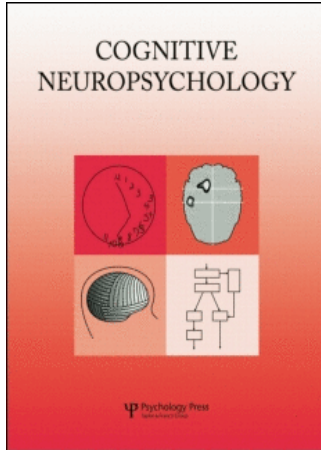


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### Semantic memory is an amodal, dynamic system: Evidence from the interaction of naming and object use in semantic dementia

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# SEMANTIC MEMORY IS AN AMODAL, DYNAMIC SYSTEM: EVIDENCE FROM THE INTERACTION OF NAMING AND OBJECT USE IN SEMANTIC DEMENTIA

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Classic neurological accounts and some contemporary theories of semantic memory assume that concepts are acquired through a learning process that draws together information experienced in each of our verbal and nonverbal modalities. These accounts embody three critical assumptions: semantic representations are amodal; the mapping between surface form and meaning varies for different modalities; and the representations are dynamic. The influence of these three factors was revealed in data collected over a 4-year longitudinal period in two patients with semantic dementia. Semantic assessment revealed a parallel decline in verbal and nonverbal aspects of conceptual knowledge, reflecting a gradual degradation of a single amodal semantic system. As expected, when the patients' semantic impairment was mild, they presented with profound anomia but relatively preserved object use. Over time, performance on all semantic tasks including object use declined. High item-by-item consistency across these tasks was observed in all testing sessions. The impact of dynamic semantic representations was revealed by a striking clinical finding. Although unable to name many of the objects in isolation, their performance was significantly facilitated if they were asked to name while they demonstrated the use of each object. These results are discussed in the context of contemporary models of semantic memory.

## INTRODUCTION

Warrington (1975) was the first in the cognitive neuropsychology literature to describe patients who had a selective impairment of semantic memory or conceptual knowledge. More recent studies have confirmed that these patients—those with semantic dementia—do have a selective and progressive impairment of conceptual knowledge that spares many other aspects of cognition including nonverbal problem-solving, visuospatial skills,

orientation for time and place, memory for current events, single-word phonology, and expressive and receptive syntax (Hodges, Garrard, & Patterson, 1998; Hodges, Patterson, Oxbury, & Funnell, 1992; Snowden, Goulding, & Neary, 1989). Although semantic deficits are found in other aetiologies (CVA: Chertkow, Bub, Deaudon, & Whitehead, 1997; AD: Hodges & Patterson, 1995; HSVE: Wilson, 1997), assessment is always clouded by other concomitant cognitive and language impairments. Semantic dementia represents,

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therefore, one of the best patient models with which to explore the nature of semantic breakdown, the organisation of conceptual knowledge and, through its interaction with other cognitive systems, the influence of semantic memory on verbal and nonverbal tasks. The present study is concerned primarily with the internal structure of semantic memory and the interactions that support verbal (e.g., naming) and nonverbal activities (e.g., object use).

The Wernicke-Meynert theory of semantic memory assumed that conceptual representations are the conjoint activation of information within perceptual and motor association cortices (Eggert, 1977). In a similar vein, Allport (1985) proposed that concepts are acquired through a Hebbian-like learning process that draws together information experienced in each of our verbal and nonverbal modalities. The concept of *telephone*, for example, comprises information acquired through each of the modalities in which we experience this object (auditory, haptic, visual, and verbal). The theory proposed by Damasio and colleagues (Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996; Tranel, Damasio, & Damasio, 1997) builds upon this traditional neurological approach by assuming that constituent semantic features are stored within primary association areas but they are indexed or linked via nodes stored within temporal lobe regions. A specific role for temporal areas is intriguing given that patients with semantic dementia do not have widespread damage to all primary association areas but instead have relatively circumscribed atrophy of the inferolateral, polar temporal region bilaterally, including the inferior temporal lobe gyrus (Galton et al., 2001; Mummery, Patterson, Price, Ashburner, Frackowiak, & Hodges, 2000).

Rogers et al. (in press) used an implemented parallel distributed processing model that draws together known neuroanatomy and neuropsychology to provide a comprehensive description of semantic memory and its breakdown, as observed in patients with semantic dementia. Like previous proposals, this model assumed that semantic representations reflect the totality of our verbal and nonverbal experience with each concept. The

model was trained to take one form of input (e.g., a visual representation) and, via a set of mediating hidden units, to reproduce correct information about that concept (e.g., its name, propositional features, etc.). Through a gradual learning process that required all information about each concept to be activated from any input, abstract semantic representations were formed across these hidden units. When the connections to the hidden units were damaged, the model was able to reproduce a wide variety of semantic dementia data. Although a full summary of this computational model is beyond the scope of the present paper, the simulation captured three critical assumptions that are central to the present study: semantic representations are amodal; the mapping between surface form and meaning varies for different modalities; and the representations are dynamic. All three assumptions are not unique to this computational model. They are also central characteristics of other neuropsychological models of semantic memory, most notably, the Organised Unitary Content Hypothesis (OUCH; Caramazza, Hillis, Rapp, & Romani, 1990; Hillis, Rapp, Romani, & Caramazza, 1990; Rapp, Hillis, & Caramazza, 1993). Each of these assumptions is discussed below.

