

The role of conceptual knowledge in object use

Evidence from semantic dementia

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Summary

It has been reported that patients with semantic dementia function well in everyday life and sometimes show striking preservation of the ability to use objects, even those specific objects for which the patient has degraded conceptual information. To explore this phenomenon in nine cases of semantic dementia, we designed a set of semantic tests regarding 20 everyday objects and compared performance on these with the patients' ability to demonstrate the correct use of the same items. We also administered a test of mechanical problem solving utilizing novel tools, on which the patients had completely normal ability. All but the mildest affected patient showed significant deficits of naming and on the visually based

semantic matching tasks. Object use was markedly impaired and, most importantly, correlated strongly with naming and semantic knowledge. In a small number of instances, there was appropriate use of an object for which the patient's knowledge on the semantic matching tasks was no better than chance; but this typically applied to objects with a rather obvious relationship between appearance and use, or was achieved by trial and error. The results suggest that object use is heavily dependent upon object-specific conceptual knowledge, supplemented to some degree by a combination of visual affordances and mechanical problem solving.

Keywords: semantic dementia; apraxia; semantic memory; object use; pantomime

Introduction

The aim of this study was to explore the impact of degraded semantic memory on the ability to use familiar objects and, more specifically, to delineate the contributions of semantic and non-semantic processes to this important aspect of human interaction with the environment. Semantic memory is the term applied to our representational knowledge base which enables us to interpret sensory perceptions and experiences and to act upon these in meaningful ways. It occupies, therefore, a central role in many cognitive processes such as language comprehension/production and object recognition (Tulving, 1972).

Patients with semantic dementia have been reported previously under a variety of descriptions including selective loss of semantic memory (Warrington, 1975) or of the semantic components of language (Schwartz *et al.*, 1979), and progressive fluent aphasia (Mesulam, 1982; Hodges *et al.*, 1992a; Mesulam and Weintraub, 1992). Since the report by Snowden and colleagues (Snowden *et al.*, 1989), the term semantic dementia has become widely accepted for this pattern of progressive disruption to conceptual

knowledge. Structural and functional imaging in semantic dementia reveal atrophy and hypometabolism in the polar and inferolateral temporal region, typically in both hemispheres but often with an asymmetrical distribution (Mummery *et al.*, 2000). Neuropathological studies are still limited, but a recent meta-analysis determined that, of 13 cases, all had non-Alzheimer pathology and classic Pick bodies were present in a significant proportion of cases (Hodges *et al.*, 1998). Although the most prominent symptoms at presentation are anomia and impaired word comprehension, there is evidence of a more pervasive breakdown in the appreciation of the meanings of objects as well as words (Bozeat *et al.*, 2000; Lambon Ralph and Howard, 2000). In contrast, other components of language, notably syntax and phonology, as well as perceptual skills, non-verbal problem-solving abilities and episodic memory, are relatively spared (Patterson and Hodges, 2000). The syndrome of semantic dementia provides an ideal testing ground for investigating the role of conceptual knowledge in various cognitive domains. The issue to be addressed here is whether the ability

to use familiar objects is reliant, in whole or in part, upon intact conceptual knowledge about those items.

It has been noted on the basis of clinical assessment that patients with semantic dementia, despite their severe semantic deficits, are relatively competent in their daily activities (Snowden *et al.*, 1996b). For instance, a number of patients with notable loss of conceptual knowledge have continued to be engaged in hobbies (Snowden *et al.*, 1996a; Graham *et al.*, 1997; Lauro-Grotto *et al.*, 1997; Hodges *et al.*, 1998, 1992a). These cases have been reported to use a number of objects correctly, even the same objects to which they cannot provide names, descriptions or correct associative semantic judgements. Such observations are, however, largely anecdotal—very few investigations have explored the use of real objects in semantic dementia systematically. Buxbaum and colleagues (Buxbaum *et al.*, 1997) reported a patient who used most objects normally, and concluded that this preserved ability was supported by contributions from degraded, but partial, functional and associative knowledge, enhanced by sensorimotor information. Another study by Lauro-Grotto and colleagues (Lauro-Grotto *et al.*, 1997) did not evaluate single object use *per se*, but assessed the ability of the patient to prepare food, which she did without error for nearly all ingredients. In contrast, two studies have concluded that semantic impairment does impair object use. Hodges and colleagues described two patients with severe loss of conceptual knowledge about objects associated with many failures to use the same items correctly (Hodges *et al.*, 1999). Where success in object use appeared to exceed conceptual knowledge, the authors attributed this to reliance upon visual/tactile affordance in conjunction with good problem-solving skills, a conclusion bolstered by the patients' efficient and accurate manipulation of novel tools. Hamanaka and colleagues also reported the co-occurrence of impoverished conceptual knowledge and impaired object use in two patients with semantic dementia (Hamanaka *et al.*, 1996). There is some indication from this report that the degree of semantic impairment may be a critical factor. One of the patients initially presented with a mild semantic deficit affecting verbal comprehension and production, and at that stage had preserved object use. Over time, however, as the patient's comprehension deteriorated further, the ability to use common objects also declined.

The goal of the current study was to determine the degree of success in use of everyday objects in a case series of patients with semantic dementia, and to explore the relationship between object use and conceptual knowledge of the same items. Following our own previous work (Hodges *et al.*, 1999) and other observations in the literature, we predicted that the patients might use some objects correctly, but that this would reflect a degree of residual conceptual knowledge supported by problem-solving abilities. Note that this hypothesis requires patients with semantic dementia to have preserved mechanical problem-solving skills in a task involving selection and use of novel objects. Where a patient had severely degraded conceptual knowledge for a particular

item, we predicted that the demonstrated use would be determined by the character and quality of the object's affordances.

