

MODALITY-SPECIFIC OPERATIONS IN SEMANTIC DEMENTIA

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ABSTRACT

A patient suffering from semantic dementia is described who consistently demonstrated the preserved ability to support specific types of semantic judgements from visual, but not from verbal, input. In addition the representations accessed from visual input were found to trigger complex behavioural schemata, while with verbal materials the patient performed almost invariably at chance level. A preliminary description is given of the nature of visual semantic representations, and the privileged relationship between this modality of input and some aspects of semantic knowledge is also explored. The richness of the semantic representations accessed from visual input can be accommodated within the "Multimodal Semantics" framework; alternative views, derived from the Identification Semantics and the Organized Unitary Content Hypothesis, are also discussed.

INTRODUCTION

The term *semantic system* has been used in a rather different way in neuropsychology from what one would expect from the standard use of *semantics* by linguists. In neuropsychology the term *semantic system* has been derived from the concept of *semantic memory* in cognitive psychology to refer to the system which holds "those representations (whether or not they may be properly considered to be semantic) that are assumed to mediate between modality-specific representations of the stimulus inputs and modality-specific representations of the task-determined responses" (Caramazza et al., 1990, p. 164). We will use the term in this sense.

Important evidence on the organization of the semantic system has been obtained from investigation of neurological patients. Of particular interest has been the evidence of dissociations in performance on different semantic categories (e.g.: representations of non-living items more preserved than living, and the converse (Warrington and McCarthy, 1983; Warrington and Shallice, 1984; Sartori, Miozzo and Job, 1993) and the existence of deficits mainly affecting one input modality (e.g.: better performance on visual presentation of the stimuli than on verbal (Warrington and McCarthy, 1988; Chertkow and Bub, 1990).

Such findings on category-specific and modality-specific dissociations have been used to argue for the view of the semantic system as a multimodal, highly structured system (McCarthy and Warrington, 1990). This can be contrasted with another major position which views the semantic system as a unitary amodal storage system, accessible from each input modality (Caramazza et al., 1990;

Humphreys and Riddoch, 1987a, 1987b). Variations exist within the two more extreme classes of positions. On the version of the multiple storage account adopted in Warrington and McCarthy (1988), considerable duplication of semantic knowledge accessible from different modalities of input, has been proposed. A less strong version holds the semantic system to be a highly interconnected multimodal network in which the modality of the acquisition process together with the intrinsic nature of the stored information determines the final structure of the semantic representations (Shallice, 1988). Within the multiple system framework, at least to a first approximation, however, dissociations are thought to emerge as a direct consequence of selective damage to one or more components or subregions of the network, or to the pattern of connections among them. For example in the case of optic aphasia (Lhermitte and Beauvois, 1973; Beauvois, 1982; Manning and Campbell, 1992), a syndrome characterized by a deficit in naming visually presented objects, with knowledge of the visually presented object being manifest, the impairment in naming to visual confrontation is held to arise from a difficulty in accessing the verbal semantic subsystem, which is assumed to be necessary for naming, from the visual semantic subsystem.

Probably a more common pattern of impairment, and one with which this paper is concerned, is where patients show better performance for particular modalities of input (Warrington and McCarthy, 1988, 1994). The issue of how to explain these kinds of dissociation within the framework of an unitary amodal semantic storage, had been, and in our view still is, a challenge for the opponents of the multiple storage hypothesis (but see Hillis and Rapp, 1995, for an alternative view).

On the unitary storage system account, the observed pattern of better performance with visual than verbal presentation of the stimuli (Chertkow and Bub, 1990), has been explained by assuming that for visual presentation, some features of the item can have privileged access to the semantic system and so support for example, correct miming of the use of that object; in the case of verbal presentation on the contrary, no such privileged link exists between the lexical and the semantic representations (Hillis and Rapp, 1995). However the opposite pattern occurs in visual associative agnosia: such patients, despite intact visual perceptual processes, can fail to identify visual stimuli, while demonstrating normal comprehension of words (McCarthy and Warrington, 1990). Supporters of the unitary hypothesis ascribe associative agnosia to fine grained, and often undetectable, misperception of visual stimuli (Caramazza et al., 1990), or to disconnection of the structural description system from the semantic one (Humphreys and Riddoch, 1987a, 1988).

In this article we present a single case study of a patient with a clear cut visuo-verbal dissociation. The patient was suffering from a degenerative process mainly affecting the inferior part of the left temporal lobe. Despite a profound deficit in all tasks requiring verbal comprehension, this patient showed relatively intact performance both in everyday life activities and in experimental tests designed to investigate the preservation of non verbal knowledge. The profound impairment of verbal comprehension in this patient provides the opportunity to investigate non-verbal knowledge and the nature of the tasks that can still be

supported by the semantic system in the presence of this type of damage.

In the investigation we experimentally characterize some types of semantic judgements that the patient is able to perform on visual material only. By devising certain "ecological" tests, we show further how the patient is in fact able to access complex behavioural schemata in response to visual, but not to verbal, stimuli. Finally we investigate subordinate level visual knowledge and show that it is preserved.

These data are interpreted in the context of a new neural network multimodal model of semantic memory (Lauro-Grotto, Reich and Virasoro, 1997): in this model the semantic system is thought as a multimodal network in which different areas are accessed by each modality, and store modality-specific information. In non-pathological conditions the various components of the net are connected to each other so that it is always possible to retrieve the entire representation from any input channel, via previous activation of the corresponding modality-specific one. In pathological conditions one or more components of the net can be preferentially damaged or become inaccessible, which gives rise to neuropsychological dissociations. In the model the Verbal Semantic component is thought to mediate on-line verbal comprehension and to support access to lexical output channels. Our findings suggest that this Verbal Semantic component is profoundly degraded in the present patient. It is interesting to note that not all kinds of semantic tasks can be performed in the absence of the Verbal component even when the material is *not* presented in the verbal modality. This reflects the distribution of information in the semantic network and possibly the presence of different coding processes. The present experimental investigation allows us to provide a preliminary sketch of the content of another Non-Verbal component, the so called Visual Semantic sub-system.

As a final point, we compare our account of the Visuo-Verbal dissociation with another account, the so called "Identification Semantics" hypothesis proposed by Chertkow, Bub and Caplan (1992). These authors also based their model on findings from patients with progressive dementia, who showed qualitatively similar modality-specificity effects, in having performance on verbal material worse than on visual. They argued that this pattern of performance can be explained by assuming that the information that allows perceptual identification of visually presented items is segregated in a separate *modality-specific* component of an otherwise amodal semantic system. This information is held to be sufficient to support naming, but not to allow for any other semantic operation, such as the ones that require the linking of a concept to other concepts in an associative semantic net. They hold that better performance in the visual modality is best explained by damage to the amodal associative semantic store, which is directly accessed from verbal input, together with selective preservation of the modality-specific "Identification Semantics". This might also appear to be a plausible account for the pattern of performance of our patient, who is severely impaired in the verbal modality. However we argue that the richness and complexity of behaviours elicited in our patient by visual stimuli is not compatible with this type of development of Identification Semantics hypothesis, and fits better in the context of models that assume a different fractionation in the semantic system.

CASE REPORT

R.M., a right-handed woman, born in 1931, left school at the age of 12. Until 1991, when she retired, she had worked in her husband's textile manufacturing business. Around that time, she started complaining of difficulties in remembering the names of common objects, phone numbers and well known people's names. Family members also noted the occurrence of mood changes and increasing irritability, egocentricity and a slightly decreased involvement in her family's daily problems. In 1992 neither a cranial CT scan nor an EEG revealed any abnormality, but an MRI scan indicated atrophy in the temporal lobes and frontoparietal cortices, with minimum enlargement of the ventricular system and Virchow-Robin spaces. R.M. was referred to the Neurology Department in Careggi (Florence) for further assessments in February 1994. Her objective neurological examination was normal. A second MRI scan (Feb. 1994) showed some mild generalized atrophy, with a few scattered areas of high signal in the cerebral white matter, which could just be age related changes. The striking finding was inferolateral atrophy of the left temporal lobe, most marked anteriorly but with some early focal atrophy posteriorly (See Figure 1). The left temporal pole was also distinctly atrophic compared to the right. The atrophy seemed to spare the superior temporal gyrus except for the most anterior part.

The asymmetric nature of the atrophy was later confirmed by a PET scan, performed at S. Raffaele Hospital (Milano) in December 1994, where a hypometabolism of the left polar and mesoinferior temporal lobe was detected, as well as a slight metabolic asymmetry of the inferolateral frontal regions, the basal ganglia and the thalamus, again with left hemisphere structures being more compromised. The appearance of the atrophy is compatible with left temporal lobe Pick's disease; its localization and time course is typical of the semantic dementia syndrome, having as cognitive counterpart the break-down of semantic knowledge.



Fig. 1 — Nuclear Magnetic Resonance scan of patient R.M. carried out in February 1995. The section shown is -20 mm from the planum temporale. The inferolateral left temporal lobe is distinctly atrophic compared to the right. Right and Left are reserved in the picture.

