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Pantomimes are special gestures which rely on working memory

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Abstract

The case of a patient is reported who presented consistently with overt deficits in producing pantomimes in the absence of any other deficits in producing meaningful gestures. This pattern of spared and impaired abilities is difficult to reconcile with the current layout of cognitive models for praxis. This patient also showed clear impairment in a dual-task paradigm, a test taxing the co-ordination aspect of working memory, though performed normally in a series of other neuropsychological measures assessing language, visuo-spatial functions, reasoning function, and executive function. A specific working memory impairment associated with a deficit of pantomiming in the absence of any other disorders in the production of meaningful gestures suggested a way to modify the model to account for the data. Pantomimes are a particular category of gestures, meaningful, yet novel. We posit that by their very nature they call for the intervention of a mechanism to integrate and synthesise perceptual inputs together with information made available from the action semantics (knowledge about objects and functions) and the output lexicon (stored procedural programmes). This processing stage conceived as a temporary workspace where gesture information is actively manipulated, would generate new motor programmes to carry out pantomimes. The model of gesture production is refined to include this workspace.

Keywords: Apraxia; Pantomimes; Working memory; Cognitive models

1. Introduction

The purposive movements hampered in apraxia include different types of gestures: transitive, involving tool use; intransitive (or symbolic); pantomimes, the mime of tool use; and meaningless (or novel). Several apraxia taxonomies have been proposed (see for a review De Renzi & Faglioni, 1999) based on the categories of gestures.

However, pantomimes presented a problem to this approach. For example, Morlaas (1928) distinguished between a deficit of transitive gestures, which he assimilated to ideational apraxia, and a deficit of intransitive gestures, matched to ideomotor apraxia; yet this dichotomy is ambiguous for pantomimes. They could be classified as transitive gestures, since objects are somehow involved, but could also be thought of as intransitive, since objects are not present during the miming. Indeed, some contemporary authors have suggested the use of pantomimes to assess ideomotor apraxia (e.g., Heilman, Rothi, & Valenstein, 1982), while others have used them to examine ideational apraxia (e.g., De Renzi, Faglioni, & Sorgato, 1982). Pantomimes have been listed among the diagnostic tools for ideomotor apraxia (e.g., Andrewes, 2001), yet correlations have been reported between pantomimes and tool use (e.g., Foundas et al., 1995; Goldenberg & Hagmann, 1997; Hécaen, 1978).

The classic dichotomy ideomotor/ideational apraxia is an oversimplification (for a discussion, see Buxbaum, 2001; Goldenberg, 2003). To circumvent it, recently cognitive models of praxis processing have been proposed (Cubelli, Marchetti, Boscolo, & Della Sala, 2000; Rothi, Ochipa, & Heilman, 1991, 1997) in analogy with the models devised for language (Coltheart, Curtis, Atkins, & Haller, 1993; Patterson & Shewell, 1987). These models depict two independent processing routes, one dealing with the selection of meaningful gestures to be

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retrieved from long term memory, the other responsible for the on-line assembly and the execution of novel gestures. Within the context of studies on apraxia, pantomimes of objects use should not be confused with symbolic gestures describing objects use. The two gestures may be very similar. However, in some instances they differ, as in the case of scissors, the symbolic representation of which would require the rhythmic overlaying of the extended index on the extended middle finger, whilst their correct pantomime would imply a paced adjoining of the flexed thumb and index. Hence, pantomimes are meaningful gestures rarely performed in everyday life, which are therefore novel. Therefore, no motor programmes would be readily available from the long-term stores to produce pantomimes.

In this paper, we tackle the issue of whether or not pantomimes are a special category of gestures. If they were, could selective deficit of pantomimes be observed? How could the cognitive models for praxis account for such deficit?

1.1. Current status of the cognitive models of praxis

The models distinguish between a lexical route responsible for the production and the imitation of meaningful (familiar) gestures, and a non-lexical route, assumed to be responsible for the imitation of all seen gestures, familiar and non-familiar alike (see Fig. 1).

The "form" and the content of the familiar gestures are thought to be stored in two long-term memory systems, the gestural lexicon and the action semantics. The lexicon is further divided into input and output. The input gestural lexicon stores the representations of all known gestures allowing for the recognition of familiar gestures. The output gestural lexicon contains the procedural knowledge for the production of known gestures. The semantic system (see Roy & Square, 1985) stores the knowledge about objects and tools, their function and the way in which they are used. The semantic system also stores the meaning of symbolic, intransitive (i.e., performed without the object) gestures, either iconic, which represent the shape of an object (e.g., binocular), or arbitrary (e.g., the military salute). The two systems deal with two different types of information. The semantic system allows one to "know" how a given object should be used, the lexicon contains the specific instructions allowing one to actually use it, e.g., one "knows" how to play a violin (and even be able to perform gestures representing the conventional description of a violin player), yet have no idea on how to really play it.