Method

Participants

Nine patients with semantic dementia were identified through the Memory and Cognitive Disorders Clinic at Addenbrooke's Hospital, Cambridge, UK, where they were seen by a senior neurologist (J.R.H.), a senior psychiatrist and a clinical neuropsychologist. In addition to a clinical assessment, each patient was given a number of standard psychiatric rating scales to exclude major functional psychiatric disorders such as depression and schizophrenia, as well as MRI scanning and the usual battery of screening blood tests to exclude treatable causes of dementia.

All patients fulfilled previously proposed criteria for semantic dementia: principally, impoverished semantic knowledge (as reflected in the domain of language processing by a progressive loss of both expressive and receptive vocabulary), with contrastingly good preservation of visuospatial abilities, day-to-day memory and non-semantic aspects of language, i.e. phonology and syntax (Hodges *et al.*, 1992a, 1995; Snowden *et al.*, 1996a). Structural brain imaging by MRI revealed focal atrophy involving the polar and inferolateral regions of one or both of the temporal lobes in all nine cases. Two of the patients (D.J.E. and I.F.) had been included in a previous, shorter report on object use (Hodges *et al.*, 1999).

All subjects gave informed consent to participate in the study which was approved by the Ethical Committee of Addenbrooke's Hospital, Cambridge.

Eight normal participants, approximately matched to the patients for age and years of education, were selected from the MRC Cognition and Brain Sciences Unit's subject panel and tested on the same object use assessments. An additional five control subjects completed the semantic knowledge tests, naming, general praxis and novel tool task.

General neuropsychology

The following battery of neuropsychological tests was administered: the Mini-Mental State Examination as a general measure of cognitive status (Folstein *et al.*, 1975); the digit span subtest of the Wechsler Memory Scale—Revised (WMS-R) (Wechsler, 1981) to assess auditory-verbal short-term memory; verbal fluency for the letters F, A and S as one measure of executive function; the Raven's Advanced or Coloured Progressive Matrices to assess non-verbal problem solving (Raven, 1962, 1965); and various subtests of the Visual Object and Space Perception Battery to measure visuospatial skills (Warrington and James, 1991).

Semantic assessments

The patients were tested on portions of a semantic battery which uses a single set of stimulus items in a variety of tasks

in order to assess semantic knowledge across different input and output modalities. The battery contains 64 items from the corpus of line drawings by Snodgrass and Vanderwart (Snodgrass and Vanderwart, 1980); the items are drawn from three categories of living things (animals, birds and fruit) and three categories of artefacts (household items, tools and vehicles). The following subtests from this semantic battery were administered: category fluency, in which the subject is asked to produce as many exemplars as possible in 1 min for each of the six categories; naming of the 64 line drawings; and word–picture matching in which a single spoken object name is to be matched to its corresponding line drawing from a picture array containing the target plus nine within-category foils.

As an additional test of associative semantic knowledge, the Pyramids and Palm Trees Test (Howard and Patterson, 1992) was administered. In this task, triplets of either pictures or words are presented, and the subject is asked to choose one of two response items that is most closely associated with the target item (e.g. for the target *pyramid*, the choice is between a *palm tree* and a *pine tree*).

General praxis testing

The subjects were asked to produce nine symbolic, intransitive gestures to verbal command (e.g. *wave goodbye*, *salute*). Two points were awarded for a correct gesture, and a single point was given if the response contained spatial and/or temporal errors but the gesture was nevertheless recognizable. The subjects were then asked to copy the examiner making the same nine meaningful gestures, in order to screen for other features of apraxia. Imitation was scored in the same way as production.

Novel Tool test (Goldenberg and Hagmann, 1998)

The materials for this test consist of a set of six wooden cylinders, each of which can sit in a wooden base, and a selection of novel tools (see Goldenberg and Hagmann, 1998). Each cylinder has a part to which one of the tools can be fitted to lift the cylinder out of its base. During testing, one cylinder at a time is placed in the well of the base and a collection of three tools placed beside it. The subject is asked to select the tool best suited to lift out the cylinder. If the correct tool is not chosen as the initial response, the subject is asked to choose an alternative.

The selection and use of the correct tool were scored separately. For the first part, two points were given when the correct tool was selected at first choice, one point if the subject selected the correct tool on second choice (maximum score = 12). The second part of the test evaluated the use of the tool (either selected by the subject or given by the examiner if two incorrect selections were made by the patient). Two points were awarded if the subject inserted the

tool and lifted the cylinder without hesitation or error, one point if the subject demonstrated the correct use after trial and error (maximum score = 12).

Twenty object test of functional semantic knowledge

A multiple component battery was constructed with the purpose of assessing associative information, functional knowledge and use of 20 common objects. The same 20 stimulus items were used in all subtests. The battery comprised the following subtests.

Naming

The subjects were shown colour photographs of each of the 20 objects and asked to name them. Two points were given for the correct name, one point for a response indicative of partial semantic knowledge. Errors were coded as omissions, circumlocutions or the production of a name that had a semantic or phonological relationship to the target object name.

Visual associative knowledge

Each of three matching tasks consisted of 20 sets of four colour photographs mounted in a vertical column on card. A photograph of the target item (the same photograph used for naming) was located at the bottom of the column, and the subject was asked to choose one of three response alternatives as the best match to the target according to one of three types of relationship described below. The order of items was randomized across tasks and each was preceded by two practice trials.

Every effort was made to ensure comprehension of the task. Data were not included if there was any doubt about the patient's ability to understand the instructions, which occurred in just one subject, V.H., when she was asked to match objects for shared purpose.

Matching object to recipient

In this test, the subjects were asked to choose the correct recipient to match the target object. There were two foils for each item, one typically found in the same location as the target and one unrelated (e.g. for the target *corkscrew*, the choice is between a *wine bottle*, a *glass* and a *piece of wood*).