TABLE I
Performance at Bracco's Protocol

| Subtest | R.M. (Max.) | Normal | Deficit |
|------------------------------------|-------------|------------|-------------|
| Mini Mental | 15 (30) | > 24 | |
| Info. – Mem. – Concentr. (Blessed) | 22 (34) | 33.4 ± 2.5 | Mild |
| C.A.S.: Orientation | 7 (12) | 8 ± 0.4 | Moderate |
| C.A.S.: Mental Capacity | 9 (12) | 10.2 ± 1.2 | Mild |
| Digit Span | 4 | 4.2 ± 1.2 | Absent |
| Randt: 5 Words-Acquisition | 0 (15) | 11.8 ± 1.9 | Very Severe |
| Randt: 5 Words-after 10 min | 4 (20) | 17.6 ± 1.9 | Moderate |
| Randt: 5 Words-after 24 h | 5 (20) | 15.4 ± 5.0 | Moderate |
| Paired Associates: Acquisition | 3 (18) | 13.3 ± 2.5 | Moderate |
| Paired Associates: after 10 min | 6 (24) | 21.2 ± 2.8 | Moderate |
| Paired Associates: after 24 h | 14 (24) | 20.3 ± 3.1 | Mild |
| Babcock Story: Acquisition | 3 (13) | 9.1 ± 4.2 | Mild |
| Babcock Story: after 10' | 0 (13) | 11.2 ± 5.0 | Very Severe |
| Corsi Test | 5 (9) | 4.2 ± 1.2 | Absent |
| Token Test | 17 (36) | 33.1 ± 2.2 | Severe |
| Set Test | 18 (40) | 38.5 ± 1.6 | Severe |
| 3 Digit Subtractions* | 8 (10) | | |
| Copying Drawing Test | 16 (16) | 13.2 ± 1.9 | Absent |
| Gibson Maze | 10 (12) | 10.9 ± 0.8 | Absent |

Note – Performance on Bracco's Protocol for Dementia (Bracco et al., 1990). Comparison is made with a control group of 146 age-matched controls. The degree of impairment (Deficit) is rated in 5 levels: Absent, Mild, Moderate, Severe, Very Severe. "Info.-Mem.-Concentr." = Information-Memory-Concentration (IMC) Test (Blessed, Tomlinson and Roth, 1968), including Information, explored by means of 12 easy questions about time and space, Personal Memory, explored by means of 12 easy questions about time and space, Non-Personal Memory, explored by questions on well-known people and events, and Concentration, assessed by production of the months of the year forward and of the first 20 numbers backwards. "C.A.S." = Clifton Assessment Schedule (Pattie and Gilleard, 1975); its Subtest on Mental Capacity is composed of 4 parts: writing to dictation, reading, counting and producing the alphabet. "Randt" = Randt Memory Test involving delayed recall of a list of 5 words after a filled interval (Randt, Brown and Osborne, 1980). "Babcock Story" = the Babcock Story Test (Babcock and Levy, 1930). "Corsi Test" = the Corsi Block Tapping test (Milner, 1971). The "Token Test" is used in the short version (De Renzi and Faglioni, 1978). The "Set Test" is a category fluency task (the Isaacs and Kennie (1973) version, with a time limit of 40", and with 4 categories: colours, towns, animals and fruits). The task marked* is the filler task of the Randt Test and has no standardization. The Copying Drawing Test includes drawings of increasing complexity (Arrigoni and De Renzi, 1964). The Gibson Spiral Maze is taken from the Clifton Assessment Schedule.

In February 1994 the patient was alert, lucid and cooperative; she was able to deal appropriately with people, and continued to take care of herself, her house and family. She could drive and go shopping alone. Insight was well maintained. She complained of increasing word finding difficulties, which started to affect her daily communication with other members of her family. At a preliminary assessment, spontaneous speech was fluent, but with frequent word finding problems. No phonemic paraphasias were noted.

As an initial neuropsychological examination the patient was tested on a battery originally devoted to assessing mental deterioration in probable DAT patients (Bracco et al., 1990). This battery utilizes 16 subtests, many existing as independent tests; it explores orientation in time and space, concentration capacity, verbal and spatial memory, simple arithmetical skills, language (verbal comprehension, fluency, writing and reading capacities), and visuomotor functions. Scores, as well as normal performance ranges for comparison, are reported in Table I.

The patient was well oriented in time and space; she retained knowledge about her personal history, but performed poorly on questions tapping knowledge of well-known people and events. She was impaired on tests requiring verbal comprehension and long term verbal memory. In reading she showed a surface dyslexic pattern of performance, with stress errors. Writing was preserved. She also performed poorly in the category fluency task. By contrast, her performance on non-verbal tests was preserved: she had normal spatial memory for her age, and good visuo-spatial abilities. She was also able to perform simple additions and subtractions, although she used counting strategies. No sign of buccofacial apraxia was recorded. The patient was able to imitate meaningful gestures (such as to

hitchhike, to salute, "O.K." and "crazy") but could not produce them to verbal command. Further details or miming abilities are given in Experiment 5.

This preliminary investigation revealed a dissociation between tests requiring verbal comprehension or other verbal semantic memory functions, where performance was severely compromised, and other tests relying on visuo-spatial abilities, in which performance was entirely preserved. The dramatic impairment in naming and word comprehension, together with the reduced category fluency and the surface dyslexic error pattern in reading, suggested that the impairment should be located at the level of the semantic memory system. As she did not have a primary clinical amnesia, her low performance on verbal memory tests can also be attributed to semantic memory problems (Warrington, 1975).

Some time later (February-March 1995), a more detailed evaluation of R.M.'s language skills was carried out. In a two choice spoken sentence-picture matching task designed to assess syntactic competence (Bisiach, Cappa and Vallar, 1983) the patient scored 11/12 correct (Feb. 1995), demonstrating normal syntactic comprehension. The patient was then given the Italian version of the AAT (Aachener Aphasia Test) (Luzzatti, Willmes, De Bleser, 1991). The equivalent T scores for the different subsections are shown in Table II. At this time the impairment profile was classified as that of Wernicke's Aphasia. The reading performance again showed occasional surface dyslexic errors. The mild level of deficit on repetition and on the Token Test could be attributable to a primary auditory-verbal short memory problem, with no evidence of phonologic processing deficits. She did however show phonemic paraphasias very occasionally in spontaneous speech. Most critically comprehension and naming were the most seriously impaired functions; statistical comparison between subsections showed significantly poorer performance in naming and comprehension than in the other subsections (Psychometric Single Case Analysis $p < 0.01$).

At this stage of her progressive disease, a deficit of semantic functions appeared to be at the core of the patient's pattern of impairment. In addition she had some problems with auditory-verbal short term memory and made very occasional phonemic paraphasias. However even as late as February 1996, the patient scored 29.5 on the Raven Matrices (A, B, C, D), which is more than one standard deviation above the mean for aged matched controls (27.0 ± 2).

Overall R.M. presents with a specific semantic memory problem with other cognitive functions much less impaired. The experimental investigations which follow are concerned with a detailed analysis of her semantic memory problem. As it will be evident by looking at the experimental results, the time course of R.M.'s pathology as regard the semantic memory deficit is rather slow; the progression involved addition of new systems rather than the semantic memory impairment itself becoming rapidly more severe. When the same test has been repeated within a month performance was always found to be at the same level (See Tables V, VII and VIII). When the same task, or a very similar one, has been repeated several months (See Table VIII) and even one year apart (Compare Table IV and Table VI) the level of performance was also found to be stable. However as the patient had a degenerative condition we distinguished four different periods in the time course of the investigation: (I) February-May 1994; (II) November 1994; (III) February-June 1995; (IV) October 1995-February 1996.

TABLE II
Performance on the Aachener Aphasia Test

| Disturb-level (T-score) | Written language | Repetition | Token Test | Naming | Comprehension |
|-------------------------|------------------|------------|------------|--------|---------------|
| Minimal/absent (63-80) | | | | | |
| Slight (53-62) | 56.0 | | | | |
| Mild (43-52) | | 49.0 | 52.0 | | |
| Profound (20-42) | | | | 40.7 | 41.9 |

Classification of T scores obtained in the subsections (Token Test, repetition, written language, naming, and comprehension) of the AAT (March 1995) with respect to the level of impairment. T scores are derived from the actual results in the subsections, to allow a direct comparison between them.

AN INITIAL ASSESSMENT OF SEMANTIC MEMORY FUNCTIONS (PERIOD I, MAY 1994)

Experiment 1. Part I

Materials and Methods

Experiment 1 used a test battery which is basically an Italian version of the one introduced by Hodges to assess semantic dementia (Hodges et al., 1992). Six semantic categories (12 household items, 6 vehicles, 6 musical instruments, 12 land animals, 6 birds, and 6 sea-water animals) are tested in five different tasks: fluency, naming, word-picture matching, multiple level sorting, and definition of spoken names. The stimuli are taken from the Snodgrass and Vanderwart (Snodgrass and Vanderwart, 1980) set of line drawings.

