl & Poeck, 1981), to problems in categorizing objects according to manner of manipulation (Buxbaum & Saffran, 1998).

De Renzi (1985; De Renzi & Lucchelli, 1988), drawing upon Liepmann's original dichotomy, distinguished between two levels of gesture processing, a gestural semantics, which refers to long-term conceptual representations of actions, and a level of motor control, which subserves action execution. Not only do apraxics show deficits of production but also of gestures-knowledge. A semantic deficit would determine difficulty in classifying gestures and in performing familiar gestures on command. These same gestures might be well executed on imitation. On the other hand, a deficit of motor control would give rise to errors both on command and on imitation. Patients could retrieve the conceptual representations of gestures and perform classification tasks but fail in all execution tests. In De Renzi's frame of reference, which is hierarchically organized, the impairment in any task requiring the retrieval of gestures, such as demonstrating the correct use of an object, sparing imitation is labeled ideational apraxia, while a deficit on imitation tasks identifies ideomotor apraxia.

However, this influential model appears an oversimplification for at least four reasons. First, it cannot account for the reported dissociation in the opposite direction, i.e., when imitation is more impaired than response to verbal command (De Renzi & Scotti, 1970; Poncet et al., 1971; Ochipa et al., 1994).

Second, it does not predict that the imitation of meaningless gestures might be more impaired than that of meaningful gestures (Goldenberg & Hagmann, 1997). Third, it does not contemplate the possibility that ideomotor apraxia may show problems in discriminating clumsy from well-executed gestures (Heilman et al., 1982; Sirigu et al., 1995). Finally, patients have been observed showing problems with the use of objects on command, i.e., ideational apraxics, yet performing flawlessly in selecting the right object–gesture picture among alternatives (Bergego et al., 1992).

To account for the mounting evidence calling for dissociation within the praxis system, Rothi et al. (1991, 1997) proposed a cognitive neuropsychological model of limb praxis mapped onto the model of language comprehension and production (Patterson & Shevell, 1987). This model has three main features: (i) it distinguishes between a semantic and a nonsemantic route for meaningful (familiar) and meaningless (nonfamiliar) gestures respectively: the gesture may be retrieved via the semantic path or programmed through the nonsemantic route. (ii) Within the semantic route, besides the praxis conceptual system, the semantics proper, which was postulated also by earlier authors, a lexical level is assumed, which encompasses a repertoire of learned gestures. (iii) The lexicon is further subdivided into input and output, with the input level responsible for the recognition of familiar gestures, the output level for their production.

Notwithstanding the clear step forward in understanding apraxia that this model accomplished, some confusion still subsists between cognitive and anatomical categories within the model. For instance, it delineates ‘‘innervatory patterns,’’ motor schemes to perform skilled movements which are conceived to be anatomically segregated in the supplementary motor area (Rothi et al., pp. 448–449). This mingling between anatomical and cognitive concepts does not serve clarity well. Moreover, the structure and function of the SMA is far from understood (Lüders, 1996).

In Fig. 1 a revised version of Rothi et al.’s model of limb praxis is presented, which is entirely based on cognitive concepts. It differs from the original in three respects: (i) It devises a visuomotor conversion mechanism, akin to the grapheme/phoneme path pictured in models of language. This conversion mechanism is devoted to the transcoding visual analyses into the motor programs; it can also account for the deficit observed in some apraxic patients who could neither reproduce meaningless gestures on their own body nor on a mannikin (Goldenberg, 1995). As Goldberg himself pointed out (Goldenberg & Hagmann, 1997, p. 338), ‘‘the movements necessary for manipulating a mannikin are basically different from those of the gesture itself,’’ therefore visual analyses could not be directly transduced into movement pattern, and a converting mechanism is necessary. (ii) No direct link between input and output lexicon is assumed, mainly because empirical evidence supporting it has yet to be reported. In fact a phenomenon akin to hyperlexia (ability to read regular as well as irregular words without compre-

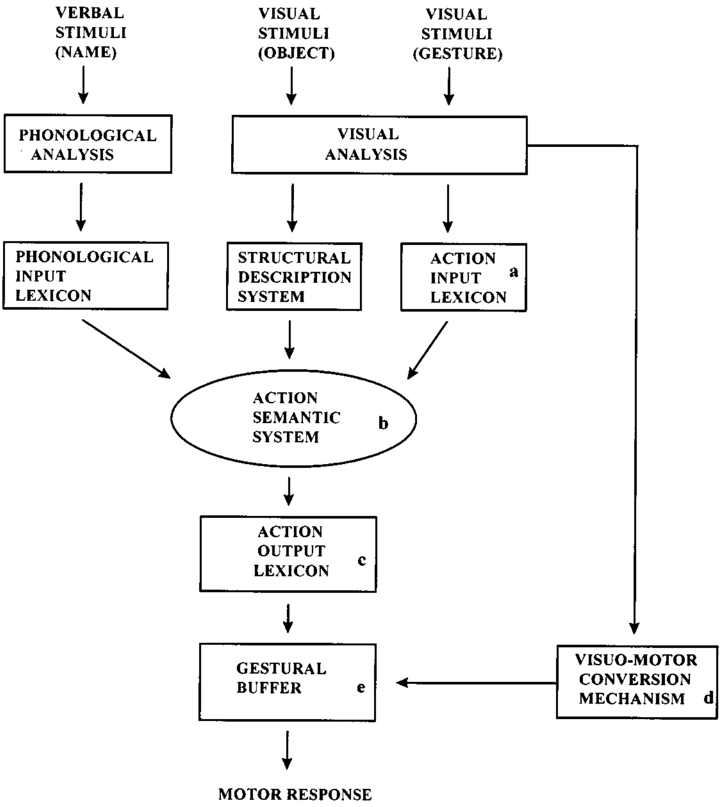

FIG. 1. Outline of the cognitive model of limb praxis (modified from Rothi et al. 1991, 1997).