Matching object to typical location

Subjects were asked to choose the location where the object typically is found (e.g. for the target *hairbrush*, the choice is between *bathroom*, *kitchen* and *study*).

Matching objects for shared purpose

Subjects were asked to choose one of three objects that could be used for the same purpose as the target item. While

Table 1 Example error types for each component of use

Error type	Component of use		
	Hold	Orientation	Movement
Partial	N/O	N/O	Only opens and closes arms on corkscrew
Omission	Soap treated as an ornament (i.e. object without use)	Soap treated as an ornament i.e. object without use)	Holds but does not move bottle opener
Incorrect	Bimanual use of scissors, secateurs, pliers (as if shears)	Using a potato peeler as a knife	Using matches as a cigarette or pencil
Ill-defined	Sellotape dispenser fiddled with	Aimless cutting with scissors/secateurs	Moving whisk from side-to-side

N/O = no specific examples observed.

pointing to the target item, the experimenter asked the subject, 'which one of the three objects above could you use instead of this one?' The foils were chosen to be either visually similar to, or from the same category as, the target (e.g. for the target *scissors*, the choice is between *Stanley knife*, *sellotape* and *pliers*). Note that the names of the objects are not involved/required as either stimuli or responses in these matching tasks, obviating any concern about whether all subjects would be familiar with a rather low-frequency term such as 'Stanley knife'.

Object use

The subjects were given each object (in this case, the real objects, from which the photographs had been made) in isolation and asked to demonstrate its use. Performance was videotaped and scored by two independent raters. The scoring scheme employed a scale of 0–3, where the principle components of object use—hold, orientation and movement—were all scored independently. This enabled a point to be achieved for a correct movement or correct orientation irrespective of whether the hold was correct. For example, if subjects incorrectly grasped the *secateurs* in two hands but made the correct movement in the right orientation, they would score two points. Errors were classified into one of four types: *omission* (no response); *partially correct* (only a part of the appropriate full use was demonstrated); *incorrect* (cases where the raters classified the use as identifiably appropriate for another object); or *ill-defined* (where the item was manipulated aimlessly and the response was not recognized as suiting an alternative object). An example of each error type for each of the three components of use is given in Table 1.

Setting

Testing was performed in a quiet environment either in the hospital or in the subject's home. Performance was videotaped for later evaluation. Testing required between 1 and 3 h (depending on the individual patient) and was completed in

one or, if necessary, two sessions separated by no more than 2 weeks.

Results

General neuropsychology

The nine patients covered a broad spectrum of impairment as indicated by their performance on the Mini-Mental State Examination (see Table 2). None had a significant deficit of auditory–verbal short-term memory, as measured by forward and backward digit span, except for F.M. who was at an advanced stage of the disease with very profound aphasia. All of the patients tested had low scores for letter fluency, which is not surprising given that this task requires word retrieval as well as executive function. With the exception of three cases (D.J.E., T.R. and F.M., again towards the more severe end of the spectrum), there was general preservation of non-verbal problem-solving skills as measured by the Raven's Matrices. Because some patients were given the advanced Raven's matrices and others the coloured, the scores are shown as percentiles. Performance on the various subtests of the Visual Object and Space Perception Battery was largely good, except for two of the most severe patients (D.G. and F.M.) on those subtests which have fairly complex instructions.

Semantic tests

The range of impairment across the nine cases is illustrated further by performance on the semantic tests, presented in Table 3 (note that, in Tables 2 and 3, the cases are ordered by the patients' scores on the naming and word–picture matching tests). All patients showed reduced category fluency and poor performance on the naming test. They were also impaired on word–picture matching and both conditions of the Pyramids and Palm Trees test, indicating degraded semantic knowledge for both verbal and non-verbal stimuli.

General praxis testing

When asked to produce symbolic gestures to command, most of the patients performed at, or near to, floor level, which

Table 2 General neuropsychology

Test (maximum score)	J.C.	G.C.	D.C.	T.R.	D.G.	V.H.	I.F.	D.J.E.	F.M.	Control mean (SD)
MMSE (30)	24	25	18	11	19	19	NT	6	8	28.8 (0.5)
Digit span										
Forward	8	5	6	6	5	8	6	NT	2	6.8 (0.9)
Backward	4	5	4	4	3	5	6	NT	NT	4.7 (1.2)
Letter fluency (total: F, A, S)	22	11	9	0	13	3	12	0	0	44.2 (11.2)
Raven's matrices (percentiles)	25 [†]	25 [†]	>95*	10 [†]	NT	NT	90*	5–10*	<5*	
VOSP										
Incomplete letters (20)	18	20	20	20	20	19	20	20	18	19.2 (0.8)
Dot counting (10)	NT	10	10	10	10	10	10	8	10	9.9 (0.3)
Position discrimination (20)	20	20	20	18	13	NT	19	20	16	19.8 (0.6)
Cube analysis (10)	9	9	10	10	4	9	10	8	NT	9.7 (2.5)
Number location (10)	10	10	10	7	8	NT	7	8	4	8.9 (2.8)

Patients are ordered according to their performance on the naming test (see Table 3). MMSE = Mini-Mental State Examination; VOSP = Visual Object and Space Perception battery; NT = not tested. *Raven's coloured progressive matrices. [†]Raven's advanced progressive matrices.

Table 3 Assessment of semantics

Test (maximum score)	J.C.	G.C.	D.C.	T.R.	D.G.	V.H.	I.F.	D.J.E.	F.M.	Control mean (SD)
Category fluency										
Living	21	15	7	0	13	2	4	0	0	60.3 (12.6)
Manmade	27	3	6	9	7	5	4	1	0	54.8 (10.3)
Naming (64)	45	27	20	20	15	12	3	1	0	62.3 (1.6)
Word–picture matching (64)	61	42	44	41	25	30	21	5*	16	63.7 (0.5)
Pyramids and Palm Trees										
Words (52)	47	35	30	30	21*	22*	33	30	30	51.1 (1.1)
Pictures (52)	44	35	40	NT	26*	28	NT	30	NT	51.2 (1.4)

NT = not tested. *Scores no better than expected by chance.