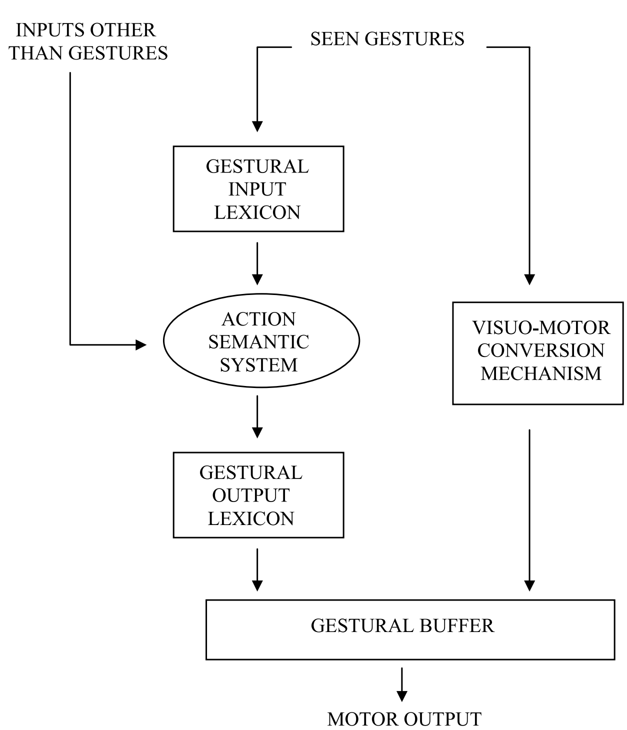

Fig. 1. Layout of the current model of praxis (modified from Cubelli et al., 2000).

The lexical-semantic route is used for the imitation of meaningful gestures as well as for their production either spontaneously or elicited on command. The non-lexical route comprises a visuo-motor conversion mechanism involved in transcoding visual information into motor programmes. Hence, meaningful gestures could be imitated through both the lexical and the non-lexical route, whilst meaningless gestures could only be imitated via the non-lexical route. Cubelli et al. (2000) further maintained that the lexical and the non-lexical routes converge into a gestural memory buffer, aimed at holding the motor programmes until the gestures are executed.

Therefore, given the redundancy for the imitation of meaningful gestures embedded in the model, a *selective impairment* of the imitation of meaningless gestures is predicted by a deficit of the non-lexical route (see, e.g., the cases reported by Goldenberg & Hagmann, 1997). However, one could never expect to observe a *selective sparing* of the ability to imitate meaningless gestures.

Bartolo, Cubelli, Della Sala, Drei, and Marchetti (2001) reported on the case of MF, who presented with a clear impairment in the production and imitation of all kinds of meaningful gestures under all modality of request coupled with an impeccable ability to imitate meaningless gestures. The current layout of the model would run into difficulty in accounting for MF's pattern of spared and impaired abilities.

Since MF's imitation of meaningless gestures was flawless, both the visuo-motor conversion mechanism and the gestural buffer ought to be spared. Her deficit in producing and imitating meaningful gestures had to be traced back to a deficit located along the lexical route. The input gestural lexicon and the action semantics were spared as indicated by her normal performance in a series of gesture discrimination and identification tasks. Her impairment with meaningful gestures could only be accounted for by a deficit of the output lexicon or in accessing it, yet it was not clear why the spared non-lexical route did not permit the imitation of meaningful gestures.

Margolin (1984) proposed two ways by means of which it would be possible to correctly copy written words. One is the lexical procedure, whereby one reads the word and reproduces it as if writing under dictation. The other is the pictorial mode, using which the word is copied point to point as if it were a meaningless pattern. However, if the word to be copied is recognised as familiar the lexical route is activated by default, preventing the use of the pictorial strategy to be implemented. Similarly, the use of the non-lexical route to imitate a shown gesture recognised as familiar would be barred by the automatic activation of the input lexicon, leading to the selection of the correspondent motor programme within the gestural output lexicon.

Gestures that carry no meaning are processed *only* by visuo-motor conversion mechanism; in contrast, meaningful gestures would be processed *only* by the lexical route that is responsible for their production both on imitation and on command. Consequently, the deficit of production and imitation of familiar gestures would be invariably yoked following damage to either the action semantics or the output lexicon (Bartolo et al., 2001). However, should the input lexicon also be damaged (agnosia for known gestures, also labelled *pantomime agnosia*—Rothi, Mack, & Heilman (1986)) the production on command would still be impaired, whilst imitation of familiar gestures would be preserved being processed by the spared non-lexical route. The same dissociation between spared imitation and impaired production of familiar gestures could derive from a defective access to the action semantics from non-gestural inputs in the context of an otherwise intact lexical route (e.g., verbal commands which fail to activate the stored semantic representations).

The production of meaningful gestures, both transitive, involving tool use (e.g., the use of a hammer), and intransitive (i.e., symbolic, e.g., hitch-hiking), draws upon long-term representations either conceptual or procedural, sitting in the action semantics system and the output lexicon respectively. Transitive and intransitive gestures are represented separately both at the level of the action semantics and the output lexicon. The meaning of intransitive gestures varies according to the different socio-cultural contexts, whilst knowledge about transitive gestures is culture-free being conditioned by the object's features. At the procedural level, motor programmes for intransitive gestures are independent of any environmental context while those for transitive gestures are less specified and conform to the physical attributes (shape, size or weight) of the objects. Thus it is plausible that intransitive and transitive gestures be selectively affected at both levels. Indeed Cubelli et al. (2000) reported on two patients with selective output lexicon impairment, limited to transitive (case 8) or to intransitive gestures (case 19). Similarly Ochipa, Rothi, and Heilman (1989) described the case of a patient whose deficits were restricted to tool knowledge.