hending their meaning; Schwartz et al., 1980) has never been observed in apraxia. This patient would show intact ability to reproduce familiar but not unfamiliar gestures, yet the meaning of familiar gestures would remain obscure. (iii) The lexical and nonlexical routes are thought to converge in a gestural memory buffer, equivalent to the phonological buffer, aimed at holding a short-term representation of the to-be-executed motor program, independent of its origin within the semantic or nonsemantic route. This buffer accounts for the time needed to translate abstract formats of complex gestures into the appropriate sequences of motor commands, giving rise to a series of linked movement segments which correspond to full-blown action.

The proposed model makes provisions for a cognitive approach to the investigation of apraxia without the need to call for neurological ‘‘contamination.’’ The original model by Rothi et al. (1991, 1997) encompasses Liepmann’s notion of ‘‘innervatory patterns.’’ Liepmann conceived these ‘‘innervatory patterns’’ as a mechanism apt ‘‘to transform . . . movement formula promptly and precisely into innervation'' (Rothi & Heilman, 1996, p. 116). If, by this definition, he meant to refer to abstract schemas of learned movements, then the ''patterns'' correspond to the programs in the action output lexicon. If, on the other hand, the innervatory patterns are synonyms of motor programs codified directly from visual inputs, then the concept is overlapping with the visuomotor conversion mechanism. Last, these patterns might have been thought of as motor commands to be sent to specific muscle groups downstream from the gestural buffer. Either way the rather aspecific label of ''innervatory patterns'' could be dismissed.

Within the revised version of the model, according to different loci of impairment it is possible to predict five clinical pictures of praxis disorders. These levels of impairments are marked in Fig. 1 with lowercase letters. At this stage of knowledge it is impossible to differentiate between representation (boxes) deficits and access (arrows) impairments (Rapp & Caramazza, 1993). The five predicted types of apraxia profiles are detailed below.

(a) Deficit of action input lexicon: difficulty in discriminating and comprehending seen gestures with spared ability to imitate and execute gestures on verbal command. A patient with an impairment at this level would show a deficit akin to that labeled ''pantomime agnosia'' (Rothi et al., 1986). (b) Impairment within the action semantic system: spared imitation but impaired execution on command coupled with problems in attributing meaning to gestures. This pattern has been called ''conceptual apraxia'' (Ochipa et al., 1992; Heilman et al., 1995). A patient showing this kind of impairment should be able to disentangle familiar from unfamiliar gestures and to tell apart well-executed from clumsy gestures. The clinical picture deriving from an impairment at this level would be characterized by ideational without ideomotor apraxia. (c) Deficit of the action output lexicon: the deriving picture differs from a semantic impairment only insofar as gesture–meaning association is spared; as in the previous pattern, imitation is supposed to be normal. (d) Deficit of the visuomotor conversion mechanism: isolated impairment of imitation is more overt for meaningless gestures. This pattern clinically could be described as ideomotor without ideational apraxia. The term ''conduction apraxia'' introduced by Ochipa et al. (1994) to denote a selective impairment of gesture imitation seems appropriate to label this pattern. (e) Deficit of gestural buffer: impairment in all execution tasks either on command or on imitation coupled with preserved ability to perform judgement and categorization tasks. The corresponding clinical picture is a sum of both ideomotor and ideational apraxia. The buffer being a temporary storage space, complex sequences should be more affected than single gestures.

None of the predicted patterns is incompatible with the original model proposed by Rothi et al. (1991, 1997). However, the modified version of the model allows for more direct predictions intrinsic to its structure (e.g., the deficits of nongestures imitation due to an impairment of the visuomotor conversion mechanism or the gesture complexity effect expected following the malfunction of the gestural buffer).

The aim of this article is to assess the model by searching for the five predicted patterns of spared and impaired functions detailed above.

METHODS

Participants

The following criteria were established for including the patients in the study: they should be right-handers, be younger than 80 with at least 3 years of full-time education (such low education is not unusual in the Italian population born before the second World War), affected by a single CT-demonstrated nonacute vascular lesion limited to the left hemisphere, should not be affected by other neurological or psychiatric diseases and/or alcoholism or take any drug which could potentially interfere with the testing results, and should perform above the age and education-adjusted cut off score (Basso et al., 1987) in the Raven Coloured Progressive Matrices (RCPM) (Raven, 1965). A consecutive series of 52 patients affected by clinical signs indicative of a left-hemisphere stroke, admitted to the Neurology Ward of the Medical Centre of Veruno between June 1996 and February 1997, were considered for the study. Sixteen patients were excluded because the CT scan demonstrated multiple lesions in the left hemisphere or previous unnoticed lesions in the right hemisphere, four performed poorly in the RCPM, five had comprehension problems too severe to allow reliable testing, five were older than 80, one was affected by Parkinson's disease; one was blind, and one patient was transferred to another hospital to be treated for an acute abdominal pain before testing was completed. The remaining 19 patients entered the study. Their individual demographic and clinical data are reported in Table 1.

Twenty normal participants, 13 men and 7 women, matched for age and education with the patients, provided the normative data for the experimental tests. Their mean age was 66.7 (SD-7.1, range-54–79); their mean education was 6.4 years (SD-3.1, range-4–17).