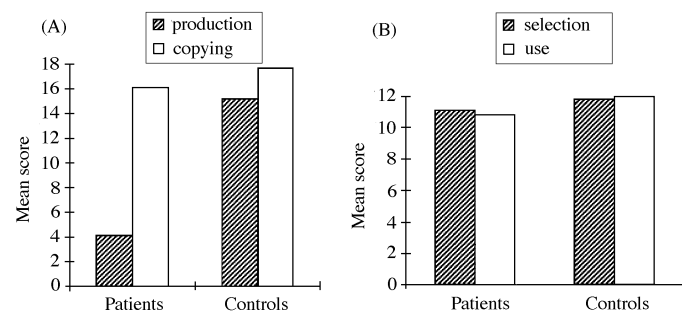


Fig. 1 (A) Performance on production and imitation of meaningless gestures. (B) Performance on the novel tool test.

is unsurprising considering their extremely impoverished comprehension (see Fig. 1A). When required to copy the gestures, however, most patients scored within the normal range. In fact, five of the patients (J.C., G.C., D.C., I.F. and D.J.E.) achieved perfect scores for imitation, and only two of these had succeeded in producing more than a single correct gesture to command.

An analysis of variance revealed significant main effects of group [$F(1,13) = 20.77, P < 0.01$] and condition [$F(1,13) = 55.43, P < 0.001$], as well as a significant interaction between group and condition [$F(1,13) = 23.80, P < 0.001$]. Paired t -tests confirmed that the patients

performed significantly better on imitation than production of the gestures [$t(8) = 8.43, P < 0.001$]. The small difference favouring imitation over production by the controls was not significant [$t(5) = 2.44, P = 0.59$].

Novel tool task

Performance on both the selection and use of the novel tools was at ceiling for most of the controls and patients (see Fig. 1B). An analysis of variance revealed no effect of group [$F(1,13) = 1.32, ns$] or condition [$F(1,13) < 1$], and no interaction between group and condition [$F(1,13) < 1$]. The patients not only achieved quantitative scores of an equivalent level to the control group on this task, but also demonstrated an entirely normal quality of performance: rapid, fluent and dexterous.

Semantic knowledge

Naming

The patients were impaired, most of them profoundly so, at naming the 20 common objects (see Fig. 2). Three of the patients (I.F., D.J.E. and F.M.) failed to name any of the items, and one patient (F.M.) was unable to produce any

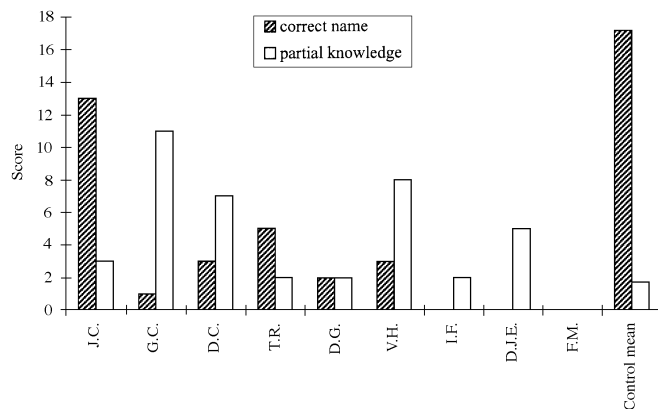


Fig. 2 Performance on naming photographs of the 20 objects.

information at all. A *t*-test confirmed that the patients' naming scores were significantly lower than those of the control participants [$t(12) = 6.33, P < 0.001$]. As is characteristic in semantic dementia (Hodges *et al.*, 1992a), none of the patients made phonological naming errors; errors of commission comprised only semantic paraphasias and circumlocutory responses, and there were many omission (no response) errors.

Visual associative knowledge

Normal controls performed well on the three matching subtests. Matching for shared purpose was the most difficult, with the lowest score of a control subject being 15/20. Five of the patients (D.G., I.F., V.H., D.J.E. and F.M.) performed at, or barely above, chance on all three matching subtests (see Fig. 3). Only J.C., the patient with the mildest semantic impairment, achieved scores within the normal range on these tests of associative semantic knowledge about common objects.

A 2 (group) \times 3 (type of matching test) ANOVA (analysis of variance) revealed a significant main effect of group [controls $>$ patients: $F(1,12) = 18.23, P < 0.01$] and test [$F(2,24) = 8.51, P < 0.01$], but no interaction between these two factors [$F(2,24) < 1$]. Paired-samples *t*-tests indicate that the patients had significantly lower scores for matching to purpose than for matching the objects to either their typical locations [$t(8) = 4.23, P = 0.003$] or their typical recipients [$t(8) = 2.77, P = 0.024$], with no difference between the latter two [$t(8) = 0.41, ns$]. The control participants showed the same pattern of difficulty, with a significant advantage for recipient $>$ purpose [$t(4) = 2.75, P = 0.05$] and a borderline advantage for location $>$ purpose [$t(4) = 2.67, P = 0.056$].

Object use

Inter-rater reliability. Reliability between the two raters of object use, assessed using Cohen's Kappa statistic, was significant and satisfactory for all three measures: hold ($\kappa = 0.71, P < 0.001$); orientation ($\kappa = 0.67, P < 0.001$);

movement ($\kappa = 0.75, P < 0.001$); and for total score ($\kappa = 0.54, P < 0.001$).