1.2. Studies with pantomimes

Hughlings Jackson (1893) discussed pantomimes in the context of other symbolic gestures, suggesting a relation between pantomimes and intransitive gestures. Pantomimes do not imply the actual use of objects, rather they "represent something and presuppose the attitude of abstraction" (Goldstein, 1948, p. 137; Goodglass & Kaplan, 1963, p. 706) defined pantomimes as "improvised movements which ... describe the physical properties of an object ... or some action imposed by the object." Wang and Goodglass (1992, p. 719) maintained that pantomimes were qualitatively different and more difficult to execute than over-learned gestures.

Performance in pantomime studies may depend upon the instructions given (see Raymer, Maher, Foundas, Heilman, & Rothi, 1997). For instance, Dumont, Ska, and Schiavetto (1999) asked their patients: "*Show me how you would brush your teeth*" (p. 450). Under these conditions participants are not asked explicitly to mime the use of a real object and they may perform a symbolic gesture associated with the object. In the example given, participants may use their index finger as if it were the toothbrush. This performance would be classed as "body part as a tool" error (BPT). Such errors (for a critical discussion see Cubelli & Della Sala, 1996) occur when patients use a part of their body as if it were the object: in the example above, the finger is used as a pretended toothbrush, representing its "physical properties." Healthy participants also produce BPT errors (Duffy & Duffy, 1989) on command (under verbal, visual or tactile conditions) as well as on imitation (Mozaz, 1992).

Raymer et al. (1997) used more detailed instructions and asked participants to "*imagine holding and using the tools just as they would if they had the actual tool*" (p. 290). They showed that only apraxic patients committed BPT errors. BPT errors reflect the retrieval of the semantic knowledge about an object in the absence of the procedural information specifying the correct way of handling or using it (McDonald, Tate, & Rigby, 1994). As a consequence, a symbolic gesture would be produced rather than a pantomime. Some objects (i.e., scissors) are particularly sensitive of being described in symbolic, conventional ways, using parts of one's body as a tool (Duffy & Duffy, 1989, Appendix pp. 234–235). In some cases the symbolic gestures are formally identical to the pantomimes (for instance the gesture of smoking a cigarette is akin to miming its use), masking possible difficulties the patients may have in pantomiming. However, most BPT errors produced by apraxics are novel gestures, generated by the patients to convey the object's meaning and function. For instance, some patients use their index finger as if it were a pen. BPT errors may result from a "compensatory strategy" (Heilman & Rothi, 1985, p. 147) to overcome failures in pantomiming.

Pantomimes should be consistent with the characteristics of the objects, the use of which has to be mimed. The correct gesture has to be performed considering distance (i.e., the distance of the fingers from the table when miming how to use a pen), configuration (i.e., shape of hand on object) and orientation of the acting hand. Failure to properly consider these features results in spatial or postural errors that are frequently observed in apraxia (e.g., Mozaz, 1992; Roy, Black, Blair, & Dimeck, 1998; for a complete taxonomy see Leiguarda & Marsden, 2000, Table 2, p. 864).

1.3. Aims of the current study

To execute a pantomime it is necessary to re-produce the posture sustained when holding the real object. As a result the pantomime is often a novel, unfamiliar and creative gesture that capitalises on lexical and semantic representations. Hence, the integrity of the lexical route is necessary for a correct pantomime. However, if pantomimes constitute a special class of gestures (at the same time meaningful and novel), their production may call for additional cognitive mechanisms. Our working hypothesis is that to produce pantomimes the information about the objects function (stored in the action semantics) and the motor programme for the object use (in the output lexicon) ought to be integrated to generate a complex, new gesture. Working memory, considered as a workspace (Della Sala & Logie, 2002; Logie, 1996), i.e., as a system that allows us to temporarily interact with and mentally manipulate long-term stored representations, would be a suitable candidate to fulfil the role of integrating learned knowledge about objects and procedures on how to use them to plan novel actions. Hints about this role of working memory can be found in the literature (e.g., Logie & Della Sala, in press; Logie, Engelkamp, Dehn, & Rudkin, 2001; Toraldo, Reverberi, & Rumiati, 2001).

In the course of a group study aimed at validating a test battery for apraxia (Bartolo, 2002) we came across the case of a patient whose pattern of performances could hardly be accounted for by the current models of praxis. The aim of the present study is twofold, to report on the case of this patient who presented with isolated deficits of pantomimes within the class of meaningful gestures (Experiment 1), and to show that these deficits are associated with a specific working memory defect (Experiment 2).

2. Case history

VL, a retired haberdasher with seven years of formal education, was 66 when she had a stroke affecting the left hemisphere basal ganglia and external capsule (see CT scan in Fig. 2).

Soon after the stroke, she was examined with the B.A.D.A. (Miceli, Laudanna, Burani, & Capasso, 1994), an Italian battery of tests assessing language functions. She showed a severe agraphia and some difficulties in language production but good language comprehension. In particular, she made some errors in naming drawings depicting objects (23/30 correct) or actions (20/30 correct); her errors were either anomias or semantic substitutions (e.g., monkey for tiger).