A central tenet of OUCH is that semantic representations are stored within a single system that is not specific to any modality (Caramazza et al., 1990; Hillis et al., 1990; Rapp et al., 1993). In the computational framework, all translations within and between verbal and nonverbal representations are mediated by the same set of hidden units. In this way, the model implements the same assumption as OUCH; that the intermediate semantic representations are a single, amodal system. The known neuroanatomy for the inferolateral temporal regions supports this architectural choice in the simulation of semantic dementia: These neural regions have extensive afferent and efferent connections to the association and classical language cortices (Gloor, 1997). This, in turn, leads to the prediction that damage to the semantic system will have an impact upon all semantic tasks in any modality. Previous studies of patients with semantic impairment, consequent on CVA, have

shown that performance was equivalent across many types of task (e.g., patient KE; Hillis et al., 1990). Likewise, case-series studies of patients with semantic dementia have confirmed this prediction (Bozeat, Lambon Ralph, Patterson, Garrard, & Hodges, 2000). Patients demonstrate impairments on verbal and nonverbal receptive and expressive tasks that are commensurate with the severity of semantic impairment in each case.

In contrast to the position adopted by OUCH and the computational model, other researchers have argued in favour of modality-specific semantic systems. Two lines of evidence have been used in favour of the multiple semantic systems position. First, there are patients who demonstrate different levels of performance across tasks/modalities (McCarthy & Warrington, 1988; Shallice, 1988). These differences are readily explained by assuming that such patients have impairments within one of the multiple semantic systems. Second, modality-specific semantic systems have also been posited to explain category-specific semantic impairments. While a full discussion of this literature is beyond the scope of this paper (for recent reviews and counter-arguments, see Caramazza & Shelton, 1998; Lambon Ralph, Howard, Nightingale, & Ellis, 1998), it is important to note that both computational models of category specificity and related functional neuroimaging studies have argued in favour of modality-specific representations (Farah & McClelland, 1991; Martin, Wiggs, Ungerleider, & Haxby, 1996).

There are at least two ways in which variation across tasks can be explained within a unitary system account. First, different levels of performance might reflect damage to the specific link between an amodal semantic system and the modality in question. Second, the adoption of a single, amodal system does not mean that semantic impairments will lead to equally affected performance across different tasks. Accuracy on any particular activity (e.g., naming and object use) will be dependent not only on the degree of semantic impairment but also on the nature of the mapping between semantic memory and the surface representations engaged in a particular task. This notion was encapsulated within OUCH in terms of the

*assumptions of privileged access and privileged relationships* (Rapp et al., 1993). In addition, there are now a number of implemented PDP models demonstrating that the accuracy of semantic activation is dependent upon the nature of the mapping (Lambon Ralph & Howard, 2000; Plaut, 1999; Rogers et al., in press). Both OUCH and the computational models can be summarised in the same way. If there is no clear relationship between representations—an arbitrary mapping—then performance is extremely sensitive to semantic damage. In contrast, performance is much more resilient if the mapping is systematic—where there are corresponding or correlated elements between representations. These differences can explain why some semantically impaired patients are worse on verbal than nonverbal comprehension without positing a division within the semantic system itself (Bozeat et al., 2000; Caramazza et al., 1990; Hillis, Rapp, & Caramazza, 1995; Lambon Ralph & Howard, 2000). Likewise, part of the reason why anomia is so pronounced, even in patients with mild comprehension impairments, is the arbitrary relationship between semantic and phonological representations (Lambon Ralph, McClelland, Patterson, Galton, & Hodges, 2001).

The impact of semantic impairment on object use is theoretically and clinically important. If semantic impairment leads to poor object use then this should impact on activities of everyday living. Our working hypothesis is that single object use is supported by two routes from vision to motor systems (Hodges, Spatt, & Patterson, 1999; Milner & Goodale, 1995). One route represents a direct computation of praxis from visual input, which encompasses aspects of use that are directly afforded by an object's structure. The second route requires activation of object meaning. The distinction between praxis (i.e., how to manipulate objects) and semantic memory is supported by reported dissociations between these types of knowledge (Buxbaum & Saffran, 2002). By studying object use in semantic dementia, it is possible to reveal the relative importance of the contributions made by semantics and affordances. Two initial studies and clinical observations suggested that patients with semantic dementia

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could use objects and perform a variety of activities of everyday living (Buxbaum, Schwartz, & Carew, 1997; Lauro-Grotto, Piccini, & Shallice, 1997; Snowden, Neary, & Mann, 1996). Using a carer survey, a recent study found that, although semantic dementia patients do complete a small number of the most common tasks (e.g., grooming and eating), the repertoire of domestic activities is substantially reduced (Bozeat, Lambon Ralph, Patterson, & Hodges, 2002a). More recent experimental investigations that have assessed use and knowledge on the same set of objects have found a very strong relationship between the degree of semantic impairment and accuracy of object use (Bozeat, Lambon Ralph, Patterson, & Hodges, 2002b; Hodges, Bozeat, Lambon Ralph, Patterson, & Spatt, 2000). In addition, Bozeat et al. (2002b) found that the patients' naming of the same objects was much worse (often at floor). This follows from the functions that relate semantic impairment to object use and naming: While there is a strong linear relationship between semantics and use (Bozeat et al., 2002b; Hodges et al., 2000), the relationship for naming is nonlinear, such that mild semantic impairment produces amplified levels of anomia (Lambon Ralph et al., 2001). An interpretation of this difference is that it reflects two factors noted above. First, the relationship between the structural aspects of objects and meaning is quasi-systematic whilst semantics and phonology are arbitrarily related (Lambon Ralph & Howard, 2000; Rapp et al., 1993). Second, in addition to semantic representations driving object use, there are direct vision-to-motor translations (affordances) that contribute to object use (Bozeat et al., 2002b; Milner & Goodale, 1995). In contrast, there is only semantic input for naming.