Group analyses. It is clear from Fig. 4 that the patients' ability to demonstrate the correct use of these 20 common objects was substantially poorer than that of the control subjects on all three rated dimensions. A *t*-test confirmed that the patients' overall object use score was significantly lower than that of the controls [$t(15) = 6.34, P < 0.001$]. ANOVA on the individual components of object use yielded significant main effects of both group [$F(1,15) = 34.03, P < 0.001$] and component [$F(2,30) = 35.88, P < 0.001$], plus an interaction between the two factors [$F(2,30) = 14.24, P < 0.001$]. Paired *t*-tests revealed that the patients scored significantly higher on correct hold for the objects than either orientation [$t(8) = 5.91, P < 0.001$] or movement [$t(8) = 7.44, P < 0.001$], with no difference between the latter two components [$t(8) = 0.86, ns$]. The control subjects showed a numerically small but statistically reliable advantage for both hold and movement relative to orientation [$t(7) = 7.94, P < 0.001$; $t(7) = 2.39, P < 0.05$], but the small difference between hold and movement in control performance did not reach significance [$t(7) = 2.05, P = 0.08$].

The individual components of object use were scored separately to enable us to detect any evidence for a degree of independence amongst these types of knowledge. Chi-squared analysis of the patients' scores, however, revealed significant associations between all three pairs of the hold, orientation and movement dimensions ($23.83 < \chi^2 < 46.36$, all $P < 0.001$), suggesting that these components of object use are non-independent.

Analysing the relationship between conceptual knowledge and object use

Pearson's correlations produced significant associations between all six combinations of the patients' scores on four semantic tests: the two from the semantic battery (picture naming and word-to-picture matching, both $n = 64$) and the two designed for this study [naming of the 20 object photographs, and a combined score for the three associative matching tasks ($0.71 < r < 0.90$, all $P_{\text{one-tailed}} < 0.05$)]. These relationships support the view that these patients suffer from a modality-independent, central semantic impairment (Hodges *et al.*, 1992b; Bozeat *et al.*, 2000).

The primary aim of the current study was to explore the role played by conceptual knowledge in object use. We found that, with two exceptions, both overall object use and each of the individual components of object use (hold, movement and orientation) correlated reliably with all four of the semantic tests mentioned in the previous paragraph ($0.61 < r < 0.87$, all $P_{\text{one-tailed}} < 0.05$). The two exceptions were that the correlations of object hold (the best preserved of the three dimensions for the patients) with word-picture matching ($n = 64$) and object naming ($n = 20$) did not quite

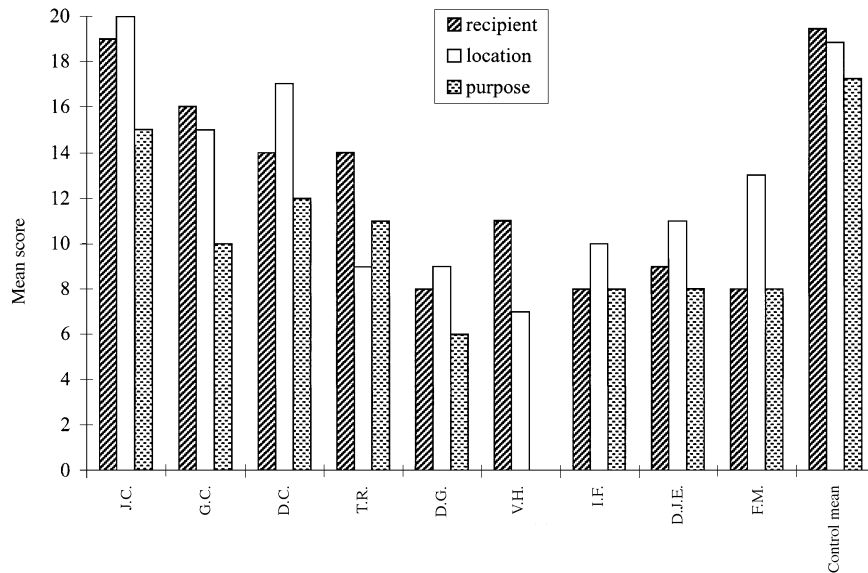


Fig. 3 Performance on the three tests of visual associative knowledge.

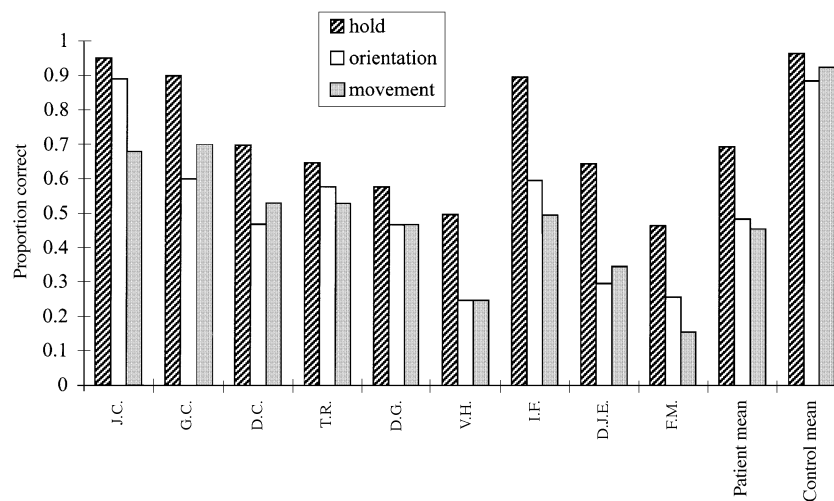


Fig. 4 Performance on the individual components of object use.

reach conventional levels of significance ($0.528 < r < 0.471$, both $P_{\text{one-tailed}} < 0.1$). By-subjects regression analyses were carried out to determine whether any individual patient's performance deviated from the significant group-based relationship between object use (total score or any of the three components) and knowledge (as measured by the total score on the three associative matching tests). With two standard residuals either side set as criterion, none of the nine patients deviated significantly from this relationship on any measure of object use. It is important to note that the confidence interval for the estimated gradients of the linear regression equation included the value 1.0, suggesting that object use and conceptual knowledge are directly linked. If correct object use could be achieved despite degraded semantic knowledge of the object in question, these regression functions should have been closer to horizontal (i.e. a gradient of zero) or at least substantially less than 1.