VL came to our attention nine months after her stroke. She had no overt neurological deficits and performed above the cut-off scores in all the tasks of a general neuropsychological battery, including language, visuo-spatial, executive and reasoning tasks (Table 1); moreover she was no more agraphic or anomic. She performed normally also in four tasks (Bartolo et al., 2001) assessing the discrimination and the identification of intransitive gestures and pantomimes (Table 2). The two recognition tests assessed the ability to discriminate

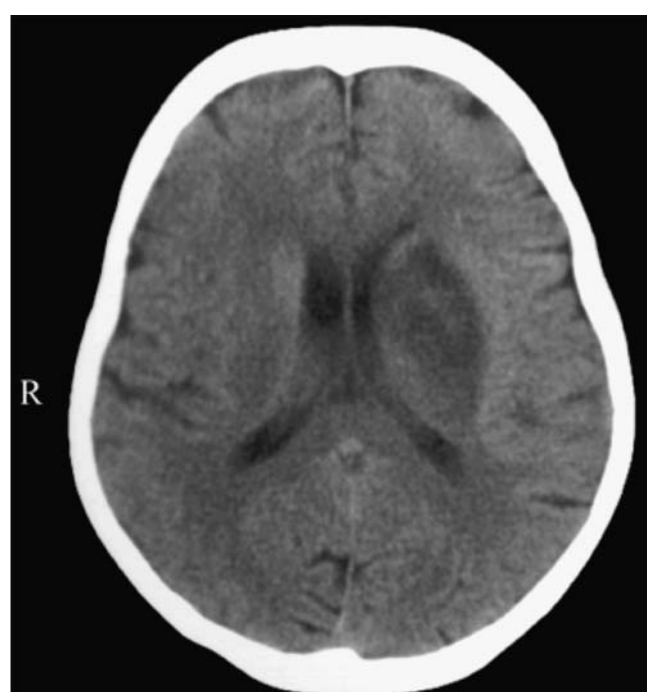

Fig. 2. VL's CT scan showing the lesion affecting the left hemisphere basal ganglia and the external capsule. As customary, the neuroimage is reversed, the right hemisphere (R) is on the left side of the picture.

Table 1
VL's performance in the general neuropsychological assessment battery

General neuropsychological assessment	Cut-off (range)	VL
Language		
Oral comprehension (AAT) (Willmes et al., 1988)	52 (0–60)	57
Picture naming (Laiacona, Barbarotto, Trivelli, & Capitani, 1993)	61 (0–80)	68
Token test (De Renzi & Faglioni, 1978)	26.5 (0–36)	32
Visuo-spatial functions		
Scrawl discrimination (Spinnler & Tognoni, 1987)	21 (0–32)	32
Unfamiliar faces (Benton & Van Allen, 1968)	38 (0–54)	43
Figure copying (Arrigoni & De Renzi, 1964)	8 (0–14)	14
Executive functions		
Tower of London (Allamanno, Della Sala, Laiacona, Pasetti, & Spinnler, 1997)	9.25 (0–18.8)	19.24
Weigl test (Spinnler & Tognoni, 1987)	4.5 (0–14)	10
Verbal judgement (Spinnler & Tognoni, 1987)	33 (0–60)	36
Reasoning		
Raven's coloured progressive matrices (Basso, Capitani, & Laiacona, 1987)	18 (0–36)	29

Table 2
VL's performance in the tasks assessing discrimination and identification of intransitive gestures and pantomimes (Bartolo et al., 2001)

	Cut-off*	VL
Discrimination (score range = 0–30)		
Pantomimes	26	30
Intransitive gestures	26	28
Identification (score range = 0–15)		
Pantomimes	12	14
Intransitive gestures	11	14

* Cut-off scores were determined as the worst score achieved by the controls minus two further points as for the tests assessing gesture production (Experiment 1) and were derived from the same group of 36 controls (see text).

real gestures from made-up, but similar, ones either transitive or intransitive ("*Is the gesture performed by the examiner correct or wrong?*"). Two gesture-object matching tasks assessed the identification of transitive and intransitive gestures performed by the examiner. The patient was asked to select from among four alternatives the picture associated with the target transitive gesture ("*Which object did the examiner pretend to use*?") or the scene evoking the target intransitive symbolic gesture ("*With which drawing does the gesture performed by the examiner match*?").

3. Experiment 1: Assessment of gesture production

3.1. Testing procedures and scoring

A battery was devised to assess the production of four types of gestures (pantomimes, transitive, intransitive, and meaningless) on two testing conditions (on command and on imitation) and with different input modalities. A series of pilot studies including 120 participants (Bartolo, 2002) allowed us to select fifteen objects, fifteen symbolic gestures, and fifteen meaningless gestures (see Appendix). The purposes of the pilot studies was to ensure that the objects were not eliciting BPT errors in healthy controls and that the symbolic items were familiar to all controls and were not ambiguous.