The third assumption in OUCH and the Rogers et al. model of conceptual knowledge is that these representations are dynamic and not entirely fixed in nature. As noted by Rapp et al. (1993), even in a unitary system the semantic information activated by various inputs will vary and will be coloured by the nature of the input modality and context. This observation was supported by results from a combined neuropsychological and computational investigation. Lambon Ralph and Howard (2000)

found that IW, a patient with semantic dementia, was (a) consistently worse when semantics were required to interact with verbal representations (e.g., word definition and the word version of the Pyramids and Palm Trees test—PPT: Howard & Patterson, 1992) than when activated by pictures (e.g., picture definition and the picture version of the PPT); but, (b) although certain meanings seemed to be consistently unavailable to her from verbal-only input, her comprehension was improved with simultaneous verbal and picture presentation (e.g., the target word plus a semantic related picture). The model demonstrated exactly the same behaviour. Activation of semantic representations was significantly worse for word than picture input because the model incorporated both arbitrary (for word input) and quasi-systematic (for picture input) mappings. The consequence of an arbitrary mapping is that a relatively inaccurate/impoverished activation of the meaning is achieved following damage to the semantic system. The same verbal input is much more effective, however, if the semantic system is first activated by a pictorial input (even one that is only approximately semantically related). The patient and model suggest that although conceptual knowledge is represented within a single amodal system, the activated meaning is influenced by the form of input and the context. In short, conceptual representations are dynamic.

The present study reports longitudinal data from two patients with semantic dementia. Both patients were tested longitudinally on a neuropsychological battery that included various measures of semantic memory and the ability to perform certain tasks, using the same set of objects (in a similar fashion to previous studies: e.g., Hodges et al., 2000). Specifically, the battery included measures of naming, comprehension, and object use. Like previous reports (Bozeat et al., 2002b), when these patients had a mild impairment of comprehension, their object use was good but their naming of the same items was poor. Over time, further semantic deterioration was coupled with increasing problems with object use. The striking and novel finding from these two patients is that, when their semantic impairment was

relatively mild, although unable to name many objects in isolation, they were able to name a significantly greater number of the objects whilst they demonstrated the correct use.

## CASE STUDIES

Elvezio was a 62-year-old right-handed man with 13 years of education who worked as an employee in an insurance company. He presented in 1998 with a 1-year history of progressive word-finding difficulties. During this first clinical interview, his spontaneous speech was found to be fluent with sporadic semantic paraphasias and word-finding difficulties. No phonological nor syntactical errors were observed. At this time, subtle and vague behavioural changes, including anxiety, were noted. Elvezio's semantic impairment had become more apparent following a surgical operation (haemorrhoidectomy) in 1997. The post-operative phase was complicated by copious bleeding. Elvezio's wife tried to persuade him to call the doctor but Elvezio responded, "Blood? What is it? I never heard this word. What is it used for? Try to speak properly, please."

Family and personal histories were unremarkable. General, neurological, and psychiatric examinations were in the normal range. Blood screening for dementia (cell blood count, thyroid function, immunity profile, B12 vitamin and folic acid, syphilis serology) excluded symptomatic cognitive impairment. An MRI showed mild diffuse atrophy with prevalent involvement of the temporal lobes, more marked on the left than the right. A HMPAO SPECT revealed left temporal lobe hypoperfusion (Figure 1).

Elvezio was clinically reviewed again in 1999. Word-finding difficulties and semantic paraphasias had become more common in his spontaneous speech. There were no phonological or syntactical errors. Relatives reported that he was still able to perform activities of daily living. He was still working during this period although colleagues had started to notice that Elvezio had occasional problems in understanding what they said to him.

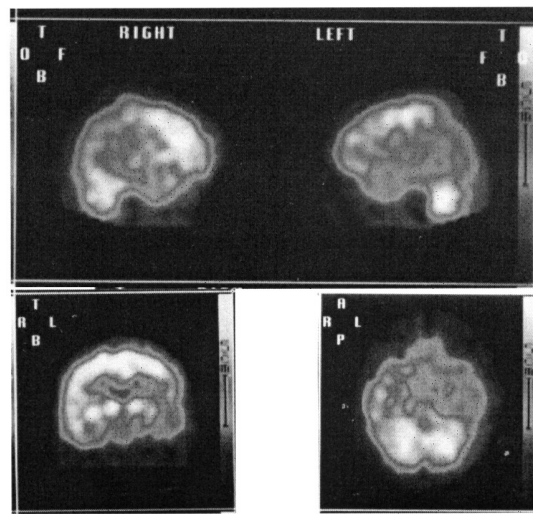


Figure 1. SPECT scans for Elvezio.

Psychiatric and neurological examinations were normal.

By 2000, Elvezio's spontaneous speech was severely compromised by word-finding difficulties and semantic paraphasias. He had clear difficulties understanding complex phrases and commands. At home he was still autonomous and able to use various objects correctly. His poor verbal comprehension compromised his ability to complete tasks to verbal command but he was able to comply if the objects and tools were given to him. For example, when his wife asked him to hang a picture on the wall he didn't do anything but when given a hammer, the nail and picture he hung it without difficulty. His receptive and expressive language impairments severely compromised his ability at work. Neurological and psychiatric examinations were still normal.