Results

R.M.'s results on the different subtests are summarized in Table III. On fluency, R.M. was unable to produce a single word in any of the categories. The patient was not able to define any of the spoken words, although she was able to repeat them without difficulty. Only 6 items were correctly named; R.M. also produced 5 circumlocutions specifying the function, a possible phonemic paraphasia ("becchia" for "bicicletta" (bicycle) and 2 perseverative errors. Phonemic cueing did not improve performance. In the word-picture matching task there were five distractors belonging to the target category for each target item. The patient was asked to repeat the spoken word before the selection of the target picture. Repetition was correct on all the items. Performance was perfect on the household objects and vehicles categories, while being at chance on the others. The dissociation between living and non-living items reached statistical significance in a logistic regression taking into account visual agreement, name agreement, imageability, lexical frequency and familiarity ($p < 0.05$).

The multiple level picture sorting included three sections. In the living vs non-living section the percentage of correct answers was 93%. What we will call the ordinate level section (e.g.: land animal vs water animals vs birds and household items vs vehicles vs musical instruments) was performed separately

TABLE III
Semantic Memory Battery

| | Defin. | Cat. fl. | Nam. | N. - p. - M. | Pict. sort. |
|-------------------------|--------|----------|------|--------------|-------------|
| Land animals (12) | 0 | 0 | 2 | 3 | 12 |
| Water animals (6) | 0 | 0 | 1 | 1 | 5 |
| Birds (6) | 0 | 0 | 1 | 1 | 5 |
| Household items (12) | 0 | 0 | 1 | 12 | 10 |
| Vehicles (6) | 0 | 1 | 1 | 6 | 6 |
| Musical instruments (6) | 0 | 0 | 0 | 1 | 6 |
| Total (48) | 0 | 1 | 6 | 24 | 44 |

The number of correct responses for a given category of living (land animals, water animals and birds) and non-living (household-items, vehicles and musical instruments) items on the different subtests of the Hodges' semantic memory battery (Experiment 1. Part I. May 1994): definition of spoken names (Defin.), category fluency (Cat. fl.), naming (Nam.), word-picture matching (W.-p.-M.; chance level 17%) and picture sorting (Pict. sort.; chance level 33%). Results on picture sorting include only the ordinate level classification (land animals vs water animals vs bird for living items and household-items vs vehicles vs musical instruments for non-living items).

on living and non-living items. In the subordinate section¹ R.M. was 67% correct on non-living and 84% correct on living items. While the results reproduce the well known trend for greater impairment of subordinate level knowledge (Warrington, 1975), it should be noted that the different subtasks are not equally balanced for the possibility of the patient using presemantic information.

Experiment 1. Part II

Materials and Methods

A verbal version of the sorting task, employing the same items, categories and classification criteria as for picture sorting, was given to the patient in the same period (May, 1994). The patient first had to read the name on a card, being corrected if she made a reading error; in this case she was asked to repeat the correct pronunciation. Then she had to sort the card. Exemplars from the groups in which the items had to be sorted were presented in the same format as the stimuli, and included only frequent words; verbal descriptions of the different categories were also provided.

Results

R.M. performed 58% correct at living vs non-living sorting (at chance: Binomial test $p > 0.05$), 62% correct at the ordinate level (better than chance (33%), Binomial test $p < 0.01$), and 64% correct at subordinate sorting (not different from chance (50%), Binomial test, $p > 0.05$). R.M.'s performance is significantly worse with verbal than visual stimuli, even excluding all stimuli on which reading errors occurred (Sign test $p < 0.01$) (See Table IV). With respect to the reading performance, the patient made 8/48 errors, 4 involving the misplacing of stress (e.g.: 'lampáda' instead of 'lámpada' = lamp), which is typical of the surface dyslexic error pattern for Italian (Chiacchio et al., 1993).

The initial investigation confirmed the evidence of a semantic memory deficit. Perfect performance on repetition of single words, and the nature of the few reading errors half involving misplacing of stress, possibly due to lack of semantic support (Patterson and Hodges, 1992; Chiacchio et al., 1993; Miceli,

TABLE IV
Picture and Written Words Sorting

| | Pictures | Words | Chance level |
|------------------------------|----------|-------|--------------|
| Superordinate Classification | 93% | 53% | 50% |
| Ordinate Classification | 92% | 62% | 33% |
| Subordinate Classification | 50% | 64% | 50% |

Percentage of correct answers at Picture and Written Word Sorting (Experiment 1. Part II. May 1994). Superordinate classification: living vs non-living; Ordinate classification: land animals vs water animals vs birds and household items vs vehicles vs musical instruments; Subordinate classification: 2 perceptual and 3 associative classes.

¹ Including 'electric vs non-electric' (10/12 correct), 'smaller or bigger than a T.V. monitor' (5/12 correct), 'found in the kitchen or not found in the kitchen' (9/12 correct) for household items, and 'smaller vs bigger than the well known dog Rocky', R.M.'s neighbours' German Shepherd', (11/12 correct), and 'fierce vs domestic' (9/12 correct) for land animals.

Capasso and Caramazza, 1994) – also suggested that more peripheral phonological and orthographic deficits, if any, were not crucial in defining the pattern of impairment.

R.M.'s performance appeared to be dependent on the type of semantic knowledge required by the task: the experimental results pointed to a dissociation between tasks requiring verbal comprehension, which seemed to be dramatically compromised, and tasks relying mostly on non-verbal semantics, such as picture sorting (Warrington and McCarthy, 1988), which were relatively intact.

VISUAL AND VERBAL SEMANTICS

In the previous section it was suggested that R.M. might show different degree of impairment for visual and verbal material. The following experiments explored this possibility more formally.

1. The Pyramids and Palm Tree Test (Period II: Nov. 1994): Verbal and Visual Presentations

Experiment 2

Materials and Methods

The patient was given the original version of the Pyramids and Palm Trees test and, two days later, the corresponding verbal version. The same tests were given again ten days later in the opposite order. In both the verbal and visual presentations the cards, with line drawings or words respectively, were arranged in a triangular set, with the stimulus at the upper vertex and the target and the distractor randomized at the bottom. For the verbal administration the same procedure was used as in the verbal sorting experiments.

Results

The patient scored 31/54 on visual and 35/54 on verbal presentation on the first occasion, and 26/54 with visual and 33/54 with verbal presentation on the subsequent administration. On the first verbal administration the patient produced just one reading error. On the second verbal administration 16/54 words were not properly read: errors included 5 stress misplacing errors, 7 single phoneme substitutions and 4 additions of an 's' at the beginning of the word².

As the Pyramids and Palm Tree Test involves somewhat uncommon items, some fairly abstract references, and was derived for use with English patients, we developed a version using a similar structure, in which the inferences were of particular predefined types.

² In these last cases, which occurred in sequence ('criceto', 'trapano', 'chiodo' and 'ghianda'), the patient was not able to produce the right pronunciation even after the experimenter's correction. These errors could be related to a phonological phenomenon, which is peculiar to syllabification in Italian. Current theory holds that CCCVX syllables do not exist in the basic structure of Italian syllables (Nespor, 1994). However, words starting with S + CCV do exist (e.g.: 'stretto'), and for them it has been proposed that the initial 'S' is added by a special mechanism as a C syllable.

2. The Semantic Judgement Type Test (Period III: Feb. 1995)

Experiment 3

Materials and Methods

The material for the test was a collection of household items, foods, clothes, jewels, cosmetics, commonly used personal objects, such as cheques and identity cards, and some familiar items used outside the house, like a windscreen wiper and a tax stamp. During the first session, which was videotaped, a preliminary assessment of the patient's recognition abilities was produced by asking the patient to mime the use or give any other kind of indication she could about the object. Some objects were excluded at this stage because they were unfamiliar. For each of the 60 remaining objects a 3 alternative forced choice set was formed.

The proposed 60 forced choice sets were classified by 3 independent judges. They had to decide, for each set, which of six possible kinds of semantic judgements was relevant for providing the correct response. On 51 occasions all the judges agreed. On 9 occasions one judge gave a divergent assessment. In these cases the majority assessment was used. The decisions of the judges led to the following semantic classes being adopted for the forced choice experiment:

- 14 judgements were classed as simple common category judgements (e.g.: earings: bracelet vs belt vs lipstick);
- 7 were classed as involving the matching of items which are typically seen together but not related by common use or function (e.g.: windscreen wiper: car tax sticker vs scarf vs detergent);
- 12 were classed as requiring pure semantic inferences (e.g.: cork: raisin vs pepper vs scissors);

The broad class of functional relationship was further fractionated into:

- 10 cases in which the stimulus and target were judged to share the same function, and with it being achieved by a similar kind on action (e.g.: brush: comb vs sponge vs glove).
- 7 cases in which the same function was judged to be achieved by a very different action (e.g.: button: zip fastener vs belt vs glove).
- 10 cases in which the stimulus and target were judged to be used jointly in the achieving of the same function or goal (spring clip: hair curler vs shampoo vs bottle opener).

Exemplars from the different classes were presented in random order, but with the same order being followed in the visual and verbal sections, which were administered on successive days. Both the visual and verbal presentations were repeated 3 weeks after the first assessment, in reverse order with respect to the first administration. In the object presentations, the stimulus was placed on a coloured sheet of paper to enhance its role; the target and two distractors were placed on the table in front of it, in randomized positions. For the verbal administration, the procedure used in the Pyramids and Palm Tree test was applied.