By-items analyses of object use and knowledge scores revealed that only three items, the *corkscrew*, *scissors* and *watering can*, were characterized by a significant deviation from the predicted relationship. Scores on both the hold component and the overall use of the *corkscrew* were >2 standard residuals below that predicted by the patients' knowledge, and scores on movement of the *scissors* and orientation for the *watering can* were significantly better than would be predicted by the patients' knowledge. These results can be interpreted mostly by considering the physical properties of the objects. The *corkscrew* has two sets of moving parts, each requiring a separate movement executed in a specific order. Demonstration of the entire correct use is, therefore, quite a complex process (see also the error analysis below). The same complex manipulation is also true of the *sellotape dispenser*, and it is interesting to note that correct hold for this item was 1.4 standard residuals below

Table 4 Distribution of error types for each component of use (raw number collapsed across patients)

Object	Hold				Orientation				Movement			
	Partial	Omission	Ill-defined	Incorrect	Partial	Omission	Ill-defined	Incorrect	Partial	Omission	Ill-defined	Incorrect
Pliers	0	0	0	5	0	0	1	3	3	2	0	0
Secateurs	0	0	1	2	0	0	4	2	0	1	0	0
Scissors	0	0	0	1	0	0	5	1	0	0	0	0
Corkscrew	0	0	1	5	0	0	2	5	7	0	1	0
Matches	0	0	2	0	0	0	4	2	1	1	1	3
Sellotape dispenser	0	0	5	0	0	0	4	1	1	4	1	1
Nail clippers	0	0	4	0	0	0	2	3	1	3	1	0
Soap	0	1	2	1	0	1	3	0	0	3	3	1
Watering can	0	1	1	0	0	1	1	0	0	2	2	0
Pencil sharpener	0	0	4	0	0	0	7	0	0	5	3	0
Kettle	0	0	1	0	0	0	2	0	0	2	1	0
Bottle opener	0	0	1	3	0	0	1	6	0	3	1	3
Dish brush	0	0	0	0	0	0	1	4	0	0	6	0
Hammer	0	0	0	0	0	0	2	1	0	2	0	1
Toothbrush	0	0	1	1	0	0	3	1	0	2	1	1
Pencil	0	0	1	0	0	0	0	2	0	3	0	0
Whisk	0	0	0	1	0	0	1	3	0	0	3	1
Hairbrush	0	1	0	0	0	1	0	1	0	1	2	2
Spoon	0	0	0	0	0	0	1	0	0	0	1	0
Potato peeler	0	0	1	2	0	0	0	2	0	2	2	1
Sum	0	3	25	21	0	3	44	37	13	36	29	14

that expected. Manipulation of a pair of *scissors* is highly constrained by the object's construction: it is almost impossible not to move them correctly, irrespective of the hold and orientation adopted. Again, another object with the same characteristics, the *secateurs*, also achieved a correct movement score a little better than expected (1.4 residuals above the level predicted). The unexpectedly good orientation for the *watering can* does not have such an obvious explanation, but it should be noted that when this object is sitting on a table (as it was presented to the subjects), it is upright, i.e. already in its correct, stable orientation.

Error analysis

The types of errors produced by these patients, presumably in the face of insufficient support from conceptual knowledge, may reveal important non-semantic contributions to object use. Table 4 summarizes the distribution of error types for each component of use—hold, orientation and movement—for each of the 20 objects. The distributions are summed across patients; this seems appropriate because, although cross-sectionally increasing semantic impairment was associated with a greater number of errors, it yielded no changes in the overall pattern of error types. As noted above, there were significantly fewer errors in the manner of holding the objects than in either orienting or moving them. There were only three occasions on which a patient failed to attempt to hold an object (hold 'omission' errors). For example, patient I.F. treated the bar of soap as if it were an object without a function, leaving it sitting on the table and commenting 'you just put it there'. There were no hold

'partial' errors; this is perhaps unsurprising for objects that are held in one hand, but this error type is at least theoretically possible for those items that require either a bimanual hold (e.g. the *sellotape dispenser*) and/or a change in hold during use (e.g. the *corkscrew*). The bulk of the hold errors were rather evenly split across the remaining two error categories. The 'ill-defined' errors for hold (also for the other two components of use) appear to be relatively uninformative: they often seemed attributable to a process of detailed visual, and perhaps tactile, investigation by the patients. The hold 'incorrect' errors, however, are somewhat more revealing. For example, there was complete consistency of the errors in this category for the *pliers*, *secateurs* and *scissors*: each was held with one of the two handles in each hand (as appropriate for a pair of shears). It is possible that this reflects the influence of object affordance on performance.

The distribution of orientation errors was similar to that of the hold errors. There were no 'partial' errors for orientation, and only three 'omission' errors which were, of course, exactly the same examples as the hold 'omission' errors. The remaining errors were split evenly between ill-defined and incorrect (e.g. several patients used the dishbrush to demonstrate washing their own bodies).