When seen again in 2001, Elvezio's condition was significantly worse. Although grammatically and prosodically normal, his spontaneous speech was almost contentless, with severe word-finding difficulties and empty circumlocutions. At work he was reduced to performing calculations and other small activities. Behavioural changes were also noted. He had developed a mild Klüver-Bucy syndrome with compulsive food intake and a mild

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verbal disinhibition. Neurological examination was still normal.

The second case, Dirce, was a 72-year-old right-handed woman with 5 years of education. She presented in 1997 with a history of anomia. Although an accomplished gardener, her family had noticed that she wasn't able to remember the name of plants and flowers, and sometimes produced semantic paraphasias for these items (e.g., *rose* → "carnation"). Clinical assessment revealed that her spontaneous speech was fluent, with sporadic word-finding difficulties and semantic paraphasias. Neither phonological nor syntactical errors were noted. Neurological and psychiatric assessments were normal, and personal and family histories were unremarkable. Blood screening for dementia excluded treatable causes of cognitive impairment. An MRI showed modest diffuse atrophy with prominent involvement of the temporal lobes bilaterally. A HMPAO SPECT showed left temporal lobe hypoperfusion (Figure 2).

By 1998, Dirce's spontaneous speech had become more impoverished, with more frequent word-finding difficulties and semantic paraphasias. Phonological and syntactical errors were absent. Her relatives reported that she was still completely

self-sufficient in daily activities and housework chores and often went for walks unaccompanied. She refused to do shopping. Psychiatric and neurological examinations were normal.

When seen again in 1999, her language function had declined significantly. She was unable to understand complex phrases or commands while her speech was replete with word-finding pauses and semantic paraphasias. At home she was still self-sufficient and able to use various objects correctly even though she was unable to name them or describe their use. Psychiatric and neurological examinations were still normal.

By 2000 her overall condition had declined considerably. Verbal interaction was almost impossible. She was disoriented and her spontaneous speech was contentless—characterised by gross word-finding difficulties, semantic paraphasias, and empty circumlocutions. All activities at home had to be supervised by carers. Her behaviour had also changed: She had developed a Klüver-Bucy syndrome with hyperorality plus exhibited aggressiveness, irritability, and wandering behaviour.

## INVESTIGATION

### General neuropsychology

The following battery of neuropsychological tests was administered longitudinally to both patients. Dirce's behavioural problems together with her attentional deficit, exhibited on her last examination in 2000, made it hard to administer the complete test battery. A general measure of cognitive status was obtained by the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) and the Raven's Coloured Progressive Matrices (Raven, 1962). Executive functions were examined using the Visual Search Test (Spinnler & Tognoni, 1987), Luria's Motor Sequences (Piccirilli, Piccinin, D'Alessandro, Finali, & Agostini, 1989), and the Trail Making Test (Retain, 1958). Working memory was assessed by the Corsi block tapping task and bisyllabic word repetition (Spinnler & Tognoni, 1987). Long-term memory was examined using the

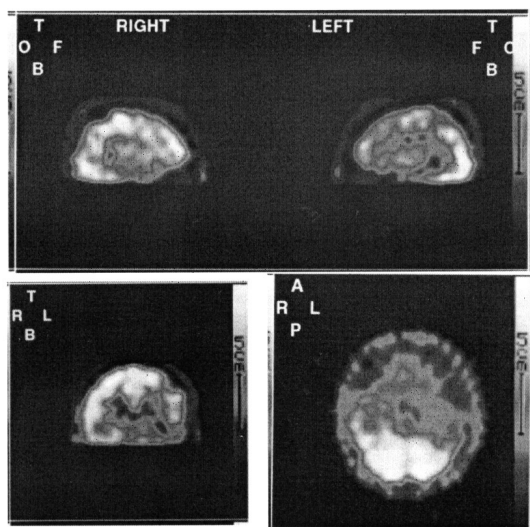


Figure 2. SPECT scans for Dirce.

Rey auditory verbal learning test (Caltagirone, Gainotti, Masullo, & Miceli, 1979), Rey-Osterrieth Figure "B" long-term retrieval (Lezak, 1976), the Prose Test, and Supra Span Sequences (Spinnler & Tognoni, 1987). The patients' scores were compared to age- and education-matched normative data for these assessments.

General language assessment included the Token Test (De Renzi & Vignolo, 1962), verbal fluency for categories (Spinnler & Tognoni, 1987), the Controlled Word Association Task (F, A, S letter fluencies; Lezak, 1976), and the Sartori reading test (Sartori, 1984). Visuo-perceptual skills were examined by the Overlapping Figures Test (Gainotti, D'Erme, Monteleone, & Silveri, 1986). Visuospatial abilities were assessed by Kohs Blocks (Wechsler, 1955) and constructional apraxia was evaluated by copying the Rey-Osterrieth Figure (Lezak, 1976). Ideomotor and bucco-linguo-facial

praxias were evaluated according to the De Renzi and Faglioni test (De Renzi & Faglioni, 1996).

As shown in Table 1, there were no signs of general cognitive impairment in either patients' longitudinal neuropsychology, with the exception of Dirce's last examination in 2000. Executive functions, visuo-perceptual and visuospatial abilities, constructional, ideomotor, and bucco-linguo-facial praxias, working memory, and long-term spatial memory were in the normal range. Verbal long-term memory was in the normal range in the first examination for both patients but the scores declined over time.