Results

The overall performance on verbal material was at chance (33%) in both sessions while with real objects the percentage of correct answers was 65% on the first and 73% on second evaluation, significantly better than chance on both occasions (See Table V). Considering the different kinds of semantic judgement, the performance with verbal input was at chance on all subsections. The performance with visual and verbal material was compared for each of the different subsections (See Table V). Two consistent patterns could be distinguished. For three classes of semantic judgements, performance was at chance on visual as well as verbal presentation, and there was no statistical

TABLE V
Semantic Judgement Type Test

| | Real – object: 1st – 2nd | Verbal: 1st – 2nd | Visual-verbal difference |
|---------------------------|--------------------------|-------------------|--------------------------|
| Co-occurrence (7) | 6*** – 5* | 1–2 | <0.05 |
| Comm. concr. func. (10) | 8* – 10*** | 5–1 | <0.02 |
| Joint use to a func. (10) | 8*** – 9*** | 2–4 | <0.02 |
| Comm. category (14) | 7 – 9 | 5–5 | N.S. |
| Comm. abstr. func. (7) | 3 – 5 | 2–3 | N.S. |
| Sem. inference (12) | 7 – 5 | 3–5 | N.S. |
| Total (60) | 39*** – 43*** | 18–20 | |
| Overall | 65% – 73% | 28% – 33% | |
| Chance level | 33% | 33% | |

Number of trials where matching was correct on the first and the second real object and verbal administrations of the Semantic Judgement type Test (Experiment 3, February 1994). Results are given separately for each kind of semantic judgement in the test; judgements were classified as co-occurrence, common concrete function, joint use for a function, common category, common abstract function and semantic inference. In the first two columns levels of significance of the scores with respect to chance (Binomial test, one tail) are given by: * $p < 0.01$, and *** $p < 0.005$. In the last column, the statistical significance of the visual-verbal dissociation as measured by the Wilcoxon Rank test (N.S. = Not Significant) is given. In the last two rows, the percentage of overall correct answers is given for direct comparison.

difference between visual and verbal material; these classes were semantic inferences, detection of common category and detection of common abstract function³. For three other classes of semantic judgements however, performance was significantly above chance with visual presentation on both testing sessions but not on either for verbal presentation. Moreover with these classes of semantic judgements R.M.'s overall performance was significantly better with visual than with verbal material. These latter classes are detection of common concrete function, joint use of a function and spatial co-occurrence.

Discussion

The dissociation in performance between visual and verbal presentation obtained using the Hodges' Battery, was confirmed in the present experiment. R.M.'s performance on verbal material was at chance for all subsections of the Semantic Judgement Type Test. On the visual version, however, performance was significantly above chance and significantly better than on the verbal version in the sections concerning spatial co-occurrence, similar function and action, and joint use in a function. On the other sections, the performance on the visual version was not better than chance. These were the sections where the question could not be answered on the basis of common location or similarity of action. Could one assume that this dissociation can be accounted for by assuming that presemantic information is supporting performance? For example could one argue that retrieval of a visual scene would indeed be sufficient to perform the task, but this hypothesis would not explain the overall pattern because in the classes of judgements where performance is at chance there are also many items that can be found together on some occasions; this is particularly true for items belonging to the same category, like fruits (e.g.: apple

³ On one of the two testing sessions performance with verbal presentations was just significantly above chance on this judgement.

and banana vs onion vs cork), clothes (e.g.: gloves and pullover vs belt vs hammer) etc., but also for items that share the same 'abstract' function (e.g.: zip fastener and button vs skirt vs plate). Also the distractors in the critical test where performance was preserved were often chosen expressly as items belonging to the same loose context of the target (e.g.: hair pin and roller vs shampoo vs bottle opener). What therefore we would claim is that information about the typical context in which an item is found should be considered as part of the semantic representation (see Shallice, 1993). If this was not the case one would be obliged to assume that the context is also represented at the level of structural descriptions, which does not fit with the experimental evidences found in agnosic patients (Humphreys and Riddoch, 1987a).

It should be noted that R.M. spontaneously provided some support for her choice on almost one third of the errors on visual presentation, often based on her personal experience. For example, while incorrectly matching earrings with a lipstick instead of a bracelet, she showed how she would have put on earrings and some make up before going out. In these cases, although the retrieval of a personal experience is incorrect with respect to the kind of judgement formally required in the test, it does reveal access to the semantic system, because the retrieved experience clearly relates to the meaning of the stimulus, and the selected pairing is linked by proximity.

3. Visual and Verbal Categorization (Period III: June 1995)

Experiment 4

Materials and Methods

In view of the difficulty the patient had in the common category part of the Semantic Judgement Type Test, R.M. was given a simplified version of the sorting task from in Hodges' Battery. The same items were used. For each item, the picture or the written name was presented on a card, and a simple question was asked. For written material, the same procedure was used as for the original Pyramids and Palm Tree test. For the living vs non-living classification the patient was asked if the item was an animal or not. Then for what we will call the "ordinate level" classification she was asked if the item was found in a house or outside in the case of man-made objects, and if it was found in water or not for animals. This last classification could not be carried out on the base of the structural description of the items. The categories of "musical instruments" and "birds" were not included in this last session of the test. The test was repeated twice in an ABBA design.

Results

The results are summarized in Table VI. The dissociation in performance between visual and verbal input was significant at both the superordinate (Sign test: $p < 0.01$) and ordinate levels (Sign test: $p < 0.05$) on both testing sessions. The results of the two ordinate level classifications with verbal material and of the corresponding ordinate level sorting task of Hodges' Battery (on the same items) were analysed using a statistical procedure which extends the stochastic approach of Faglioni and Botti (1993) to the case of multiple choice tasks (Lauro-Grotto, Treves and Shallice, in preparation). Based on the assumption

TABLE VI
Visual and Verbal Categorization

| | Visual: 1st – 2nd | Verbal: 1st – 2nd | Visual-verbal difference |
|------------------------------|-------------------|-------------------|--------------------------|
| Superordinate classification | 47/48–46/48 | 30/48–29/48 | <0.01 |
| Ordinate classification | 34/36–35/36 | 28/36–23/36 | <0.05 |
| Chance level | 50% | 50% | |

The proportion of correct classifications on the categorization task (Experiment 4, May 1995) using visual and verbal materials, on two administrations (1st and 2nd). Superordinate classification refers to correct answer to the question "Is it an animal?". Ordinate classification of living items refers to the question "Does it live in the water?". Ordinate classification of non-living items refers to the question "Is it found at home?".

that consistency of results in repeated trials is a feature of storage deficits while inconsistency is a feature of access impairments, this analysis produces two indices ranging from zero to one, *s* and *r*, which correspond to estimates of the probability of correct storage and the probability of correct retrieval (given correct storage) respectively. In the present case the analysis produced *s* = 0.44 and *r* = 0.97 which correspond to a degraded storage type of impairment (for further details see the General Discussion and Appendix A).

4. Further Experimental Investigations about Visual Semantics (Period III: May-June 1995)

The findings obtained with the semantic Judgement Type Test suggested that it was indeed still possible to explore R.M.'s residual semantic competence in dealing with visual stimuli. During a preliminary videotaped examination in Feb. 1995, the patient was recorded in the usual test room, while performing a series of daily activities elicited by visual stimulation. The patient was presented with some objects which were intended to elicit specific behaviours: a white coat with one button missing, an empty coffee machine, some spaghetti, a watch set to the wrong hour. The material necessary to carry out each of the related task was placed on a nearby table, mixed with many distracting items in order to see if the patient was able to distinguish what was needed. R.M. immediately and appropriately reacted to the stimulus. She was also extremely rapid and self confident. However it was evident that simple verbal request was almost completely ineffective in eliciting any kind of answer. For example when asked to show how to cook 'spaghetti', she simply stared at the experimenters, but when she was presented with the actual spaghetti she rapidly collected what was needed and gestured an extremely faithful and detailed account of the cooking procedure. She spoke at the same time, but virtually without using any relevant content words other than superordinates. The same kind of reaction was recorded on all the verbal requests. On the contrary a high standard of performance was attained in all the tasks with visual presentation.

In the videotaped sessions, it was possible to unmask complex levels of organized behaviours (schemata), that were elicitable by visual stimulation. This result, if confirmed, would help to explain one of the phenomenological observations that prompted our analysis, namely that the patient still had quite high standards in daily activities.

Experiment 5 (Period III: May 1995): The Cooking Procedures Test

Materials and Methods

The cooking domain was selected as a relevant one to investigate, because cooking procedures have many specific requirements and are of a sufficient level of complexity. The patient was tested in a kitchen and asked to cook 8 different foods, and to mimic in the most detailed way the cooking procedure for 16 other foods. The whole section was videotaped. The patient was placed in front of a table where the materials necessary for cooking the whole set of 24 foods had been arranged randomly; the set included 7 different types of pans and related varieties of cooking dishes, with two exemplars of different dimensions for each type, 6 types of plates, 2 types of glasses, and common ingredients, including salt, pepper, oil, vinegar, sugar, butter, flour, ham, bread crumbs and eggs. On other surfaces of the kitchen 17 types of cooking implements, such as spoons, forks and knives of different dimensions, a wooden spoon, a tin-opener, a gas-lighter, some paper towels, some toothpicks, etc. were randomly arranged. On another table, placed next to the first, a big basket contained all the types of vegetable toe used in the test, plus onions, garlic, celery, parsley and carrots, which could be used as ingredients; another basket contained four types of fruit, oranges, lemons, apples and bananas.