The battery comprised ten tasks. Two of them investigated the actual use of objects (transitive gestures) on command ("Show me how you would use this object"), and on imitation. Three tests assessed the production of intransitive gestures on verbal command (e.g., "Show me the military salute"), on imitation, and responding to a visual stimulus respectively. The latter task has been added to examine the production of symbolic gestures in patients with language difficulty other than on imitation. Fifteen vignettes depicting situational contexts were employed to elicit the target symbolic gestures. An arrow indicated one of the characters in each vignette. Participants were invited to produce the gesture that the indicated character would have produced in that context (see Fig. 3). The instruction given to participants was "*Please perform the gesture that according to you the person indicated by the arrow is on the verge of performing*." The testing items were chosen from a larger set of vignettes through a series of pilot studies aimed at selecting those that most consistently elicited the expected symbolic gestures.

Four tasks investigated the performance in pantomimes on command with verbal, visual or tactile input, and on imitation. In the verbal condition the name of the object was spoken by the examiner, in the visual condition the real object was shown to the participants who were prevented from touching it, in the tactile condition the participants were blindfolded and allowed to handle the object for recognition. The instruction was "*Imagine to hold this object, show me how you would use it*." The final task required the imitation of meaningless gestures.

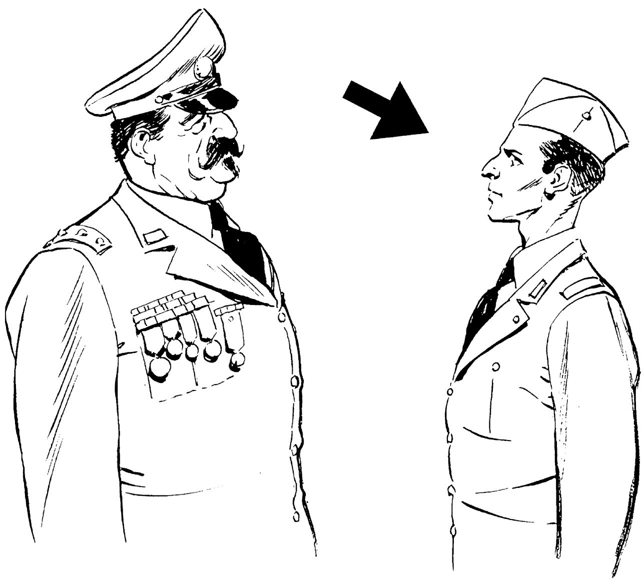

Fig. 3. One of the vignettes used in the task assessing the production of symbolic gestures used in Experiment 1. This drawing would elicit the military salute. This and all the other vignettes used in the experiment were drawn by Claudio Villa.

The same fifteen objects were used in all tests assessing pantomimes and transitive gestures. Likewise, the symbolic gestures were the same across all tests assessing intransitive gestures. In all imitation tasks the target gestures were performed by the same actor and videotaped. The score for all tasks ranges from 0 to a maximum of 15.

The patient entering the study was not paretic and performed all tasks with her right hand. She underwent a second examination six months later.

Her performance was compared to that of a group of 36 controls, 16 men and 20 women. Their mean age was 67.8 ($SD = 5.97$, range = 60–79). Their mean years of formal education were 5.58 ($SD = 2.22$, range = 3–13). All controls were tested with their right hand, and performed normally (i.e., 27 or above) in the Mini Mental State Examination (mean = 28.75, $SD = 0.94$, range = 27–30).

The pilot studies allowed us to include in the final version of the tests only items with a high level of accuracy. Hence, the performance of normal controls was expected to be near ceiling. To avoid false positive diagnosis we decided to establish conservative cut-offs as the scores of the worst control minus two points. When all controls were flawless, the cut-off score was 13, i.e., two points below the maximum possible score. A performance was considered pathological when the score was below cut-off. Two independent judges scored the performance of the patient. The experimental procedure established that in case of disagreement a third judge would have been consulted, though this never proved necessary.

The tests were given in two sessions in two consecutive days. Session one included pantomimes on visual, tactile and verbal commands, actual use of objects and production of intransitive gestures on verbal and visual input. Session two included the four imitation tests (pantomimes, transitive, intransitive, and meaningless gestures).

3.2. Results and discussion

Table 3 shows VL's performance on the two testing sessions compared with that of the control group on the tests of the gesture production battery.

VL's performance in the production of both transitive and intransitive gestures either on command or on imitation was consistently normal. On the contrary, she

Table 3
Experiment 1: VL's performance in the gestural prodution tasks compared to that of the control group. Scores for all tests range from 0 to a maximum of 15

Gesture production battery	Normal controls			VL	
	Mean (*SD*)	Actual range	Cut-off	1st test	2nd test
Pantomimes					
Verbal input	14.6 (0.6)	13–15	11	10*	8*
Visual input	14.4 (0.8)	12–15	10	8*	9*
Tactile input	14.7 (0.5)	13–15	11	10*	9*
Imitation	15	15	13	10*	12*
Transitive gestures					
Actual use	15	15	13	15	15
Imitation	15	15	13	15	15
Intransitive gestures					
Verbal input	14.9 (0.2)	14–15	12	14	14
Visual input	14.3 (1.0)	11–15	9	13	14
Imitation	15	15	13	15	15
Meaningless gestures					
Imitation	15	15	13	12*	12*

VL was tested on two occasions.
Asterisks indicate pathological scores.

failed all pantomime tests on both testing sessions. Her score in the imitation of meaningless gestures was below the cut-off.