General language examination showed good performance on the Token Test. Although there was a mild decline in scores over time, FAS letter fluency fell into the normal range for all sessions except for Dirce's last score. Category fluency was abnormal throughout. A pattern of surface dyslexia

Table 1. *General neuropsychology*

| <i>Test (maximum score)</i>                | <i>Elvezio</i>  |                 |                 |                 | <i>Dirce</i> |                 |                 |                 |
|--|-----------------|-----------------|-----------------|-----------------|--------------|-----------------|-----------------|-----------------|
|  | <i>1998</i>     | <i>1999</i>     | <i>2000</i>     | <i>2001</i>     | <i>1997</i>  | <i>1998</i>     | <i>1999</i>     | <i>2000</i>     |
| MMSE (30)                                  | 25              | 15 <sup>a</sup> | 10 <sup>a</sup> | 8 <sup>a</sup>  | 27           | 25              | 15 <sup>a</sup> | 4 <sup>a</sup>  |
| Raven's Coloured Progressive Matrices (36) | 32              | 32              | 30              | 29              | 27           | 27              | 25              | 18              |
| Visual Search (60)                         | 60              | 60              | 57              | 54              | 43           | 45              | 40              | 20 <sup>a</sup> |
| Trail Making Test A                        | 42              | 45              | 50              | 53              | 75           | 82              | 138             | NT              |
| Trail Making Test B                        | 56              | 60              | 84              | 90              | 150          | 178             | NT              | NT              |
| Kohs Blocks (48)                           | 48              | 48              | 44              | 44              | 40           | 40              | 40              | 30              |
| Luria's Motor Sequences (15)               | 15              | 15              | 15              | 15              | 15           | 15              | 15              | NT              |
| Bisyllabic word span                       | 5               | 5               | 5               | 5               | 4            | 4               | 4               | 3 <sup>a</sup>  |
| Corsi's blocks                             | 5               | 5               | 5               | 5               | 4            | 4               | 4               | 4               |
| Rey AVLT total effect (75)                 | 33              | 23 <sup>a</sup> | 18 <sup>a</sup> | 15 <sup>a</sup> | 32           | 23 <sup>a</sup> | 15 <sup>a</sup> | NT              |
| Rey AVLT long term (15)                    | 14              | 9               | 8               | 7               | 10           | 8               | 5 <sup>a</sup>  | NT              |
| Corsi's Supraspan                          | 19.38           | 19.10           | 19.00           | 19.00           | 17.81        | 19.10           | 17.14           | NT              |
| Rey Figure Delayed Recall (31)             | 31              | 31              | 30              | 30              | 21           | 20              | 19              | NT              |
| Verbal fluency for categories              | 25 <sup>a</sup> | 10 <sup>a</sup> | 10 <sup>a</sup> | 8 <sup>a</sup>  | 33           | 14              | 9               | 0               |
| FAS  | 35              | 25              | 21              | 19 <sup>a</sup> | 30           | 25              | 18              | 9 <sup>a</sup>  |
| Token Test (36)                            | 35              | 35              | 34              | 32              | 31.5         | 30              | 23              | NT              |
| Rey Figure Test copy (31)                  | 31              | 31              | 31              | 31              | 31           | 29              | 29              | 25              |
| Ideomotor praxia (20)                      | 20              | 20              | 20              | 20              | 20           | 20              | 20              | 18 <sup>a</sup> |
| Bucco-linguo-facial praxia (20)            | 20              | 20              | 20              | 20              | 20           | 20              | 20              | 17 <sup>a</sup> |
| Overlapping Figure Test (9)                | 9               | 9               | 8               | 8               | 9            | 8               | 8               | 8               |

NT: not tested.

<sup>a</sup> pathological performance.



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was demonstrated by both patients on all four occasions.

#### *Assessment of semantic memory*

The general semantic battery used the same 42 items for all assessments: 21 selected from three animate categories (land animals, sea creatures, and birds) and 21 from three artefact categories (vehicles, musical instruments, and household items). For each category, both patients were asked to complete the following tasks:

1. Naming colour photographs of the 42 items.
2. Category fluency—1 min for each of the six categories.
3. Picture sorting at the superordinate and category levels.
4. Drawing each of the 42 items from memory (a correct score was given if two markers judged the picture to have uniquely identified the target object).

5. Verbal definition for each of the 42 items from the spoken name (a correct score was given for definitions that contained uniquely identifying information).

In addition, associative semantic knowledge was assessed using an Italian version of the Pyramids and Palm Trees Test (Howard & Patterson, 1992) in which the subject is asked to pick one of four items that is most closely associated with the target concept. The patients' performance was compared to that of 20 age- and educated-matched control participants. Normal controls performed at ceiling across all tasks. For the category fluency subtest, control data was taken from Hodges et al. (1992). The controls in that study produced a total mean of 47.5 items ( $SD = 8.9$ ) for the three animate categories and 49.9 ( $SD = 9.5$ ) for the man-made categories.

The patients' scores on these semantic tests are shown in Table 2. Both Elvezio and Dirce showed