When foods were actually cooked, the patient was shown the food she had to prepare on a chopping-board, she was not asked to name it, nor was the name pronounced by the experimenters during the whole session, but spontaneous naming was allowed. R.M. was asked to say if she could recognize the food and if it was one that she usually prepared at home or not; finally she was asked to cook it. First she had to select the quantity that would be appropriate for a given number of people from 3 to 7 (the size of her family); then she had to select the most suitable pan for that quantity and specific kind of food. She was instructed to collect whatever she needed from the two tables, without any feedback from the experimenters. She received no assistance during the cooking procedure. As she was rapid and self confident in carrying out the procedures, she was allowed to cook more than one food at a time.

The mimicking procedure was devised because the patient considered it inappropriate to cook more than a given number of different foods, which could not be eaten. The procedure applied was the same, except that, after the selection of the stove, the patient was required to gesture the rest of the cooking procedure: for example, she actually cleaned the artichokes and put them in the pan, but then she just selected the remaining ingredients from the basket and mimicked the action of adding water and putting them on the stove. All ingredients and implements the patient used in a given procedure were returned to their place before the beginning of the next trial.

Results

In Table VII we have summarized the results of the videotaped section on cooking abilities. For every food, the level of performance reached by the patient is given, as assessed by three independent judges, two of whom were present at

TABLE VII
The Cooking Test

| Scores | Number of foods |
|------------|-----------------|
| Perfect | 13 |
| Good | 4 |
| Sufficient | 2 |
| Scarce | 3 |
| Null | 2 |

Performance on the videotaped section on cooking abilities (Experiment 5. April 1995).

the experiment, while the third assessed the videotaped material. The judges were in 100% agreement in the categorization. The scores have been selected according to the following criteria:

'Perfect' is attributed to a procedure which is highly specific and appropriate in every single step;

'Good' refers to an appropriate and specific procedure that has been simplified in some passages without compromising the final results;

'Sufficient' refers to a procedure which is appropriate, but not specific to a particular food;

'Scarce' refers to an oversimplified procedure or to one where some crucial intermediate section was missed out;

finally 'Null' is attributed to a case where no response is elicited at all.

An example of a Good/Perfect procedure is one in which the patient correctly achieves each of the following steps:

(a) general selection of the method of preparing the food (e.g.: the chicken breast must be cooked, it cannot be eaten raw);

(b) selection of the appropriate stove for the given food;

(c) selection of the appropriate type and dimension of the pan for a given quality and quantity of food;

(d) selection of the ingredients needed for a given procedure (e.g. for the chicken breast: flour, ham, oil, salt);

(e) organization of the subprocedures needed (e.g.: removing the central bones from the chicken breast; cleaning the ham slices; cutting the slices in the appropriate dimension to be stuffed in the chicken breast slices... and at least 7 other subprocedures of comparable complexity to complete the task.);

(f) selection of the implements needed in each subprocedure (the big knife to cut the chicken breast, the toothpicks to close the slices together, the paper towel to coat the slices with flour);

(g) timing and sequencing of the behaviours.

Over 24 foods presented, for 13 performance was rated as perfect; for 4 it was good; for 2 it was sufficient; for 3 it was scarce and on 2 more it was judged as null (See Table VIII). So in 71% of the cases performance was rated as at least 'good'.

The patient was usually self confident and rapid in carrying out the task. Ignoring the 'Sufficient' category, where the issue of the specificity of the response cannot be assessed, the patient gives evidence of specific knowledge of the procedures appropriate to a certain food: for example, in cleaning the artichokes the patient removed the external leaves, cut the top of the remaining

TABLE VIII
The Materials Tests

| Materials Test: | % Correct | Chance level |
|--------------------------------|-----------|--------------|
| 1st Adm.: Jun. 1995 | 86 | 25 |
| 2nd Adm.: Jun. 1995 | 73 | 25 |
| 3rd Adm.: Dec. 1995 | 81 | 25 |
| Word-Object Match. – Dec. 1995 | 29 | 33 |

Performance on the repetitions of the Materials Test (Experiment 7). Performance on the corresponding Word-Object Matching Test is also shown for comparison.

leaves and the backs of the artichokes, then while she threw away the leaves that had been cut, she cleaned the backs by peeling away the hard external part and added them to the cleaned artichokes. This procedure is item-specific and cannot be inferred from general properties, like just 'being a vegetable', nor by affordances on perceptual features (why should the patient remove just a few of the leaves, which look exactly the same as the ones she is not going to remove?).

The behaviour of the patient in the trials marked 'null' (aubergine and 'gnocchi') suggests that she is not sensitive to perceptual features which could prompt particular responses: thus she was not able to produce any response to the aubergines, which have a smooth violet part and a tough green more leaf-like part, that could be removed just on the base of an analogous perceptually based distinction. Nor did she respond to the 'gnocchi', which on colour and texture share many perceptual attributes with 'tortellini', a food she cooked very well. Furthermore, if the patient was basing her selection of the correct procedure on the recognition of an item as a member of a given category (a vegetable, a kind of meat, a kind of pasta etc.), one would have expected to find a much greater proportion of the trials in the 'sufficient' class, where procedures not specific for a given item are applied. In this respect our results contrast with the 'identification semantics' position.

Discussion

In this experiment R.M. showed not just recognition of the foods, but also good ability to select, among a large variety of closely related semantic distractors, the implements and the cooking dishes appropriate to a given procedure, and perfect recognition of the ingredients needed. The ability to use implements appropriately and to recognize ingredients has been considered as part of the correct execution of a given cooking procedure, and in consequence has not been independently scored. In the case of the foods actually cooked by the patient (8), the mean number of implements used is 6.5, while the mean number of ingredients is 5, which gives a quantitative idea of the richness of the procedures applied, as well as of the ease of the patient with respect to the use of the implements and to the knowledge of the peculiarities of the ingredients.

The patient did not appear to be confused or disturbed by the novelty of the material and surroundings: for example, she inferred correctly how to use the automatic gas-lighter of the oven, and she suggested keeping some kind of foods, such as fish and meat, in the refrigerator. During the whole videotaped section, R.M. spontaneously named only oil, salt, water, broth, rice, chicken and tomato sauce. On one occasion, she added that, while shopping, she could not remember names, but she had no problems in pointing to the items she intended to buy.

Experiment 6 (Period III: June 1995): The Verbal 'Counterpart'

On initial pilot observations R.M. was unable to carry out the sequence of actions required in miming given the word instead of the project. However to

gesture a complex sequence of actions from verbal command in the absence of the object is an intrinsically more difficult task than carrying it out with objects. We therefore decided to use the simplest control for the ability to identify this type of objects from verbal presentation, namely multiple choice word-object matching test. This experiment was performed two weeks after the cooking experiment.

Materials and Methods

The experiment employed the same items as in the cooking procedure test. We selected a list of 56 items which consisted of all the foods tested in the cooking procedure (24), plus the essential ingredients (14), and the implements (18) that were necessary in the preparation of the different foods; they also included ingredients and implements that were necessary to cook those foods on which the patient's performance had been poor on the 'cooking procedures' test. In the word-real object matching test, each name had to be matched to the target inserted in a group of 5 distractors, chosen as the items most closely related semantically to the target among the whole set. For example, for a vegetable, other members of the same category were used as distractors. The patient listened to the spoken name, was asked to repeat it, and finally she had to select the matching object, within a time limit of 30 seconds after she repeated the name (this is quite long for a multiple choice test, but the task was made as easy as possible in order to provide more relevant data). R.M. then moved to another group of items, listened to another name and so on. The presentation order was random within each group, but cyclical across groups.

The whole test was administered twice to the patient.

Results

The patient's percentage of correct answers was 53% (30/56) on the first trial and 62% (35/56) on the second (chance level 17%). Performance was consistent across trials (Contingency coefficient = 0.47). On foods and ingredients performance reached 52% (20/36) and 72% (27/36) on the first and second testing sessions, while on implements the percentage of correct performance were 50% (9/18) and 44% (8/18) respectively. Neither frequency nor word-length was found to be predictive of performance in a linear regression analysis ($p > 0.05$). These levels of performance (30/56 and 35/56) are significantly worse than those occurring during the cooking procedures test: 86% of the same items (48/56) had been correctly employed by the patient during the videotaped section (Sign Test, $p < 0.01$ for the first session and $p < 0.05$ for the second). The value 48/56 is obtained by considering those items included in Experiment 1 on which R.M. reached a score of at least 'good', plus the ingredients and the implements which were used correctly and specifically in the cooking procedures (data derived from the videotape). So performance on this very simple task requiring verbal input (in fact the simplest we could think of!) was significantly worse than performance during the complex cooking procedures test. There was no correlation between the levels of performance reached in the cooking procedure test and the results on the same items in the word-object matching test (Wilcoxon Rank test ($p > 0.05$)). As only two weeks had elapsed between the cooking test and the word-object matching, and given the slow progression of R.M.'s pathology (See Case Report), it is highly unlikely that the difference can be attributed to worsening of the cognitive impairment.