There were examples of all four types of error for the movement component of use. The 'partial' movement errors were only observed for objects that require a sequence of movements for correct use (*pliers*, *corkscrew*, *matches*, *sellotape dispenser*, *nail clippers*). For example, the pliers typically were opened and closed, but without a subsequent pulling or twisting motion; in effect, the demonstrated use was indistinguishable from that of scissors. Although the

patients nearly always held the objects in some way, they often failed to demonstrate any specific movement ('omission' errors) or the movement was ill-defined, which again was attributable in many cases to prolonged investigation by the patients. Finally, there were a number of examples where an object was used as if it were another item ('incorrect' movement errors). These provide some of the most striking clinical examples. For instance, after I.F. removed a match from the matchbox, instead of showing how one would strike it against the strip, he demonstrated the process of smoking it, like a cigarette. For the hairbrush, I.F. seemed to use it as a tool for cleaning surfaces (like a feather duster). D.J.E. used the potato peeler as an implement for scraping, using the pointed end rather than the blade.

Discussion

This study was designed (i) to assess the degree to which patients with semantic dementia can achieve normal use of familiar objects and (ii) to explore the relationship between object use and semantic knowledge, based on a common set of items for all the relevant assessments. The results give relatively clear answers to these questions. The nine patients that we tested, representing a spectrum of impaired conceptual knowledge, were not capable of using everyday, common objects in a normal, object-specific fashion. Furthermore, as indicated by significant, high correlations, the degree of success in demonstrating the conventionally correct use for objects was directly related to the patient's degree of semantic impairment, both in general semantic assessments and, more to the point, on tests of knowledge concerning the same specific objects employed in the object use assessments.

There was no evidence of ideomotor apraxia in these nine cases. The patients' ability to imitate meaningful, symbolic gestures was essentially normal, and their significant impairment in producing these same gestures to command is readily explained by their poor verbal comprehension. Of even greater importance, all nine cases, even those with the most severe semantic deficits, had preserved mechanical problem-solving ability. In the novel tool task, all of the patients showed normal and usually flawless performance. This was reflected not only in the scores, but also in the fast and unhesitating manner in which the patients performed the task.

Our finding that semantic impairment was associated with poor use of common objects, while in line with the previous studies of Hamanaka and colleagues, and Hodges and colleagues (Hamanaka *et al.*, 1996; Hodges *et al.*, 1999), seems to contradict several reports noted in the Introduction. Why were the patients assessed here, but not those reported by others (Buxbaum *et al.*, 1997; Lauro-Grotto *et al.*, 1997) markedly impaired in using common objects? Furthermore, how can a number of the patients included in the present study still engage successfully in hobbies and sports requiring object use? Finally, why are there some, albeit only a few, objects for which the demonstrated use is correct or at least

partially so? We shall outline two contrasting proposals for the way in which knowledge of object use might be represented, followed by five additional factors that may help to explain these apparent discrepancies.

Hypothesis 1: multi-modal semantic systems

One position is that 'action semantics' constitutes a domain of object-specific conceptual knowledge that is separable from the remainder of semantic memory. This position represents one version of a 'multi-modal semantic system' framework of the type advocated by McCarthy and Warrington (McCarthy and Warrington, 1988) to explain dissociations between visually and verbally accessed knowledge. In an extension of this viewpoint, Lauro-Grotto and colleagues proposed that knowledge of how to act with or upon objects constitutes one facet of non-verbal semantic knowledge (Lauro-Grotto *et al.*, 1997). In support of this position, these investigators reported a patient R.M. with semantic dementia who performed very poorly on standard semantic tests involving words as either stimuli or responses (e.g. object naming, word-picture matching), but nevertheless (i) functioned fairly normally in everyday life, (ii) succeeded in using foods and utensils to prepare a meal under controlled observation, and (iii) did well on semantic tests lacking a verbal component, such as matching pictures to other pictures according to various functional parameters (e.g. things found together, used in the same context, etc.). The opposite dissociation, impaired action semantics with preserved general knowledge, has been postulated in some patients with a disorder labelled ideational or, more recently, conceptual apraxia (De Renzi and Lucchelli, 1988; Ochipa *et al.*, 1989, 1992). For example, Ochipa and colleagues (Ochipa *et al.*, 1989) documented severe impairment of real object use following a right cerebral infarct in a left-handed patient: this patient was able to name, and to identify from name, objects that he could neither use nor explain how to use.

According to this hypothesis, patients with semantic dementia might—despite substantially degraded conceptual knowledge—have preserved object use because of this functionally and anatomically separable action-semantic subsystem. There should be no necessary correlation between successful object use and the ability to name or perform other conventional verbal semantic tasks based on the same objects. According to Lauro-Grotto and colleagues, however, the fact that action semantics are subsumed within non-verbal (mainly visually based) semantic knowledge should lead one to expect a significant correlation between appropriate object use and performance on tests of visually based knowledge, such as matching a picture of an object to a picture of its typical recipient (Lauro-Grotto *et al.*, 1997).

Our results from nine patients with semantic dementia documented significant and in some cases profound deficits with respect to a common set of 20 everyday objects in all three of these domains: real object use; visually based semantic judgements on colour photographs of the same

objects; and naming of the same photographs. There were strong correlations amongst all pairs of domains, with no evidence for disproportionate preservation in one aspect of semantic memory when another was degraded. The significant association between impairments in visually based semantic tasks and in object use does fit the predictions of Lauro-Grotto and colleagues (Lauro-Grotto *et al.*, 1997) but the correlation between naming and object use does not. Furthermore, although it would always be possible to argue that only one of two separable subsystems was affected by the brain abnormality in R.M. (the case studied by Lauro-Grotto *et al.*) while both have been disrupted in our cohort of cases, this seems an unlikely explanation: the striking inferolateral left temporal atrophy of R.M. looks identical to that seen in the majority of the patient series reported here. Neither is it the case that the patients in our study all clustered at the severe end of the spectrum of semantic dementia, where widespread atrophy might be expected to have affected all aspects of semantic memory. Our group included at least one mildly affected patient (J.C.): his ability to use (especially to demonstrate the correct movement of) objects, though less disrupted than that of the other eight cases, was measurably outside the normal range and commensurate with his degree of semantic deficits on the other tasks such as naming.