A single item analysis indicated that most of VL's errors were BPT (73%), for instance she used her index finger as if it were a needle, the remaining errors were clustered as non-classifiable with accuracy because of complex behaviour or multifarious errors in the same action, e.g., she mimed the use of a cigarette positioning her fist close to the mouth with her thumb entangled between the index and the middle finger sucking her thumb. She never made spatial errors or performed clumsily individual gesture components. The frequency of BTP errors could be interpretable as a compensatory strategy; the patient would capitalise on her intact semantic system to produce a simple movement conveying the correct semantic information representing the object function, but disregarding the correct configuration of the hand.

The patient's pattern of spared and impaired abilities confirm the prediction that, within the category of meaningful gestures, isolated deficits of pantomimes are possible, supporting the view that pantomimes should be subsumed as an independent category of gestures, the production of which calls for specific cognitive mechanisms. The current models of praxis (see Fig. 1) would run into trouble in trying to account for VL's pattern of performances.

Her profile shows that all the processing levels constituting the lexical route are spared insofar as their performances in the discrimination and identification (Table 2) and production (Table 3) of transitive and intransitive meaningful gestures under all modalities of presentation and execution are preserved. The patient's poor performance in imitating meaningless gestures indicates that the visuo-motor conversion mechanism is impaired. However, this deficit could not, per se, account for the defective pantomime performance. It would imply that pantomimes are treated as meaningless, and, crucially, it contrasts with the agreed upon notion that the non-lexical route is meant for imitation only, not for production on command.

Pantomimes are meaningful, yet novel. For a correct execution new programmes should be generated based upon available semantic and procedural information. There should be a workspace where this activated information, in itself incomplete to produce a pantomime, is manipulated and transformed into novel motor programmes. Logie et al. (2001) stated: "Where the activated information is incomplete, working memory acts as the workspace to manipulate the information… to generate new knowledge (p. 178). Thus, working memory may provide this workspace. In the case at issue, this new "knowledge" ("new motor nervous arrangements," in Hughlings Jackson's (1893) words) would be the pantomimes. Indeed, executing pantomimes is not dissimilar from "mental synthesis" tasks, which fall within the remits of working memory (Barquero & Logie, 1999). Our hypothesis, as detailed in the Introduction, would predict that the impairment in executing pantomimes in the absence of semantic or lexical deficits should always be coupled with a malfunction of this workspace. In the next study the efficiency of working memory was explored.

4. Experiment 2: Assessment of working memory

To test the hypothesis that working memory is necessary to correctly carry out pantomimes, we assessed VL with a classic test of working memory, the dual-task. A key function of the assumed workspace would be that of integrating information simultaneously activated from different long-term memory sources with new environmental inputs. The dual-task typically taxes the coordination function of working memory (Baddeley, 1996). Hence, it is a suitable candidate to fulfil the purposes of our experiment.

4.1. Testing procedures and scoring

A pen and paper version (Della Sala, Baddeley, Papagno, & Spinnler, 1995) of the dual-task paradigm (Baddeley, Logie, Bressi, Della Sala, & Spinnler, 1986; Cocchini, Logie, Della Sala, MacPherson, & Baddeley, 2002) was used. VL was tested on the second session. Her performance was compared to that of eleven healthy participants (3 men and 8 women, mean age = 65.0; $SD = 4.4$, range = 56–69; education 7.9, $SD = 4.7$, range = 3–17).

The dual-task paradigm consists of four stages, as follows: Digit Span Determination, List Memory (Single Task), Tracking (Single Task), Dual Task.

First the participants' baseline Digit Span was determined. Then participants were read lists of digits of the length corresponding to their memory span for 1.5 min, and were asked to repeat each list in serial order (List Memory—Single Task). The score of the List Memory task was the proportion of correct digits in the correct place in each sequences of digits presented in the allotted time. In the second single task, which also lasted for 1.5 min, each participant was asked to use a pencil to trace a path through a maze, thereby drawing a line through circles arranged along the path of the maze depicted in an A3 sheet of paper (Tracking—Single Task). The subject's Single Task Tracking score was the number of circles crossed out. Finally, in the dual-task condition, also lasting for 1.5 min, the participant performed the tracking (as in the single task condition) while at the same time repeating lists of digits at their span length. Two scores were thus obtained: the List Memory Score (Dual-Task) and the Tracking Score (Dual Task).

Table 4
Experiment 2: VL's performance in the working memory task compared to that of the eleven control participants

Working memory co-ordination task	Normal controls		VL	
	Mean (*SD*)	Range	Test	Retest
List memory[a]				
Single task	0.92 (0.08)	0.71–1.0	0.9	—
Dual task	0.91 (0.09)	0.71–1.0	0.82	0.92
Tracking[b]				
Single task	57.8 (12.7)	36–74	79	—
Dual task	60.5 (12.3)	36–77	45	31
Combined index	102.31 (4.9)	92.0–111.2	74*	71*

Asterisks indicate pathological scores.
[a] List memory is the percentage of digit sequences correctly recalled in serial order.
[b] Tracking score is the total number of crossed out boxes within the allotted time.