Table 2. Results on the assessment of semantic knowledge<sup>a</sup>

| Test (maximum score)                 | Elvezio |      |      |      | Dirce |      |      |      |
|--------------------------------------|---------|------|------|------|-------|------|------|------|
|                                      | 1998    | 1999 | 2000 | 2001 | 1997  | 1998 | 1999 | 2000 |
| <i>Sorting</i>                       |         |      |      |      |       |      |      |      |
| By domain (42)                       | 38      | 23   | 19   | 16   | 38    | 38   | 32   | 19   |
| By category (42)                     | 27      | 22   | 20   | 19   | 29    | 27   | 18   | 3    |
| <i>Category fluency</i>              | 22      | 9    | 6    | 3    | 30    | 12   | 6    | 0    |
| Land animal                          | 5       | 3    | 2    | 1    | 5     | 3    | 1    | 0    |
| Birds                                | 3       | 1    | 1    | 1    | 3     | 1    | 1    | 0    |
| Water animal                         | 4       | 1    | 1    | 0    | 3     | 1    | 1    | 0    |
| Vehicles                             | 5       | 3    | 1    | 1    | 6     | 2    | 1    | 0    |
| Musical instruments                  | 1       | 0    | 0    | 0    | 7     | 2    | 1    | 0    |
| Household                            | 4       | 1    | 1    | 0    | 6     | 3    | 1    | 0    |
| <i>Naming (21)</i>                   | 14      | 8    | 5    | 1    | 13    | 11   | 6    | 0    |
| Living                               | 6       | 4    | 2    | 0    | 5     | 4    | 2    | 0    |
| Artefacts                            | 8       | 4    | 3    | 1    | 8     | 7    | 4    | 0    |
| <i>Drawing from memory (21)</i>      | 20      | 12   | 8    | 3    | 5     | 3    | 3    | 0    |
| Living                               | 9       | 5    | 3    | 1    | 0     | 0    | 0    | 0    |
| Artefacts                            | 11      | 7    | 5    | 2    | 5     | 3    | 3    | 0    |
| <i>Verbal definition (21)</i>        | 13      | 8    | 2    | 0    | 8     | 7    | 4    | 0    |
| Living                               | 3       | 1    | 0    | 0    | 2     | 1    | 1    | 0    |
| Artefacts                            | 10      | 7    | 2    | 0    | 6     | 6    | 3    | 0    |
| <i>Italian PPT (30)</i> <sup>b</sup> | 12      | 8    | 5    | 5    | 12    | 8    | 5    | 0    |

<sup>a</sup> Controls perform at ceiling on all tasks. See text for category fluency control data.

<sup>b</sup> Pyramids and Palm Trees Test.

impaired performance on all subtests that declined in parallel over time. The combination of semantic deficits and preserved performance on other aspects of cognitive tasks (see Table 1) is the standard pattern for semantic dementia (Hodges et al., 1992; Snowden et al., 1989). These results also replicate the finding that both verbal and nonverbal aspects of conceptual knowledge are compromised in semantic dementia, and support the notion that these patients suffer from a progressive impairment to an amodal semantic system (Bozeat et al., 2000).

#### *Assessment of object use and knowledge*

In order to compare directly across different measures of object use and knowledge, a battery assessing the same 20 common objects was constructed.<sup>1</sup> The battery contained the following subtests.

1. Naming of the 20 objects in four different conditions: (a) *visual naming*—naming the visual presented object; (b) *tactile naming*—naming each object from touch and without vision; (c) *naming during use*—the patients were asked to name the item whilst demonstrating the use of an object; (d) *naming during pantomime*—the patients were asked to name the item whilst pantomiming the use of an object.

2. Single object use: the patient was asked to grasp the object and to demonstrate how the object is usually manipulated.

3. Pantomiming the use of each object in two different conditions: (a) *visual pantomime*—the object was visually presented and the patient was asked to demonstrate its use without holding the object (i.e., mime); (b) *pantomime-to-name*—the patient was told the name of an object and asked to mime its use.

4. Description of object use in two different conditions: The patient was asked to describe how one uses each object in as much detail as possible. They described the use of either the visually

presented object (*visual description*) or its spoken name (*description-to-name*).

Each subtest was administered in a separate session, twice a day for four consecutive days. The following order was used in test administration: visual naming, tactile naming, visual pantomime and naming during pantomime, object use and naming during use, pantomime-to-name and finally the verbal description tasks. Naming, object use, and pantomimes were scored as correct or incorrect. A relatively strict criterion was adopted for scoring object use and pantomime. The full use of each object had to be demonstrated for a correct score to be given. If the demonstration contained some correct elements as well as some intrusive or omitted components, then the use or pantomime was scored as incorrect. The description of object use was scored using a 4-point scale. Three points were awarded for a correct description containing specific details (e.g., *knife*: “it is used to cut food when you are cooking or having a meal”). Two points were given for a correct description containing little or no detail (e.g., *knife*: “it is used to cut something”). One point was awarded when there was little or no information about the use per se but other correct semantic facts were provided (e.g., *knife*: “it’s on the table when you eat, you use it”). No points were given if the patient failed to give any information or the description was incorrect. The patients’ performance on each subtest was compared against that of 20 age- and education-matched control participants. These control subjects performed at ceiling for all tasks.

Elvezio’s and Dirce’s longitudinal object use and knowledge data is shown in Table 3. The pattern demonstrated by both patients was very similar. Over time, both patients’ scores for all measures declined in parallel. This is consistent with the notion that an amodal semantic impairment should give rise to deficits in naming, object use, and verbal definitions (Bozeat et al., 2002b; Hillis et al., 1990; Lambon Ralph & Howard, 2000). Visual and

<sup>1</sup> Items included in the object use and knowledge tests: glass, pipe, whistle, toothbrush, stamp, harmonica, mask, knife, comb, scissors, brush, spoon, fork, sponge, plate, pen, screwdriver, lighter, syringe, match.