Tests and Procedures

General Neuropsychological Assessment

All patients underwent a general neuropsychological assessment comprising three verbal and three visuospatial tests. The verbal tests were Picture Naming (Laiacona et al., 1992), the Token Test (De Renzi & Faglioni, 1978), and the Oral Comprehension section of the Italian version of the Aachener Aphasie Test (Willmes et al., 1988). The visuospatial tests were the Scrawl Discrimination Test (Spinnler & Tognoni, 1987), whereby the participants are asked to judge whether two meaningless scrawls are the same or different; the Benton and Van Allen's (1968) unfamiliar Face Recognition Test; and the Copying of Geometrical Shapes proposed by Arrigoni and De Renzi (1964). The cut off scores employed were those reported in the relevant literature.

Praxis Assessment

All patients and controls underwent four tests of gestural processing. For the purpose of this investigation tests already available (some in the original version, some others slightly modified) have been employed. Three tasks tested gesture production (two on command and one on imitation), while one tested the recognition of transitive (with objects) gestures. We decided against the use of pantomimes due to the difficulty in categorizing them as transitive

TABLE 1
Demographic and Clinical Data of the Left Brain-Damaged Patients

Patients	Sex	Age (years)	Education (years)	Days from onset	Lesion type	Lesion site	Raven's CPM*
1	Male	66	5	42	I	BG, WM	21.5
2	Male	54	11	53	I	T-P	24
3	Male	64	5	50	H	Th, WM	25.5
4	Female	75	5	41	I	BG, WM	22
5	Male	68	5	53	H	BG, IC	27
6	Male	68	5	115	I	Th, IC	18
7	Male	72	5	57	I	IC, WM	33
8	Male	66	5	79	I	BG, IC	23.5
9	Male	58	10	19	I	F-T-P	22
10	Female	60	5	390	I	F-T	22.5
11	Male	79	8	82	H	F-T	34.5
12	Male	57	8	1920	H	T-P	34.5
13	Female	67	5	45	I	T-P	18.5
14	Male	75	5	19	I	IC, WM	26
15	Female	57	5	850	I	F-T	33
16	Female	75	17	97	I	F-T	21.5
17	Female	68	4	25	H	F-T	20
18	Male	65	5	26	H	Th, IC	33.5
19	Male	66	5	40	I	T	22.5

Abbreviations: I, ischaemic stroke; H, haemorrhage; T, temporal; F, frontal; P, parietal; BG, basal ganglia; Th, thalamus; IC, internal capsule; WM, white matter.

* Age- and education-adjusted scores (range: 0–36; cut off: 18).

or intransitive and, indeed, the difficulty in interpreting most of the errors in terms of apraxia (for a discussion see Cubelli & Della Sala, 1996). The patients performed all production tasks using their left hand, ipsilateral to the damaged hemisphere. Therefore their performance could not be influenced by basic motor impairments. Controls as well performed the production tasks with the left, nondominant limb. All production tasks performances were videotaped.

Imitation of intransitive (without object) gestures. The test devised by De Renzi et al. (1980) was employed. This is a 24-item imitation test consisting of half meaningful and half meaningless movements, half requiring to hold a posture and half the execution of a motor sequence. Following the authors' instructions, the score for each item ranges from 3 to 1 depending on whether the performance is errorless on the first, second, or third attempt. A score of 0 is given when the performance is incorrect all three times. Therefore the total score ranges from 0 to a best of 72. In relation to the model depicted in the Introduction, the meaningless items of this test assess the functioning of the entire nonlexical pathway (from visual analysis to gestural buffer), while the meaningful items make use of both the lexical and the nonlexical pathways. Sequences may be more demanding than postures for the gestural buffer or the visuomotor conversion processes. The relative ''difficulty'' of the different sections of this dichotomy is reflected also in the performance of the normal controls reported by De Renzi et al. (1980).

Production of meaningful intransitive gestures (e.g., wave goodbye and military salute) in response to verbal command. A set of 20 gestures was employed for this task. Ten gestures were those proposed by De Renzi et al. (1968), and 10 new ones were added to increase the score range. To evaluate the familiarity and transparency of the added gestures, a group of 15 normal participants (8 males and 7 females, mean age 45.5, mean education 10.8) was shown the 10 gestures and asked to describe their meaning verbally. Their definition of the meaning and the name of the gestures matched entirely with that embedded in the test. The name of each gesture was therefore presented individually to patients and controls entering the study. The score for each item was 2 or 1 depending on whether the performance was errorless on the first or second attempts respectively. A score of 0 was given if the performance was wrong on the second attempt. The total score ranges from 0 to a best of 40. As mentioned above, the production of gestures on verbal command needs spared access to the semantic representation system and to the action-output lexicon.

Recognition of object utilization gestures and actual use of objects. These two tests were derived from Bergego et al. (1992). Twenty sets of colored photographs, 12.5 × 18 cm, with four pictures in each set, were used for the visual-recognition task. Each set showed the same actress demonstrating the use of different everyday objects (e.g., toothbrush and chopping knife). In each four-item set, one photograph depicted the correct use of the object. The remaining three photographs showed the objects well positioned in relation to the relevant body part but incorrectly oriented (e.g., bristles of the toothbrush pointing outward and knife with the blade upside-down), inappropriately held (e.g., toothbrush held between the forefinger and the second finger and knife held by the blade), or used as if it were another object (e.g., toothbrush as a comb and knife as a pencil). An example of the material used is given in Fig. 2. The stimuli were presented on a white paper background, two photographs beside each other with the other two directly underneath. The position of the target and the various distracters was balanced across the stimulus set.