In the subsequent experiment we investigated R.M.'s competence in dealing with visual stimuli in a domain different from the cooking one. We document the existence of another qualitatively different domain of preserved visual semantic knowledge. At the same time we show the richness of the semantic representation available from visual input; in particular we focus on the presence of subordinate level information.

*Experiment 7: The "Materials" Multiple Choice Test
(Period III: Mar.-Apr. 1995; Replicated in Period IV: December 1995)*

Materials and Methods

As the patient had been working in a textile manufacturing business it was assumed that she had a specific competence for clothes and fabrics. In the 'materials' multiple choice test, the patient was shown an article of clothes and asked to select among four given pieces of material the most suitable to create another exemplar of the same article; for example, when given a woman's silk blouse, R.M. had to select a piece of 'vyella' as another possible material with which to make a woman's blouse, instead of tweed or lycra. 22 different stimuli, ranging from clothes to lingerie to house linen and 29 different materials were used in this test. Perceptual similarities between the stimulus and the target or distractors were always avoided: they never shared colour, texture or the kind of design. So in order to perform the task, the patient must access subordinate level visual semantic knowledge about the stimuli and must perform fine grained visual semantic discriminations between the target and distractors.

The appropriateness of the 'ideal match' was confirmed by 2 judges, who were instructed to confer to reach an agreed assessment in case of initial disagreement. In fact they always agreed. On the first administration (Mar. 1995), the patient was allowed to manipulate the materials; on the second (Apr. 1995), she was forbidden to do so.

Results

R.M. scored 19/22 correct (86%) on the first administration and 16/22 correct (73%) on the second, both significantly different from chance (25%) (Binomial test: $p < 0.01$). The results were consistent on 19/22 trials (86%); only 3 trials were successful on the first but not on the second administration, the two not being significantly different (Sign test, $p > 0.05$).

*Replication and Extension of Experiment 7
(Period IV: October 1995-February 1996)*

In order to estimate performance with verbal input for the experimental material used in Experiment 7, a three choice Word-Object Matching Test on the names of the materials used was carried out in December 1995. In this task the patient was given the name of the material auditorily, and asked to repeat it; if necessary, she was corrected until perfect repetition was reached (correction was in fact only necessary once, with the word "taffeta"). Then she was instructed to point to the corresponding material. R.M. scored 6/21 (29%) in this task, not statistically different from chance (Binomial test: $p > 0.05$).

Given the progressive nature of R.M.'s dementing illness, the visual version of the 'materials' test was repeated again after the word-object matching test,

this time presenting the patient with 16 coloured pictures of the stimuli, while the targets and distractors were the same as in the previous sessions. The storage index and the retrieval index were evaluated by applying the statistical procedure described in Appendix A to the data from the three repetitions of the material test with visual input: this analysis produced $s = 0.78$ and $r = 0.94$.

Discussion

The 'materials' test documents the existence of another domain of preserved semantic competence accessible from visual input. In this experiment, the patient was required to give a judgement on the basis of a specific ability. As the experiment was expressly devised to exclude the possibility of non-semantic cueing, such as by the use of visual similarities, the results demonstrate a fine grained preservation of knowledge about materials and access to subordinate level information on clothes as well. It is important to note that in the 'materials' test the "output" requirements were reduced to pointing to the target, so any privileged link between shape and function (Caramazza et al., 1990) is not relevant.

The exclusion of tactile information did not lead to statistically worse performance, so the knowledge necessary for carrying out this task would appear to be entirely accessible from visual input. On the other hand performance on the Word-Object Matching Test, which was chosen as an easy comparison task, was once more at chance level. Although the names of some fabrics are of low frequency for the average member of the population, as the patient had been working all her life in her husband's textile manufacturing business, we can assume that her premorbid familiarity with the names of fabrics must have been particularly high. Data from this experiment also provided an estimate of the storage and retrieval indices given visual input, to be compared with the corresponding estimates obtained from data with verbal material (see General Discussion).

GENERAL DISCUSSION

We carried out extensive experimental work with patient R.M. in order to specify the nature of her deficit. The main characteristic of her impairment was a marked modality-specific effect, with the level of performance on verbal material almost never exceeding chance, in contrast to a much better level with visual presentation.

There are a number of findings which indicate that her difficulty on semantic tasks arises from an impairment at the semantic level. One problem in drawing such a conclusion is that distinguishing impairments of semantics from those of phonology is not straightforward because of the possible existence of semantic support for basically purely phonological processes (Caramazza and Hills, 1991; Patterson and Hodges, 1992). However R.M.'s deficits in tasks involving orthography and phonology but not semantics were only mild or moderate even at a late stage in the evolution of the disease (as shown by her performance on

the AAT). Thus late in the course of the illness she was able to reproduce words adequately when word-picture matching was grossly impaired (See Experiment 4). By contrast even early in the course of the disease if semantic processing was required, performance on tasks with verbal input was always at the severely impaired level. Moreover this degree of impairment was present when R.M. was provided with both orthographic and phonological inputs, and also when phonological output had to be accessed. Thus any explanation of her performance in terms of non-semantic processes would need to assume severe deficits in three phonological and orthographic systems. Moreover in the tests where performance lay between chance and ceiling with verbal input – the ‘ordinate level’ sorting and categorization (in Experiments 1 and 4) and the word-picture matching control experiment for the cooking procedures (in Experiment 6) – phonological dimensions such as word length did not correlate with performance. Phonetic cueing, as formally tested during Experiment 1, was ineffective.

All these findings fit in the assumption that the crucial impairment was at the semantic level, with phonological systems becoming involved only in the later stages of the illness. This hypothesis is also consistent with the anatomopathological findings, the results of MRI in particular: the locus of the atrophy was in the inferior and anterior parts of the left temporal lobe, as is typical for semantic dementia (Hodges et al., 1992). The perisylvian region, responsible for phonological processes (Cappa, Cavallotti and Vignolo, 1981) appeared to be spared.

Secondly, given that the deficit is at the semantic level, then using the key criterion of consistency for distinguishing between access and storage deficits (Warrington and Shallice, 1979), the pattern of performance is of the degraded storage type. The possibility of distinguishing between these two patterns of impairments experimentally has been criticized (Rapp and Caramazza, 1993), but it has been effectively reaffirmed recently by Warrington and Cipolotti (1996) in at least a subgroup of patients. They provided an exhaustive description of a common pattern of performance in four typical “degraded storage” patients which contrast with one found in two “access” patients (using the term “refractory”). All four of the “degraded storage” patients suffered from a degenerative illness and indeed the diagnosis was the same as that for R.M., namely probable Pick’s disease. One problem in this area though, is that effective estimates of storage and retrieval parameters have not been made in such cases from the key consistency evidence, and thus the differentiation of either of the putative ‘basic’ forms from ‘mixed’ varieties has not been rigorously made. Faglioni and Botti (1993) derived a technique for estimating both the degree of impairment of the representations in the semantic store and the probability of correct retrieval given that the representation is present, using repeated sessions of confrontation naming on which the same stimuli were presented on each occasion. This analysis produces two indices, *s* and *r*, which range from zero to one; the index *s* gives an estimate of the proportion of preserved items, i.e. where sufficient information remains in the store to support the forced choice judgement (*s* = 1 corresponding to an intact semantic store). The index *r* is an estimate of the probability of retrieval of such preserved items

on any given trials ($r = 1$ corresponding to 100% correct retrieval). We have extended their approach to the case of multiple choice experiments, taking into account the possibility of correct guessing by chance (Lauro-Grotto, Treves and Shallice, in preparation). Values of r and s are most reliably calculated when the performance at the forced choice task is not at ceiling or floor and when the task has been repeated a number of times. In the present case the ordinate level three alternative verbal sorting task of Experiment 1 (one trial) was used together with the ordinate level categorization task of Experiment 4 (two trials). Appendix A gives the formula for any value of chance probability a and for any number N of items presented, in the case of three repetitions, in separate sessions, of each judgement. Table IX gives the values of r and s obtained for R.M., together with the values of r and s obtained from the results of the word-picture matching performed by the four "degraded storage" patients described by Warrington and Cipolotti (1996) using the findings reported in their Table 13. The values obtained for R.M. are very similar to the ones obtained by the "degraded storage" patients; in contrast for the "access" patient H.E.C. (Cipolotti and Warrington, 1995) we found $s = 0.99$ and $r = 0.64$. When the same analysis was performed on results obtained in a forced choice task using visual instead of verbal input, namely the materials test of Experiment 7, the retrieval index was found to be similar to the one in Table IX ($r = 0.94$), while the storage index was found to be much higher ($s = 0.78$ vs $s = 0.44$). In the other verbal condition which was not at chance level, R.M. again gave a consistent performance across repeated tests (see Experiment 6). We will therefore assume that R.M.'s impairment is at the semantic level and of the degraded storage type.