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**Table 3.** Performance on the object use and knowledge battery<sup>a</sup>

| Test                             | Elvezio |        |        |        | Dirce  |        |        |      |
|----------------------------------|---------|--------|--------|--------|--------|--------|--------|------|
|                                  | 1998    | 1999   | 2000   | 2001   | 1997   | 1998   | 1999   | 2000 |
| Visual naming                    | 10      | 5      | 2      | 0      | 8      | 7      | 4      | 0    |
| Tactile naming                   | 9       | 3      | 0      | 0      | 8      | 6      | 4      | 0    |
| Use naming                       | 16      | 12     | 8      | 4      | 17     | 15     | 11     | 4    |
| Pantomime naming                 | 19      | 14     | 10     | 5      | 18     | 16     | 11     | 5    |
| Use                              | 16      | 12     | 8      | 6      | 17     | 16     | 13     | 5    |
| Visual pantomime                 | 19      | 14     | 10     | 5      | 18     | 17     | 11     | 5    |
| Pantomime-to-name                | 17      | 11     | 11     | 6      | 17     | 16     | 11     | 0    |
| Visual description <sup>b</sup>  | 5 (16)  | 2 (14) | 2 (11) | 0 (12) | 4 (18) | 3 (17) | 0 (12) | NT   |
| Description-to-name <sup>b</sup> | 6 (17)  | 2 (13) | 2 (13) | 0 (12) | 4 (17) | 2 (17) | 0 (11) | NT   |

<sup>a</sup> Controls perform at ceiling on all tasks.<sup>b</sup> x (y): x = number of items with score = 3; y = number of items with score = 0, 1, and 2.

NT: not tested.

tactile naming were moderately to severely impaired for both patients on all testing sessions. In stark contrast, naming during use and pantomime was initially close to the normal range (i.e., a perfect score) for Dirce and only mildly impaired for Elvezio. Over time all naming scores declined but the difference between visual/tactile naming and naming during use/pantomime remained throughout. All possible pairwise comparisons between visual/tactile naming versus naming during use/pantomime for the first 3 years of assessment (before performance fell to zero) confirmed that the differences were significant (McNemar, Exact  $p$  between .02 and  $< .001$ ).

Initially both patients performed quite well, albeit not perfectly, when asked to demonstrate use irrespective of the condition (object use, pantomime, or pantomime-to-name). Over time both patients' scores declined in parallel for each of the three conditions. The verbal descriptions of object use (to the visually presented object or its spoken name) were impoverished even at the first testing round. Like all other scores these declined over time.

If the patients' impaired performance on naming, demonstrating use, and verbal description was underpinned by a progressive impairment to a

single, amodal semantic system then one might expect significant item-by-item associations across the different modalities tested for each task (Lambon Ralph, Graham, Patterson, & Hodges, 1999; Lambon Ralph & Howard, 2000). This follows if we assume that different modalities access basically the same semantic representations. If one finds that a certain set of concepts are degraded through testing in one modality, then these representations should also be affected, at least to some extent, in all other modalities. This proved to be true for Elvezio and Dirce. For naming, there were significant item associations between visual and tactile naming, and between naming during use and during pantomime (over the first three testing sessions:  $C$  between .417 and .707,  $p$  between .04 and  $< .001$ ).<sup>2</sup> The only exception was the relationship between naming during use and during pantomime for Elvezio in 2000 ( $C = .378$ ,  $p = .07$ ). Likewise for the three versions of demonstrating object use, there were substantial item-by-item associations ( $C$  between .417 and .707,  $p$  between .04 and  $< .001$ ). The same pattern held when the scores for describing the use of a visually-presented object were compared with description-to-name ( $\kappa$  between .30 and .72,  $p$  between .03 and  $< .001$ ).

<sup>2</sup> For a  $2 \times 2$  table, the maximum value of  $C$  is .707.

## DISCUSSION

In this study, the relationship between semantic knowledge, object use, and naming was investigated over a 4-year longitudinal period in two patients with semantic dementia. Until very late in the course of their disease both patients demonstrated the typical pattern of preserved cognitive, executive, and visuospatial skills in the face of progressive semantic deterioration. Longitudinal semantic assessment revealed a parallel decline in verbal and nonverbal aspects of conceptual knowledge. This was true for both receptive and expressive tasks that require semantic memory: The patients demonstrated increasing problems with comprehension of pictures and words, increasing anomia, and impoverished drawings and verbal definitions. This pattern was replicated on a separate neuropsychological battery designed to assess use and knowledge for the same set of 20 objects. Over the 4-year period both patients demonstrated a yoked decline in visual and tactile naming, demonstrating use, and describing the function of objects from visual presentation or their spoken name. Over and above this parallel decline in performance, the patients exhibited consistent differences between modalities. Specifically, visual and tactile naming was worse than their ability to demonstrate the use of the same objects. Also, the patients were unlikely to produce detailed, specific descriptions of the objects' function. Perhaps most strikingly, we found that the patients' naming was significantly facilitated by demonstration of object use (either with the object in hand or through mime)—in fact their scores for naming during use/miming were the same as for object use itself.

These longitudinal results replicate and extend previous cross-sectional and single-case studies of patients with semantic dementia. Previous investigations (Bozeat et al., 2000; Bozeat et al., 2002b; Hodges et al., 2000; Lambon Ralph et al., 1999; Lambon Ralph & Howard, 2000) have demonstrated by-item and by-subject associations for a range of receptive (spoken word, written word, picture and sound comprehension) and expressive tasks (naming, verbal definitions, object use, drawing to name, and delayed copying). The

present data replicate these item associations repeatedly over time (for naming, object use, drawing, and verbal definitions) whilst extending the domains to include tactile naming. These results support the notion that patients with semantic dementia have a progressive impairment to an amodal semantic system. They are not consistent with models of semantic memory that posit separate subsystems for verbal and visual modalities (e.g., McCarthy & Warrington, 1988; Shallice, 1988). Under these schemes, there is no necessary relationship between the decline observed for verbal and nonverbal semantic performance.