The items were selected by means of a series of pilot studies. Fifty-two highly educated, young normal participants were individually asked to classify each photograph according to the four categories: correct use, wrong orientation, incorrect holding, or use as another object. They were told that different photographs of the same object could belong to the same category (e.g., the toothbrush could be thought to be incorrectly held twice). The sets which resulted ambiguous were replaced by new items for further pilots. The best set of photographs was then shown to 12 new ‘‘judges.’’ Eight of them gave answers entirely matching the experimental categories, while only one subject made more than 3 unexpected classifications of 80 (20 four-photograph stimuli). This set was considered reliable enough and was used in the experiment. The experimental participants were asked to select the target from the distracters and 1 point was given for each correct selection for a total score ranging between 0 and 20. This test requires the participants to select the correct gesture from among distracters considering both its function and its handling, thus creating some ambiguity and drawing at the same time on semantics and lexicon for identification and dexterity judgement respectively.

In the production version of the test, participants were given the same 20 target objects and were asked to show their use. One point was given for each correct selection for a total score ranging between 0 and 20. Performance of all participants was scored according to the same four criteria detailed for the recognition task by two independent judges trained to administer the tasks to allow analysis of errors. Only in three instances did the two judges disagree on the type of error in a given item. In these cases, a third neuropsychologist, blind of the scoring given by the previous two, acted as the deciding judge.

In relation to the model reported in the Introduction, the recognition test assesses the action input lexicon and its link to semantics; the actual Use of Object Test taxes the object-recognition unit (structural description system) and the tactile-recognition process, the semantics related to the object, and the relevant gestural information stored in the output lexicon. A deficit in both is indicative of a deficit in semantics, which is the common denominator.

RESULTS AND DISCUSSION

The performance of the patients in the general neuropsychological assessment battery is detailed in Table 2.

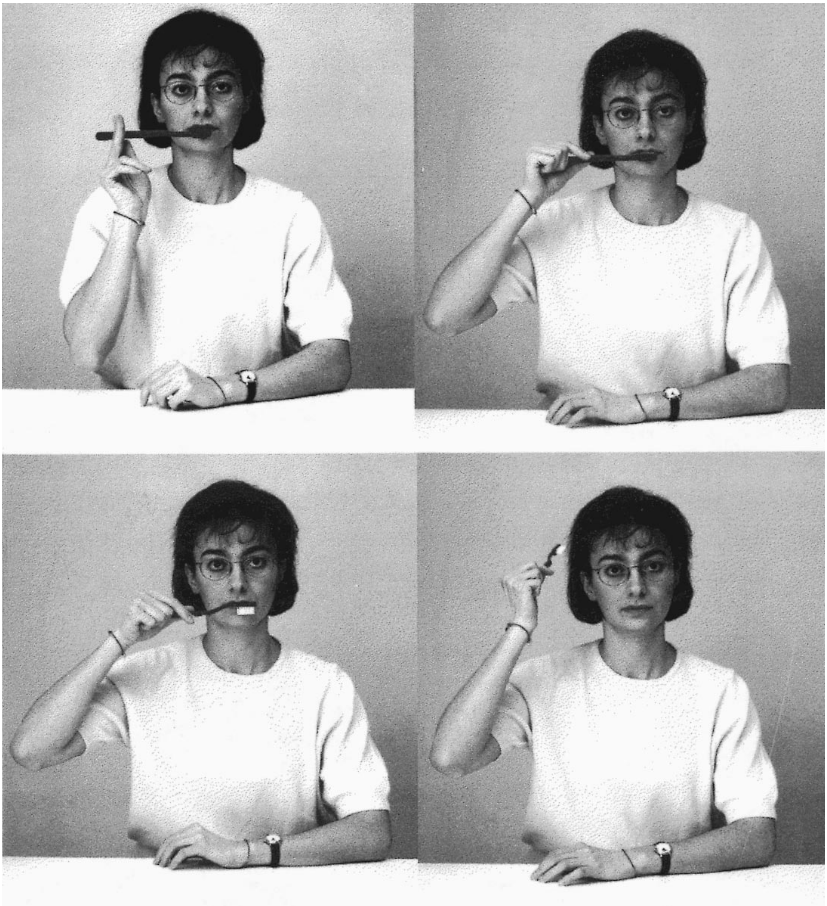

FIG. 2. Example of one stimulus set of the Recognition of Object Utilization Gestures test. Clockwise from top left: object wrongly held, correct choice, object used as another object (toothbrush as a comb), object wrongly oriented.

Two patients (cases 11 and 18) performed above the cut off scores in all the tests of the battery. Most patients performed poorly in one or another of the three verbal tasks, though some dissociation emerged, in particular case 4 performed pathologically in the comprehension subtest of the AAT, but not in the Token Test, while case 12 showed the opposite pattern. These apparent discrepancies could be traced back to the different test material employed in the two tasks: for instance the Token Test comprises complex and long sentences which call for backtracking, taxing short-term memory as well as syntactic mechanisms subserving on-line auditory comprehension. On the other hand, the subtest of the AAT requires the matching between

TABLE 2
Patients' Performance in the Neuropsychological Assessment Battery (Asterisks Indicate Pathological Scores)

	Verbal Tasks			Visuospatial Tasks		
Patient	Picture Naming[a]	Picture–Word Matching[b]	Token test[c]	Scrawl Discrimination[d]	Face Recognition[e]	Figure Copying[f]
1	39*	39*	18*	32	39	4.25*
2	0*	46*	15.5*	31	44	10.75
3	61	46*	26.5	28	45	7.25*
4	42*	37*	30.5	30	39	10.75
5	27*	41*	17.75*	22	35*	8.5
6	0*	39*	11.25*	30	37*	10.5
7	61	46*	20.25*	31	40	13.5
8	39*	40*	21*	28	35*	7.25*
9	0*	45*	9.5*	32	37*	10.5
10	16*	46*	17.25**	25	41	7*
11	62	60	30.25	32	46	14.5
12	46*	60	24.25*	32	49	12.5
13	0*	35*	3.5*	20*	26*	4.25*
14	0*	26*	4*	30	36*	3.75*
15	66	50*	25.5*	32	42	14
16	65	60	30.5	28	41	7.25*
17	0*	34*	7.75*	20*	34*	0*
18	70	58	30.5	29	47	12.25
19	0*	43*	16*	30	50	12.25