R.M.'s knowledge of the meaning of words is disproportionately poorer than her knowledge about the corresponding objects. As we discussed in the Introduction, different accounts of this pattern of performance can be given in the context of the range of divergent views on Semantic Memory that have been presented, such as the Organized Unitary Content Hypothesis of Hillis et al. (1990), the Multimodal Semantics Model (Warrington, 1975; Shallice, 1988; Lauro-Grotto et al., 1997) and the Identification Semantics hypothesis (Chertkow et al., 1992). We have attempted to characterize further the nature of R.M.'s

TABLE IX
Storage and Retrieval Indices

| Patient | r | s |
|---------|------|------|
| R.M. | 0.97 | 0.44 |
| S1 | 0.98 | 0.47 |
| S2 | 0.89 | 0.54 |
| S3 | 0.82 | 0.62 |
| S4 | 0.97 | 0.52 |

Comparison of the retrieval and storage indices for R.M. and for four typical "degraded storage" patients (Warrington and Cipolotti, 1993). The storage index s and the retrieval index r give an estimate of the proportion of representations in the semantic store which are sufficiently well preserved to support the forced-choice discrimination, and of the probability of correct retrieval of such representations from semantic memory. They are evaluated by extending the stochastic approach adopted by Faglioni and Botti (1993) to the case of multiple choice tasks (see Appendix A). The values reported for R.M. are derived from the ordinate level categorization (Experiment 4) and from ordinate level sorting (Hodges' Battery) of the same verbal material. The values reported for S1, S2, S3 and S4 are estimated from the results obtained in a word-picture matching test by the "degraded storage" patients described in Warrington and Cipolotti (1996), Table 13, p. 620.

residual semantic representations experimentally, in order to assess the plausibility of these different accounts.

R.M.'s performance on the Semantic Judgement Type Test provides evidence on the nature of the semantic operations that the semantic system is still able to support. The results show that the impaired system still has the capacity to provide information on functional relationships, such as joint use or common function, and on the co-occurrence of objects. On the other hand, there is no evidence that it is able to support inferences, such as the one needed in linking "cork" to "raisin", which depend on an intermediate concept with which the stimulus and target have different conceptual relations. This dissociation observed in the Semantic Judgement Type Test is somewhat similar to that observed by Semenza, Bisiacchi and Romani (1992). Using verbal input, they found preservation of "thematic" but not "class" relationships in patients with more posterior left temporal lesions.

The following analysis was prompted by some observations on the variety of real life situations with which the patient dealt successfully. In the Cooking Procedures Test, we have shown that the semantic representations accessed from visual stimulation are sufficient to allow the triggering of higher level complex action procedures. In this task the patient displayed a large variety of organized goal directed behaviours – the cooking procedures, with all their highly specific components – which were elicited by the visual presentation of items to which she failed to respond appropriately in a verbal task as simple as word-picture matching.

The specificity of the procedure used is shown by the ratings of the judges. Only 3 out of 24 foods were cooked using quite general methods that could apply to many different foods. For 71% of the foods presented the procedure was considered to be highly specific. To cook well requires the selection of appropriate implements, pans and dishes, spices and other ingredients, that must be recognized for their very specific functions or characteristics: thus selecting garlic instead of onion as a flavouring for a given food (e.g.: the mushrooms) requires a subtle within-category discrimination. Moreover actions must be selected at the appropriate time to satisfy a subgoal when it is relevant.

Could the level of performance on the cooking procedures test be supported by affordances elicited by the structural descriptions of the objects presented? This could not be the case. The procedures elicited by visual input would need to have operated on at least three levels. First there were the specific procedures needed to carry out any subcomponent of the activity, e.g. the cleaning of the stalk of the artichoke. Here the particular actions carried out depend on the eventual taste of the cooked object, so it would seem implausible to characterize them in terms of a process like an affordance, which is driven only by the shape of an object and the general repertoire of one's actions. The second level of action procedures involves the sequencing of the set of first level activities. This is more appropriately considered a MOP level of control – to use Schank's terminology (Schank, 1982). Such sequencing of activities is not something implicitly inherent within the structure of an object; it cannot therefore be an affordance. Even more clear is the third level where the operations are varied to take into account the specific cooking implements available, the state of the

food, the number of people for whom cooking has to be carried out, and so on. Here reasoning is clearly involved. In addition in daily life R.M. used to go shopping alone every day, and as she used to cook quite elaborate dishes, she necessarily had to keep in mind all the ingredients needed for any given recipe. The overall control of this type of behaviour would not have been possible without a detailed semantic representation of the cooking procedures, and of the ingredients needed.

Our experimental findings indicate that even in the presence of a profound deficit in the representation of "word meaning", the Semantic System is able to support complex procedures that imply some preserved, and dissociable, knowledge about "object meaning". These results can be easily accommodated in the context of a Multimodal Model of Semantic Memory in which the semantic representations are distributed over different modality-specific subregions (Warrington, 1975; Shallice, 1988). The subregions can be considered as more or less strongly connected to each other as in the neural network model of Semantic Memory proposed in Lauro-Grotto et al. (1997). In non-pathological conditions, the whole semantic representation can be retrieved from a given input, given appropriate task demands, through a preliminary activation of the modality-specific subcomponent. In pathological conditions, however, the degeneration can differentially affect the various subregions of the semantic network, giving rise to neuropsychological dissociations, which in turn provide the opportunity to investigate the content of the different subcomponents. On such a model the present case corresponds to the Verbal subcomponent being damaged by the neurodegenerative process, and so one observes behaviour sustained by the semantic network lacking one subcomponent, i.e. Verbal Semantics.

Considering the Multimodal Semantics position in more detail, it would seem inappropriate to assume that action procedures, which are relatively preserved in R.M., are represented in the modality-specific visual subcomponent, i.e. Visual Semantics. They are clearly more appropriately considered that part of semantic memory devoted to the organization of actions and indeed this view is compatible with De Renzi and Lucchelli's position that ideational apraxia represents the loss of semantic memory for actions (De Renzi and Lucchelli, 1988). R.M.'s pattern of performance would though imply that Action Semantics can be accessed from Visual Semantics independently of Verbal Semantics. Thus the argument presupposes that Non-Verbal Semantics is also not unitary (for related discussions, see Shallice, 1988, and Warrington and McCarthy, 1988).

Given the extensive disputes on the content of Visual Semantics (Caramazza et al., 1990; Shallice, 1993; Rapp and Caramazza, 1993), can one specify more explicitly what Visual Semantics contains? First, we will assume that Visual Semantics contains distributed representations directly accessed from the 3-D structural descriptions. We will further presume, given our earlier argument that R.M. lacks verbal semantic representations, that if a capacity is preserved in R.M. and cannot be easily ascribed to another putative part of the semantic system (e.g. the Action Semantic component or the Encyclopedic Store), then it will be tentatively considered to be represented in the Visual Semantic subcomponent.

More specifically, one can use the criterion that if two items are given as stimulus and target in a test like the (visual) Semantic Judgement Type Test, and the target item is selected easily, then this is most plausibly carried out through the use of partially overlapping representations at a given level; for if two representations do have significant overlap, then, on a neural network approach such as that of Lauro-Grotto et al. (1997), it is easy to elicit one from the other because the activation of one involves the activation of a part of the other (and vice-versa).

From our experimental results we can only produce a preliminary analysis; at least for objects, three types of information would be represented in visual semantics:

- visual contextual contiguity (related to the habitual spatial context for an object, e.g.: car tax sticker and windscreen wiper);
- access to functional contextual contiguity (the way objects can be used as parts of the same functional process, e.g.: screwdriver and screw).
- subordinate level perceptual knowledge (e.g.: the type of fur for an animal and the type of tissue for clothings).

Visual contextual contiguity is a part of the Visual Semantic representation of the objects in the sense that objects *that we usually see together* appear to be linked to each other, even in the absence of other semantic relationships among them: that the semantic representation of an object can be elicited from that of another object sharing the same spatial context, implies that their representations should overlap to some extent⁴; so the context is represented at this level.

“Functional-contextual contiguity” refers to the relationships between objects that are used together: ‘functional’⁵ refers to the fact that the visual representations of two objects that are used together for a given goal are typically “arguments” of the same action schema in the Action Semantics system (Cooper, Shallice and Farrington, 1995; Schwartz et al., 1991). “Contextual” refers to the fact that the majority of the actions – at least the ones we normally attend to – are carried out under visual control. For the reason given above, this will introduce an overlap between their Visual Semantic representations, due to the shared visual context during monitored actions. For the Non-Verbal Semantic System as a whole this is a very tight link, because if we look at the multimodal semantic representations of objects used together, they are also closely connected through the links between the action schema representations they activate in the Action Semantic subsystem. Finally subordinate level perceptual knowledge (e.g. textures of materials) is something that is not represented in the structural description system and that we have found to be preserved in all the categories that we have explored (See Experiments 2, 5 and 7).