Dual-task paradigms can give rise to possible difficulties when interpreting performance of each of the tasks in isolation (see discussions in Baddeley, Bressi, Della Sala, Logie, & Spinnler, 1991; Cocchini et al., 2002; Duff & Logie, 2001; MacPherson, Della Sala, & Logie, in press). Following the procedure used in previous dual-task studies (see Baddeley et al., 1986, 1991; Duff & Logie, 2001) we examined the overall effect of dual-task load for each participant in each of the four dual-task conditions. For this, we calculated the percentage change from single to dual condition performance for each of the two component tasks and combined the percentage changes in an Index (Baddeley, Della Sala, Gray, Papagno, & Spinnler, 1997a) as follows:

$$\text{Combined Index} = 1 - \frac{\text{ratio change memory} + \text{ratio change tracking}}{2} \times 100$$

A combined score of 100 would indicate that there was no difference between single and dual-task conditions; a score above 100 would indicate an improvement under dual-task conditions pointing to a working memory benefit[3]; a score below 100 would indicate a decrement in dual-task condition, i.e., a working memory cost. For the sake of reliability, VL twice underwent the dual-task condition (retest).

4.2. Results and discussion

The average serial digit span of the controls was 4.9 ($SD = 0.5$; range = 4–6). VL'S digit span was 4, well within the normal range for the Italian population (Orsini et al., 1987). Table 4 reports the performance of VL and the eleven control participants in the dual-task.

The key score is the combined index, which represents the efficiency of working memory. VL consistently performed the dual-task three standard deviations below the means of the controls and well below the worst controls' combined index score. This is particularly relevant considering her good performance in a range of executive tasks (see Table 1). The dissociation between dual-task performance and scores on classic executive tasks, already reported in the literature (e.g., Baddeley, Della Sala, Papagno, & Spinnler, 1997b), should not be surprising given the fractionation of the executive system. Taken together VL's performances speak for a specific deficit in the co-ordination function of working memory, possibly related to a selective impairment in executing pantomimes. These findings are consistent with the hypothesis of a working memory involvement in the production of pantomimes. Direct evidence supporting this claim would come from the observation that patients such as VL also fail newly proposed tasks of mental synthesis whose performance requires the integrity of the same workspace (Barquero & Logie, 1999; Pearson, Logie, & Gilhooly, 1999).

The existence of a workspace where the activated content of long-term semantic and procedural knowledge is transformed into a new gesture is plausible, compatible with the present findings and in line with the recent literature (Della Sala & Logie, 2002; Logie et al., 2001). The cognitive model of praxis needs to be updated.

5. General discussion

The findings from this study demonstrate that apraxic deficits limited to pantomime execution could be observed (Experiment 1), and that the patient showing such deficits also presented with working memory dysfunction (Experiment 2) in the absence of executive or any other neuropsychological disorders (Table 1).

The current models of praxis processing cannot account for the deficits of pantomimes shown by VL. A variation in these models will be proposed (Fig. 4).

[3] An improved performance of healthy individuals under dual task conditions in this kind of paradigm has been frequently observed, see for a discussion Duff and Logie (2001).

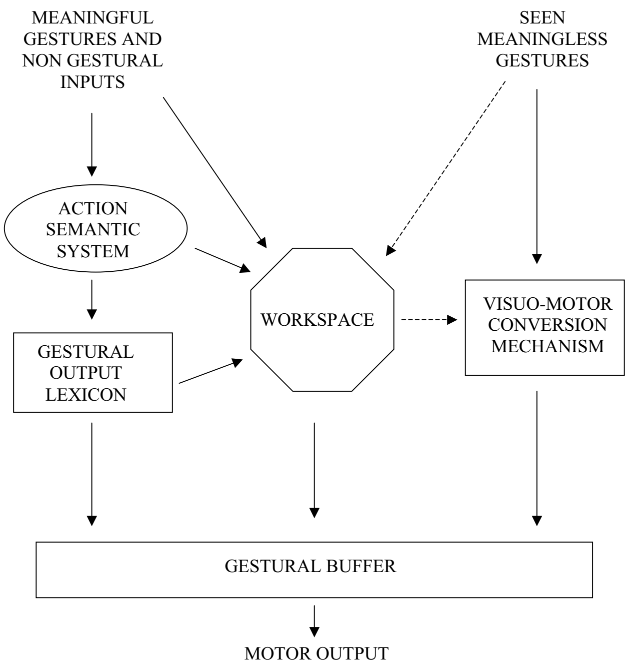

Fig. 4. Modified model of gesture production that includes the workspace whose dysfunction would account for a selective deficit in pantomiming. The dotted lines represent the alternative route that may be used to imitate meaningless gestures in the absence of stimulus support.