[a] Range: 0–80; cut off: 61.
[b] Range: 0–60; cut off: 52.
[c] Range: 0–36; cut off: 26.5.
[d] Range: 0–32; cut off: 21.
[e] Range: 0–54; cut off: 38.
[f] Range: 0–14; cut off: 8.

TABLE 3
Patients' Performance in the Praxis Assessment Battery (Asterisks Indicate Pathological Scores

	Transitive gestures		Intransitive gestures	
	Recognition (range: 0–20)	Use of objects (range: 0–20)	Verbal command[a] (range: 0–40)	Imitation[b] (range: 0–72)
Controls				
Range	17–20	18–20	26–40	53–72[c]
Cutoff	16	17	24	53[c]
Patients				
1	17	16*	13*	50*
2	19	13*	7*	38*
3	15*	19	27	67
4	13*	12*	26	53
5	17	19	18*	50*
6	15*	13*	19*	53
7	18	18	33	67
8	17	14*	28	63
9	17	18	24	61
10	20	12*	6*	42*
11	20	19	36	69
12	20	20	32	64
13	14*	0*	0*	22*
14	7*	4*	0*	4*
15	20	18	24	59
16	17	16*	16*	60
17	15*	6*	3*	11*
18	19	18	36	58
19	18	18	4*	54

[a] Only meaningful gestures.
[b] The stimuli were gestures with or without meaning (from De Renzi et al., 1980).
[c] Normative data are taken from De Renzi et al. (1982).

spoken words and outlines of objects, or between spoken sentences and sketches of actions, also drawing upon semantic knowledge.

For the purpose of this study we considered the performance of each individual task rather than lumped the scores together under a diagnostic label (e.g., aphasia/nonaphasia). As expected, visuospatial tasks were, on the whole, better performed. Only two patients (cases 13 and 17) failed the Scrawl Discrimination Test; it is worth noting that they showed the most severe failure in all the tasks of the battery.

Table 3 shows the scores achieved by the control group as a whole and by each individual patient in the praxis assessment.

In the Imitation of Intransitive Gestures Test the cut off score (53) suggested by the authors was used (De Renzi et al., 1982, 1986). In the remaining three tasks, the cut off was established as the worst score achieved by the controls participating in the present study minus an additional 5% (1 point in tasks whose score ranges from 0 to 20, and 2 points in those up to 40). For example, in the Recognition of Object Utilization Gestures Test the worst control achieved a score of 18/20, so the cut off score was set at 17; therefore each performance of 16 or below was considered pathological. A score mapping onto the worst normal performance (17 in the example above) has been considered as borderline.

Seven patients (37%) scored below cut off in the Imitation of Intransitive Gestures Test, a figure overlapping with that (32%) reported by De Renzi et al. (1982) using the same test. The performances of the patients and controls in the other tasks of the praxis assessment have been considered in group analyses. Moreover, patients' performances have also been analyzed using a multiple single-case approach.

Group Analyses

In the production of meaningful intransitive gestures in response to verbal command the patients were on the whole less accurate than the controls [$F(1, 37) = 26.983$; $p < .001$]: the patients' performance was probably hampered by the associated aphasic disorders. In the Recognition of Object Utilization Gestures and Use of Objects, both the effects of Group [$F(1, 37) = 16.955$; $p < .0005$] and Task [$F(1, 37) = 4.359$; $p < .05$] were significant: the patients were on the whole less accurate than the controls and found the utilisation task much more difficult than the recognition task. Indeed, the interaction Group × Task was significant [$F(1, 37) = 7.906$; $p < .01$].

An analysis of errors type (object misoriented, misheld, or used as another object) was performed with data from the patient group. Only the errors, not the omissions, were considered. Case 13 was not entered in this analysis because of a floor effect in his performance in the Use of Object Test, mainly due to his frequent refusals. Results from this analysis demonstrated that there was no significant difference between recognition and use of objects [$F(1, 17) = 1.512$, ns]. On the other hand, the effect of the type of error did reach significance [$F(2, 34) = 4.918$, $p < .02$]; so did the interaction Task × Error type [$F(2, 34) = 9.278$, $p < .001$]. Figure 3 shows the patients' mean error scores according to the three possible types of error. The amount of holding errors in the Use of Object Test is outstanding. Simple comparisons showed that they were more frequent in the Use of Object Test than in the Recognition Test [$F(1) = 18.500$, $p < .005$], and within the Use of Object Test they were more frequent than either misorientation [$F(1) = 15.465$, $p < .005$] or ''use as another object'' errors [$F(1) = 18.500$, $p < .005$]. Using an object as another can be accounted for in terms of object misidentification and the misorientión of an object is caused by erroneous spatial relationships. However, holding errors recognize more than one cause in the execution of a