The differences between verbal output (naming and definition) and nonverbal performance (object use and miming) could be taken as evidence in favour of a multiple semantic systems theory. Under that scheme, poor verbal performance arises from a specific impairment to the verbal semantic system (cf. Lauro-Grotto et al., 1997). It is also possible to explain the same results if one assumes that the patients have a combination of central semantic impairment and a deficit within the verbal domain. There are, however, at least two differences between object use and naming, which if taken into account make the disparity between naming and object use consistent with the amodal semantics hypothesis. As noted in the Introduction, the mappings of semantics-to-phonology (cf. naming) and semantics-to-object structure (cf. object use) are different. The relationship between semantics and phonology is arbitrary whereas the semantics-structure mapping is at least partially systematic: Elements within an object's structure are associated with knowledge about that item and, in turn, how the object is used. These differences have been highlighted previously in explanations of poor verbal performance in patients with semantic impairments (Caramazza et al., 1990; Rapp et al., 1993). When these alternative mappings are implemented in PDP simulations, the models demonstrate that semantic activation is more accurate for systematic than arbitrary mappings (Lambon Ralph & Howard, 2000; Plaut, 1999; Rogers et al., in press). This means that object use and naming performance will automatically be different for the same degree of underlying

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semantic impairment. Even a small semantic impairment leads to a significant degree of anomia (Lambon Ralph et al., 2001) whereas the quasi-systematic mapping should produce better object use.

A second factor also benefits object use. In nearly all models of speech production, there is only one route from input (semantic memory) to output (speech). For object use, there are potentially two routes from vision to action: one via conceptual knowledge and the other representing affordances: that is, direct translations between vision and praxis. These two routes may correspond to the distinction between ventral and dorsal visual pathways, which can be differentially affected in various neurological conditions (Hodges et al., 1999; Milner & Goodale, 1995). The distinction between general semantic information and praxic knowledge has been demonstrated in other studies (Buxbaum & Saffran, 2002). In addition, a previous study with semantic dementia patients attempted to specify affordances a priori and to test for their influence on object use (Bozeat et al., 2002b). This investigation found that afforded elements of object use (e.g., gripping the handle of a hammer) were relatively preserved even in patients with severe semantic impairment, supporting the notion of an independent route to action for these specific, limited aspects of object use. In patients with semantic dementia, therefore, there are two forms of constraint on their object use—their remaining semantic knowledge about objects plus affordances. Overall, this means that naming is only supported by an arbitrary mapping from conceptual knowledge while object use benefits from a quasi-systematic mapping from semantics in addition to a separate form of constraint (affordances). Viewed in this way, it is unsurprising that object use is consistently better than object naming.

Perhaps the most striking factor in this study was the finding that both patients' naming improved dramatically when they were demonstrating or miming the use of objects rather than naming in isolation (from vision or touch). At face value, this might appear to be inconsistent with an account based on a unitary semantic system. In both cases, the same object was presented to the patient

and thus an identical naming outcome might have been expected. This assumes, however, that exactly the same semantic information is activated in the two situations. As noted above, a number of theories assume that semantic representations are dynamic in nature such that the form of information activated varies across modalities and contexts (Rapp et al., 1993). This effect was demonstrated in a previous study: Lambon Ralph and Howard (2000) found that IW, a patient with semantic dementia, was consistently worse when semantics were required to interact with verbal representations than when activated by pictures. Importantly, although certain meanings seemed to be consistently unavailable to IW from verbal-only input, her comprehension for these items improved when the words were presented with a picture context (semantically related to the target word). This result shows that even degraded semantic representations are dynamic: The poor semantic activation from verbal input was improved by a semantically related picture context. Lambon Ralph and Howard were also able to demonstrate the same effect in a PDP simulation: Verbal input was much more effective if the semantic system was first activated by a pictorial input (even one that is only approximately semantically related). This simulation provides a computational account of dynamic semantic representations. Visual presentation activates semantics more accurately than verbal input because of the difference in mapping (see also Rapp et al., 1993). When the two inputs are combined, the picture context activates a partially correct semantic representation. This provides a better starting point for verbal input and, under this circumstance, words become more effective in activating the specific target representation.

This account can be extended to explain how object use might facilitate object naming. The initial visual presentation of the object activates a partially degraded semantic representation. As there is an arbitrary mapping with phonology, this impoverished conceptual knowledge is typically insufficient to drive successful speech production and the patient is unable to name the object. The combination of partially degraded semantics in conjunction with object affordances (direct visual-

to-motor translations) means that, in the early phases of semantic dementia, object use is typically preserved. In computational frameworks, semantic memory is represented within a fully interactive system (Lambon Ralph & Howard, 2000; Plaut, 1999; Rogers et al., in press). This means that all aspects of correct object use (sensorimotor/kinaesthetic information from visual, tactile, and action domains) will provide positive feedback to the amodal semantic system. It is easy to imagine, therefore, that for relatively familiar objects, the improved semantic activation is sufficient to kick-start speech production. Over time, as semantic representations degrade further, all forms of output (naming, use, and naming during use) decline because they all rely on the same single, amodal semantic system.

In conclusion, the longitudinal, cross-modality data of Elvezio and Dirce, together with those of other patients with semantic impairment (Hillis et al., 1990; Lambon Ralph & Howard, 2000), highlight three key characteristics of conceptual knowledge and its breakdown in patients with semantic dementia: semantic representations are amodal; the mapping between surface form and meaning varies for different modalities; and the representations are dynamic.

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