In particular, we propose that for the correct execution of pantomimes the intervention of a creative mechanism is necessary, which integrates and synthesises perceptual inputs together with information made available from the action semantics (knowledge about objects and functions) and the output lexicon (stored procedural programmes). This process would generate the new motor programmes to carry out pantomimes. Working memory defined as a workspace (Logie & Della Sala, in press) within which information is manipulated and transformed (Logie et al., 2001) would fulfil this role. The concept of working memory as workspace is not new in accounting for neuropsychological deficits (e.g., Beschin, Cocchini, Della Sala, & Logie, 1997; see Della Sala & Logie, 2002 for a recent review). Moreover, the involvement of working memory has been invoked to explain gesture processing with normal participants in a series of dual-task studies (Rumiati & Tessari, 2002) and in brain damaged patients (Toraldo et al., 2001).

The upgraded version of the model (Fig. 4) accounts for pantomiming deficits, both when they are associated with other impairments along the lexical route or when they occur in isolation. A deficit along the lexical route will invariably affect pantomiming together with the actual use of objects, both on command and on imitation. If the action semantics system was the impaired component, a deficit in performing non-motor matching tasks would also be expected (Cubelli et al., 2000). If the lesion is at the level of the output lexicon, pantomimes could be apparently well executed only when they coincide with the corresponding symbolic gestures activated from the intact semantic system. However, hand posture errors would be always present. Moreover, in pantomiming objects like the scissors or the gun, whose symbolic gesture represents the object itself rather than its use, frequent BPT errors should be observed.

The selective impairment of pantomime production would be accounted for by a deficit of the workspace. In the absence of such integration mechanism, patients, such as the one reported on in this study, could still perform meaningful gestures, yet they would be unable to perform pantomimes. The opposite dissociation, i.e., preserved pantomimes and impaired actual use of an object would be impossible. The observation of such a pattern would call to task the model in Fig. 4. Motomura and Yamadori (1994) reported on the case of a patient who apparently failed to use real objects but could pantomime the use of the same objects. However, the patient was affected by simultanagnosia that could have compromised the recognition of the relevant parts of the objects to be manipulated.

Perceptual inputs would also feed into the workspace to be integrated into the novel programmes (Fig. 4). This layout would make it unlikely to observe dissociations in pantomiming across modalities of presentation, unless input deficits are present, e.g., aphasia would hamper pantomiming on verbal command. De Renzi et al. (1982) reported on patients who failed to execute pantomime on specific modalities while succeeding in others. All possible dissociations (Dunn & Kirsner, 2003) were apparently observed, i.e., between tactile and verbal, between verbal and visual presentation. However, patients were assessed in one testing session only for each modality, hence the results could be explained by considering the possibility of poor reliability in pantomiming independent of the type of command. The very nature of pantomimes that, unless memorised, require a new programme devised for each instance makes the performance inconsistent. The model, as it stands, does not make strong predictions either way, though in the absence of further contrasting evidence, the assumption rests that pantomime deficits should be supramodal, and that inconsistent patterns would account for apparent dissociations across modalities observed in patients whose deficit is not severe.

VL's imitation of meaningless gestures was not perfect. This outcome may suggest that the visuo-motor conversion mechanism is also impaired. However, it would be parsimonious to interpret these mild deficits as resulting from the working memory dysfunction. Indeed, recent studies have suggested the involvement of working memory in the imitation of meaningless gestures (Rumiati & Tessari, 2002; Toraldo et al., 2001). However, such interpretation would be premature in the light of the available evidence; the association between impaired imitation of meaningless gestures and production of pantomimes has yet to be determined. In the dearth of compelling data, accounting for a sheer transcoding mechanism by invoking the same creative process necessary to perform pantomimes would be disproportionate. As depicted in the model proposed (Fig. 4) the functioning of the visuo-motor conversion mechanism could benefit from the interaction with the workspace, particularly when the processing of the converting mechanism is acting on stimuli presented only briefly and then withdrawn. The deriving prediction is that patients showing pantomime deficits could imitate meaningless gestures when the experimental procedures minimize the need to hold in the workspace the stimulus to be imitated.

In conclusion, the refined version of the cognitive model for praxis includes three different routes responsible for the different categories of gestures. These are the lexical route for the processing of meaningful gestures (both transitive and intransitive), the non-lexical route for imitating meaningless gestures, and a third pathway centred on the workspace, which allows us to perform and imitate pantomimes.

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Appendix A

Objects

Hat (practice)
Knife (practice)
Comb
Hammer
Pen
Key
Cigarette
Spectacles
Ring
Needle
Racket
Saline
Piano
Watering can
Telephone
Iron
Glass

Intransitive gestures

Clapping (practice)
Silence (practice)
Military salute
Sign of the cross
Waving goodbye
Stop
Mopping one's brow
Giving a punch
Hitch-hiking
Summon someone
Showing muscle
Removing and annoying fly
Hands up
Blind man's bluff
Feeling cold
Signing that someone is crazy
Pointing to someone

Meaningless gestures

Hand parallel to nose (practice)
Index and medium on cheek (practice)
Flexion and extension of fist
Thumb entangled between ring and little finger
Index towards nose
Open hand—thumb on index
Scratching cheek with alternate movements of index and medium
Touching one shoulder with ipsilateral thumb and index both extended
Back of hand under chin
Back of hand pressed against contralateral temple
Fist rotation
Palm on contralateral temple
Fingers "walking" on head
Hand on opposite shoulder, then on sternum, then on ipsilateral shoulder
Joint tip of thumb and of little finger
Fist with thumb on index
Fist under chin

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