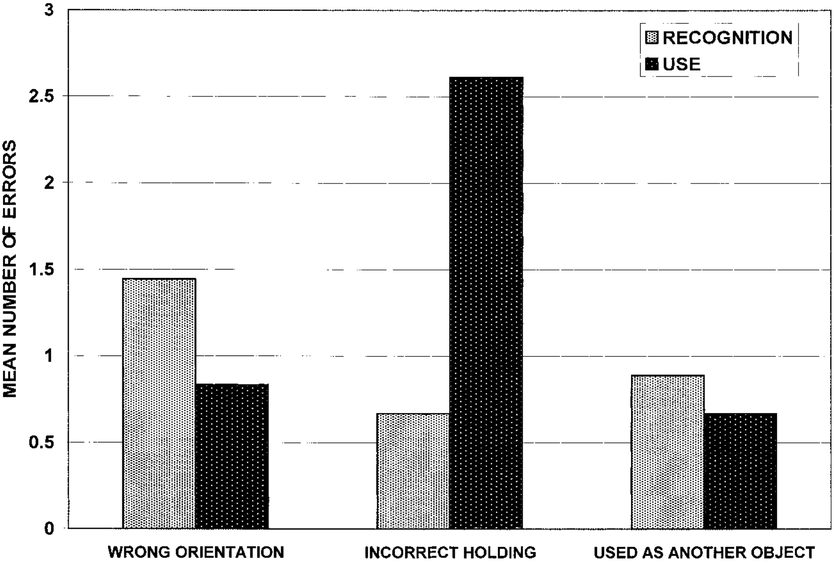

FIG. 3. Mean number of wrong responses in the Recognition of Object Utilization Gestures and Actual Use of Object tasks according to error type.

gesture, ranging from the coordination of different body parts to the selection and serialization of the various segments of a gesture program.

In the Recognition task ''orientation'' errors were more frequent than the other two types and than those in the Use of Object Test; however, these differences fell short of significance.

Multiple Single-Case Approach

Cases 7, 9, 12, and 15, who were not apraxic, performed pathologically on the Token Test and on the other verbal tasks. This observation, coupled with the neuropsychological profile of Case 16, who was apraxic though not aphasic, confirms the reported dissociation between apraxia and language disorders (e.g., Selnes et al., 1982; Papagno et al., 1993; Marchetti & Della Sala, 1997). As to the localization of the lesions, seven cases showing apraxia on one or another test had a lesion confined to subcortical structures sparing the cortex. This confirms the hypothesis that subcortical damage can be associated with apraxia (see review in Della Sala, Basso, Laiacona, & Papagno, 1992). However, the subcortical lesions of our apraxic patients (see Table 1) always encroaches upon the periventricular and peristriatal white matter, supporting the hypothesis that these white areas are crucial for apraxia to emerge following deep-sited lesions (Della Sala et al., 1992; Pramstaller & Marsden, 1996).

In the Introduction we established the five foreseeable patterns according

TABLE 4
Patterns of Performance Which Emerged in the Praxis Assessment Battery

	Transitive Gestures		Intransitive gestures		
Patients	Recognition	Use of objects	Verbal command	Imitation[b]	Assumed deficit (see model)
3	−	+	+	+	a
4	−	−	+	+	b
16	+	−	−	+	c
8	+	−	+	+	c
19	+	+	−	+	c
5	+	+	−	−	d (+ c) ?
1	+	−	−	−	e
2	+	−	−	−	e
10	+	−	−	−	e

[a] The signs + and − indicate normal and pathological performance respectively.
[b] From De Renzi et al. (1980).

to the cognitive model of gestural processing. Six of our patients performed above cut off on all tests (cases 7, 9, 11, 12, 15, and 18), while three failed them all (cases 13, 14, and 17), and one scored just above threshold only in the Imitation of Intransitive Gestures Test (Case 6). These 10 patients were either too mild or too severe to contribute to the analysis of dissociating patterns.

The pattern of performances in the praxis test battery of the remaining nine patients, summarized in Table 4, shows some interesting dissociations which deserve comments.

Case 3 failed *only* the Recognition of Object Utilization Gestures Test. This deficit cannot be interpreted as due to a visual deficit because the patient performed well on imitation, and his scores in the visual tests, such as Face Recognition and Scrawl Discrimination, were well within the normal limits. In particular, he made five recognition errors, three choosing the misoriented object and two selecting the ‘‘use as another object’’ picture; however, he never selected the ‘‘incorrect holding’’ photograph. His testing profile is compatible with pattern ‘‘a’’ deficit, characterized by a problem at the level of input lexicon (see Fig. 1). His pattern is similar to that presented by the two patients reported by Rothi et al. (1986) and labeled ‘‘pantomime agnosia.’’ Also, the patients observed by Rothi et al. (1986) performed normally in gesture-production tests both on imitation and on verbal command, but poorly in gesture discrimination and comprehension. Alternatively, one could account for case 3’s deficits by postulating a problem in accessing the semantic system from a visual route. Indeed, all his errors in the Picture Naming were verbal substitutions, which were both semantically and visually similar to the target objects (e.g., guitar for violin and dining table for writing desk).