It is also interesting to consider more abstract functional relationships, such as those not linked through a specific motor pattern. The present study provides no evidence that such a relationship is represented in the Visual Semantic

⁴ This analysis assumes that unidirectional associations are sustained by post-semantic lexical associations or by an inference-based procedure.

⁵ In this context, as has already been pointed out by Laws et al. (1995) the adjective ‘functional’ has a different meaning from when it refers to the ‘functional characteristics of living items’ (utility for man, etc.).

component; perhaps it is the existence of a verbal semantic representation that provides a link between such concepts (e.g. the *verb* 'to cut' for scissors and knife), that supports the semantic connection between them.

The pattern of performance observed in R.M. can also be related to alternative perspectives on the origin of modality differences in semantic processing such as the Identification Semantics hypothesis (Chertkow et al., 1992) and the Privileged Access position of Hillis et al. (1990). Criticisms of the Privileged Access and Multimodal Semantics position, based on the experimental evidence they reported, were put forward by Chertkow et al. (1992). Their arguments on the Privileged Access position have been discussed recently (Hillis and Rapp, 1995). We will therefore restrict consideration to their critique of the Multimodal Semantics position. The objection to the Multimodal Semantics position that Chertkow et al. (1992) considered crucial, was based on the following experimental result: on testing their dementing patients with Probe Questions they found a large overlap between the questions that were failed with visual and with verbal presentations. While the error rate with verbal presentation was higher than with visual presentation, the overall deficit with verbal presentation seems unlikely to explain the degree of overlap. There was thus little evidence that information relevant to the questions they answered is stored independently in the Visual and Verbal Semantic stores.

What essentially this indicates is that virtually no information was available to the patient from verbal input alone. As is the case for the present patient this implies that in normal subjects the operation of any part of the semantic system putatively distinguished from the Verbal and Visual Semantic systems, such as the Store of Encyclopedic Knowledge (Laws et al., 1995b), or our Action Semantics, can be accessed from the Visual as well as from the Verbal Semantic system. Then if the Verbal Semantic system is impaired the information can still be retrieved by access from the Visual Semantics. One also needs to make this assumption to explain the pattern of performance shown by patient T.O.B. described by Warrington and McCarthy (1988). As we have shown in discussing our model earlier, this assumption fits well with the Multimodal Semantic theory.

The "Identification Semantics" hypothesis assumes that access to the semantic system from visual channel occurs through a modality specific sub-system, called Identification Semantics, which stores the "schema mediating categorization and identification of visual instances" (Chertkow et al., 1992, p. 359) i.e. sketched perceptual descriptions just sufficient for identification of the items, and for naming. The remaining semantic information is stored in an Amodal Associative System; in particular, the ability to link visually presented stimuli to "*other* concepts in an associative conceptual field" (Chertkow et al., 1992, p. 359, italics in the original) is considered specific to this Amodal System. Chertkow et al. (1992) also state that whenever performance on visual input exceeds performance on verbal input, given that one can exclude an access deficit, the pattern of performance is due to preservation of Identification Semantics in the presence of damage to the Amodal Semantic System. In their own word "access (from the whole pictured object) to a partial semantic representation sufficient to support such identification (or access that was

consistently retained only for this portion of semantic knowledge), would be associated with the phenomenon of better performance on pictures than on words on semantic tasks" (Chertkow et al., 1992, p. 351). This should be the case for R.M., who shows a very profound impairment on verbal material and performed much better on visual material; this means that the present patient on their theory would be a typical case of selective preservation of "Identification Semantics". On Chertkow et al.'s hypothesis R.M. would be expected to have much more restricted semantic abilities than she does. In particular the patient should not be able to exploit knowledge about visual context, nor about detailed functional (in the sense just described in the text) properties to perform semantic tasks, because this amounts to linking a concept to another one, which is not a property of "Identification Semantics". Furthermore her residual modality-specific representations should not have been as rich in subordinate level content as the ones we have experimentally described, since that detail is not necessary for identification. Overall our findings provide no support for the idea of an 'Identification Semantics' tightly constrained in its content so as just to allow identification processes to operate.

In general the Privileged Access model appears to be more compatible with the findings. However one would need to specify it further to take into account the pattern of results obtained in R.M. This would though require that privileged access goes well beyond the "privileged relationship between information about the *form* and information about the use of an object" (our italics) (Caramazza et al., 1990, p. 178). This may require such a constrained version of the Privileged Access hypothesis as to make it quite similar, in this fundamental respect, to access to a modality-specific component. The degree to which the theories are distinct is unclear without further specification of the Privileged Access theory. However the results fit naturally with a neural network approach assuming the existence of specialized sub-regions in the semantic network, each connected to specific input and output channels.

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(Received 30 September 1996; accepted 3 March 1997)

APPENDIX A

Given as experiment a forced choice task in which each item is tested three times on separate occasions where the chance probability is equal to a , it is possible to express the probabilities of obtaining 3, 2, 1 or 0 correct responses (p_3 , p_2 , p_1 and p_0 respectively) as a function of the storage parameter s (an estimate of the proportion of semantic representations that can correctly support performance in the task) and of the retrieval parameter r (an estimate of the probability of correct retrieval of a representation still present in the semantic store):

$$p_3 = s [r + (1 - r) a]^3 + (1 - s) a^3 \quad (1)$$

$$p_2 = 3s [r + a (1 - r)]^2 (1 - r) (1 - a) + 3 (1 - s) (1 - a) a^2 \quad (2)$$

$$p_1 = 3s [r + a (1 - r)] [(1 - r) (1 - a)]^2 + 3 [(1 - s) (1 - a)]^2 a \quad (3)$$

$$p_0 = s [(1 - r) (1 - a)]^3 + (1 - s) (1 - a)^3 \quad (4)$$

These equations can be solved for s and r by substituting the a priori probabilities p_3 , p_2 , p_1 , and p_0 with the corresponding experimental frequencies of successes.

Given the following definition of the parameters Π_1 and Π_2

$$\Pi_1 = 3 (1 - a)^3 p_3 + a (1 - a)^2 p_2 - a^2 (1 - a) p_1 - 3a^3 p_0 \quad (5)$$

$$\Pi_2 = 3 (1 - a)^3 p_3 - a (1 - a)^2 p_2 - a^2 (1 - a) p_1 + 3a^3 p_0 \quad (6)$$

one obtains an estimate of the parameters s and r :

$$r_{est} = \frac{2a \Pi_2}{\Pi_1 - \Pi_2 (1 - 2a)} \quad (7)$$

$$s_{est} = \frac{\Pi_1 - \Pi_2 (1 - 2a)}{24a^3 (1 - a)^3 \Pi_1 - \Pi_2} \quad (8)$$

These estimates, as any other non linear quantity, are *biased* due to limited sampling, e.g. due to the limited number N of trials used to obtain them. The smaller the number of items tested the larger the effect of the sistematic error induced by estimating the probabilities directly from the observed experimental frequencies.

An evaluation of the amount of bias is possible in the context of information theory (for an equivalent use see Panzeri and Treves, 1996). The bias can be allowed for using a correction that must be subtracted from the biased values (Lauro-Grotto, Treves and Shallice, *in preparation*), giving

$$s = s_{est} - \Delta s \quad (9)$$

and

$$r = r_{est} - \Delta r \quad (10)$$

where the expressions for Δs and Δr are:

$$\Delta r = \frac{16a}{ND_1^3} [aF_1F_2 + F_3F_4] \quad (11)$$

$$\Delta s = \frac{2s}{N} + \frac{D_1}{24ND_2^3} [F_1F_6 + F_5F_7] \quad (12)$$

with the quantities D_1 , D_2 , F_1 , F_2 , F_3 , F_4 , F_5 , F_6 and F_7 defined as follows:

$$D_1 = \Pi_1 - \Pi_2 (1 - 2a) \quad (13)$$

$$D_2 = [a (1 - a) \Pi_1 \Pi_2] \quad (14)$$

$$F_1 = [9 (1 - a)^6 p_3 + a^4 (1 - a)^2 p_1] \quad (15)$$

$$F_2 = 3a^3 p_0 - a (1 - a)^2 p^2 \quad (16)$$

$$F_3 = (1 - a) [3 (1 - a)^3 p_3 - a^2 (1 - a)] p_1 \quad (17)$$

$$F_4 = 9a^4 p_0 + a^2 (1 - a)^4 p_2 \quad (18)$$

$$F_5 = a^2 (1 - a)^4 p_2 + 9a^6 p_0 \quad (19)$$

$$F_6 = (\Pi_1^2 - 4 \Pi_1 \Pi_2 + \Pi_2^2) (\Pi_1 - \Pi_2 + 2a\Pi_2)^2 + 6 (1 - 2a) \Pi_1 \Pi_2 (\Pi_1 - \Pi_2)^2 \quad (20)$$

$$F_7 = (\Pi_1^2 - 4 \Pi_1 \Pi_2 + \Pi_2^2) (\Pi_1 - \Pi_2 + 2a\Pi_2)^2 + 6 (1 - 2a) \Pi_1 \Pi_2 (\Pi_1 - \Pi_2)^2 \quad (21)$$