Case 4 failed both the Recognition of Object Utilization Gestures Test and the Use of Objects Test, while her performance in the imitation task was within the normal limits. Her testing profile is indicative of a problem at the semantic level (‘‘b’’ in the model; Fig. 1). However, she did not fail the execution of meaningful gestures on verbal command. Therefore, her semantic deficit ought to be restricted to transitive actions. An indirect confirmation of this diagnosis comes from her performance in the verbal tasks (see Table 2). In fact, she failed the two verbal tasks which require the processing of object names and pictures, while her performance in the Token Test was well above the cut off score. This pattern is akin to that reported by Ochipa et al. (1989) in a patient, labeled ‘‘ideational apraxic,’’ who showed a specific deficit in the selection and use of tools. It would be possible to argue that a semantic deficit should involve meaningful gestures of all kinds. However, transitive and intransitive gestures differ from each other in one important dimension: while the use of an object is constrained by its function, the symbolic, intransitive gestures vary according to different sociocultural contexts (the same meaning may be expressed by different gestures, the same gesture may convey different meanings). Given this intrinsic difference, it seems plausible to assume distinct semantic representations for intransitive and transitive gestures, which could be selectively affected. According to the definition proposed by De Renzi and Lucchelli (1988), Case 4 showed an ‘‘amnesia of usage,’’ specifically limited to the manipulation and use of objects. From the theoretical perspective the opposite dissociation (i.e., a semantic deficit restricted to intransitive gestures) should also be possible. However, we did not observe it in the present sample. Moreover, it is difficult to cull such a case from the literature because in most apraxia batteries intransitive gestures are tested only on imitation (see De Renzi & Faglioni, 1999).

Case 16 performed well in the Imitation of Intransitive Gestures Test and in the Recognition of Object Utilization Gestures but failed the other two tests in the praxis battery. Her good performance in the recognition test excludes a semantic or input lexicon deficit, while her high score in the De Renzi et al.’s test demonstrates the integrity of the nonlexical route. At the same time her poor performance in the execution tasks (use of objects and production of meaningful gestures on verbal command) suggests an output lexicon deficit (‘‘c’’ in the model, see Fig. 1). It is worth noting that the patient’s failure on verbal command cannot be accounted for in terms of language impairment since she was not aphasic (see Table 2). Some support for this diagnosis comes from the analysis of the errors that she made in the Use of Object Test, whereby three of four errors were of the ‘‘wrong holding’’ type, i.e., production errors.

A deficit in ‘‘c’’ (see Fig. 1) might also account for the pattern shown by Case 8, who only failed the Use of Object Test. It is worth noting his good performance on verbal command (Table 3), even if he had clear language impairment (Table 2). Given his good performance in gesture recognition, to account for his profile it is plausible to postulate a deficit of the output lexicon limited to the use of objects. Indeed, all six errors he made were of the ‘‘wrong holding’’ type. Case 19 shows a profile reciprocal to that of Case 8 insofar as his lexical output deficit seems confined to intransitive gestures. As is the case for the semantic system, transitive and intransitive gestures could also be represented separately at the level of the output action lexicon. Motor programs for transitive gestures are constrained by the shape and size of the objects to be manipulated. On the contrary, motor programs for intransitive gestures are geared by an arbitrary link between each gesture and its meaning, i.e., they may be triggered by environmental cues but they are not molded on physical features. As a caveat it should be pointed out that patient 19 was aphasic; therefore his failures on verbal command (intransitive gestures) could be (at least partly) due to poor auditory comprehension.

In the series of cases reported in this study a patient presenting with a pattern reflecting a pure ‘‘d’’ deficit (see Fig. 1) was not observed. Such a patient would show imitation difficulty, more pronounced for unfamiliar and meaningless gestures, coupled with spared access to semantics and to the lexicon. This pattern would translate into a poor performance in the Imitation of Intransitive Gestures Test (De Renzi et al., 1980) and good performance in the remaining three tasks of the praxis battery. Case 5 did show the dissociation between De Renzi et al.’s test, which he performed poorly, and on both tests assessing the recognition of object utilization gestures and the actual use of objects. However, he also failed in executing meaningful gestures on verbal command. Reasoning on the basis of the proposed model, it would be possible to interpret the pattern of spared and impaired praxic skills showed by Case 5 by postulating either a double deficit (‘‘d’’ plus difficulty in accessing the lexical/semantic representation of intransitive gestures) or advocating that the poor verbal-driven performance could be accounted for in terms of his severe aphasia (Table 2). However, the likelihood of a deficit limited to the nonlexical route is hindered by the absence of any effect of familiarity in the imitation task. The patient scored 25/36 and 24/36 in reproducing the meaningful and the meaningless gestures respectively in De Renzi et al.’s task. Therefore the double deficit (‘‘d’’ + ‘‘c’’) provides the more convincing interpretation of his impairments.

Cases 1, 2, and 10 failed all tasks but recognition. Their pattern is compatible with a deficit of the gestural buffer (‘‘e’’ in Fig. 1). The gestural buffer should be thought of as a short-term memory system devoted to the temporary holding of the motor plans to be implemented. A deficit at this level should hamper all tasks requiring motor responses. Therefore, patients with a deficit in ‘‘e’’ should show apraxia on verbal command coupled with apraxia in imitation tasks. Given the damage to the short-term storing buffer, a difficulty gradient is foreseen whereby the more memory loading an item requires, the more affected it may be. Typically, as stated in the Introduction, sequences should be more affected than postures. Cases 2 and 10 did show such a ‘‘complexity’’ effect. In De Renzi et al.’s (1980) Imitation of Intransitive Gestures Test, Case 2 scored 31/36 in reproducing the postural items but only 7/36 in imitating the sequences [$F(1, 20) = 30.638$, $p < .001$]. Similarly, Case 10 achieved 27/36 and 15/36 respectively [$F(1, 20) = 4.045$, $p = .05$]. Case 1 imitated the postural items better than the sequences (29/36 versus 21/36), even though the difference fell short of significance [$F(1, 20) = 1.758$, ns]. The performance of these three patients did not differ across the meaningful/meaningless dimension. The other six patients considered in some detail (cases 3,4,5,8,16, and 19), who did not show impairments at the level of the gestural buffer, did not present with such a stimulus-complexity effect.

CONCLUSIONS

As has been the case for the studies of language and several other cognitive functions, a reliable model of praxis will ease test design, data interpretation, clinical reports, and rehabilitation planning. Moreover, it will allow clinicians and experimenters to go beyond the taxonomic quagmire based on Liepmann’s legacy (Cubelli & Della Sala, 1996). Further, the availability of a dependable model will allow us to interpret results of group studies employing large test batteries (e.g., Lehmkuhl et al., 1983; Belanger et al., 1996) and to overcome the current *empasse* in accounting for individual apraxic patients showing complex clinical pictures (e.g., Motomura & Yamadori, 1994). Recently several patients have been observed who demonstrated the difficulty in interpreting their pattern of performances in apraxia tests relying on the classic syndromic labeling. A good example is the case of EJ described by Moreaud et al. (1998). EJ, a patient affected by probable Alzheimer’s Disease, was impaired in manipulating single objects in his daily life, yet he performed well in tests assessing the production of symbolic intransitive gestures on verbal command, the imitation of meaningless gestures, and the comprehension of intransitive gestures. The authors rightly pointed to the problems in accommodating such a profile under any available label of apraxia. As a possible way out they speculated on the hypothesis of the existence of a distributed semantic memory, which is a concept little specified. However, the pattern presented by EJ could easily be accounted for by considering a possible deficit of the action output lexicon limited to the use of objects, a pattern overlapping with that presented by the Case 8 in our sample.

Rothi et al. (1991, 1997) did devise such a model *a posteriori* capitalizing on evidence they could glean from the literature as well as on their own observations. We have exploited their proposal tempering their model by drawing upon new evidence and by picking on the model’s weaknesses. The validity of the revised model of limb praxis detailed in the Introduction has been assessed by testing the predictions it allowed us to make by analyzing the performance of a sample of selected left-hemisphere-damaged patients on a test battery assessing apraxia.

The model allowed us to anticipate five patterns of outcome. Four of these five patterns were found in our series, while the fifth was ambiguous. One of the predictions from the model was a selective deficit in imitating meaningless gestures as a consequence of a disconnection between the visual perception system and the mechanism of motor programs implementation (pattern ‘‘d’’). None of the patients reported in this study presented with this pattern. This may be due to the relatively small sample examined. Alternatively, it would be possible to assume the existence of a ‘‘list composition’’ effect similar to that found in word-recognition studies (e.g., Tabossi & Laghi, 1992). When meaningful and meaningless gestures are presented intermingled, the activation of the visuomotor conversion procedure might be privileged. If this were the case, an impairment of the nonlexical route would affect both types of gestures to the same extent. Therefore, a test such as De Renzi et al.’s is not suitable for observing a meaningful/meaningless dissociation. To get around this potential bias, lists containing solely meaningless items should be compared with lists made up of meaningful items only. Indeed, the two patients who showed this particular dissociation reported by Goldenberg and Hagmann (1997) were presented with the two types of gestures separately.

The outcome of the present experiment supports the notion of a dissociation between transitive (use of objects) and intransitive gestures first postulated by Morlaas (1928). In addition, our results suggest that the separation between transitive and intransitive representation ought to be present both at the semantic and at the lexical level. Therefore, a far-reaching testing battery for apraxia should also encompass a test assessing the comprehension of intransitive gestures. This would permit the differentiation between a semantic and a lexical disorder should the patient show a deficit producing the correct intransitive gestures on command.

Notwithstanding the watertight logic and well-grounded assumptions on which Rothi et al. based their model and the promising outcome of the experiment reported in this article, the available evidence is far from conclusive. In particular, several steps foreseen within the proposed cognitive model of limb apraxia still have to be translated into clinical tests to allow clinicians and researchers to investigate all its aspects cogently. A complete battery should include separate assessments of the semantic system (by means of a test tackling gesture comprehension) and of the input lexicon (by means of a test investigating the ability to distinguish between familiar and nonfamiliar gestures or between well-executed and awkward gestures). In this study these two tasks were combined in the Recognition of Object Utilization Gestures Test. Moreover, as is customary in the literature on apraxia, in this study intransitive gestures were elicited on verbal command or on imitation. This same task should also be given with visual input (e.g., a picture of a barrack to elicit the military salute) in order to assess the retrieval of semantic information by means of a language-free instrument. Similarly, the actual use of objects, usually assessed solely on command, should also be tested on imitation. Aim of future investigations should be to devise *ad hoc* tests that enable tackling all the individual components of the proposed model.

The model proposed in this article is not intended to be exhaustive. After the gestural buffer the model does not detail the mechanisms of motor program implementation. These mechanisms are thought to control execution parameters in order to deal with different contextual constraints (e.g., using various exemplars of the same object in different condition of lightning) or to modulate the features of a gesture (speed, amplitude). They could be specific for the right and the left hand (Riddoch et al., 1989). A further connection could be added to the model joining the phonological input lexicon to the gestural buffer. This connection would account for the performance of intransitive gestures made following verbal description (e.g., put your thumb between your middle finger and your index finger). However, it would be difficult to disentangle the relationship among the several processes which are involved in this passage, from verbal comprehension to verbal short-term memory to visual imagery. Therefore, although plausible, this connection was not tested within the model of limb apraxia discussed in this article.

To round off, the cognitive approach to apraxia investigation seems to bear fruit and opens up new frontiers to clinicians and researchers alike. Apraxia is not a unitary deficit. The term has to be understood as no more than an umbrella term, like aphasia, amnesia, or neglect, which covers several patterns of deficit which may dissociate from one another. The use of a cognitive model allows us to better snare the complexity of limb apraxia, abandoning the idea that we can understand a symptom simply by labeling it. However, some work remains to be done to devise new tools more appropriate to a thorough diagnosis of limb apraxia.

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