Hypothesis 2: the mapping between objects and their meaning

An alternative view is that knowledge of object use constitutes one component of a common knowledge base, some aspects of which are activated whenever a person encounters an object, or a picture of it, or its name, or its characteristic sound, etc. This position, despite eschewing distinctly separable components of a central semantic system, does not demand that patterns of semantic activation will be identical for different modalities of input. The mapping between an object's name and its meaning is arbitrary, whereas real objects have a systematic relationship with at least parts of the corresponding conceptual representation. If this difference is built into a computational model (see Lambon Ralph and Howard, 2000), simulated damage to the semantic system gives rise to better comprehension when semantic representations are activated by pictures (i.e. systematically related input) than by words (i.e. arbitrarily related input). Furthermore, comprehension errors in response to pictures nearly always involve activation of the correct semantic region, but reach this generally appropriate region much less often in the case of errors to words. This suggests that, when faced with an object (or a picture of it), a patient with degraded knowledge of that object concept may be able to extract clues from its component parts as to its function and/or the general type of thing it is (for a closely related proposal, see Caramazza *et al.*, 1990).

There are at least five other factors that may give rise to some degree of successful object use in the face of a

generalized impairment to a single conceptual knowledge base.

Factor 1: residual conceptual knowledge

Following on from the last point, it is well established that patients with degraded semantic memory may have relative preservation of superordinate knowledge despite severely impaired fine-grained or item-specific information (Warrington, 1975; Schwartz *et al.*, 1979; Hodges *et al.*, 1994, 1995). It follows that, although semantic deficits will disrupt the ability to use objects in an item-specific fashion, broad functional knowledge may permit partially correct use for some items, particularly if mechanical problem-solving skills are preserved. One would nevertheless expect a significant correlation between the degree of semantic impairment and correct object-specific use, as demonstrated in this study.

Factor 2: familiarity

Premorbid familiarity is a potent factor in predicting the impact of progressive semantic impairment on the integrity of conceptual representations (Funnell, 1995; Lambon Ralph *et al.*, 1998; Bozeat *et al.*, 2000). The assessment of object use typically includes relatively familiar items for which knowledge is likely to be relatively robust. This factor is important when comparing performance on semantic tasks and object use if the two are not based on the same set of objects. In such circumstances, an apparent preservation of action knowledge may reflect, at least in part, the greater familiarity of the objects chosen for assessment of use.

Factor 3: personally relevant schemata and contexts

Another important factor, although not explored in the present study, is the influence of personal familiarity with specific instances of objects and their normal contexts. Snowden and colleagues (Snowden *et al.*, 1994, 1995) have demonstrated significant facilitation of performance when patients with semantic dementia are given their own objects in their correct context during assessment. These authors argue that deteriorating conceptual representations are bolstered by recurrent exposure to specific instances of objects, via the hippocampally mediated episodic memory system that remains relatively intact in semantic dementia. Furthermore, it seems likely that encountering a kettle, for example, in the context of other objects specifically related to the goal of tea-making (sink, tap, teacups, teabags, etc.) might facilitate use of a kettle. This contextual factor may explain, at least in part, the excellent performance (in an unfamiliar kitchen) of the patient described by Lauro-Grotto (Lauro-Grotto *et al.*, 1997).

The present investigation was designed deliberately, as a

starting point, to assess action knowledge for familiar objects that were neither specific instances well known to the patients nor presented in their normal contexts. Nevertheless, demonstrating how to pour from a kettle that is presented across a desk and without a cup to pour into is achieved with ease by every normal person. Having documented a deficit in this kind of knowledge in semantic dementia, we acknowledge the importance of further systematic exploration of the effects of context and personal familiarity.

Factor 4: affordance

Buxbaum and colleagues argued that the performance of patient D.M. was supported by a combination of residual semantic knowledge and sensorimotor affordances (Buxbaum *et al.*, 1997). The term *affordance* seems to be used to refer to at least two potentially separate mechanisms that support object use directly from visual and/or tactile input. One is problem solving, or deliberate reasoning, about an object on the basis of its physical characteristics, which we discuss below. The other relates to a more automatic process in which information about hold, orientation, movement and purpose are related systematically to an object's physical structure (e.g. if an object has a handle, it is held; if it has a sharp edge, it is used for cutting). If visual/tactile features are paired with functions and manipulations both frequently and consistently, then these relationships may become strongly encoded somewhat independently of object-specific semantic activation. Indeed, qualitative analysis of the patients' performance suggests that visual affordance played a role: patients frequently applied the correct hold, even on many occasions where they failed to demonstrate the correct orientation and/or movement for the object.

This kind of characterization of affordance is typically a *post hoc* description; if affordance is to offer a theoretically useful tool, researchers will need to develop some criteria for specifying these systematic relationships *a priori*. Note also that, although affordance seems to carry a positive connotation, it may not always be beneficial. The bimanual hold that the patients frequently applied to the *scissors*, *pliers* and *secateurs* may be one example of affordance leading to an inappropriate outcome.

Factor 5: mechanical problem solving

The brain is able solve novel mechanical problems based upon the visual and/or tactile properties of objects. This ability can be disrupted by damage to the parietal lobes, as a result of either cerebral vascular accident (Goldenberg and Hagmann, 1998) or corticobasal degeneration (Hodges *et al.*, 1999): such patients fail, for example, to solve mechanical problems involving the selection and manipulation of novel tools. Provided that this parietal system and its connection to frontally mediated motor programmes remains unaffected, as the neuroanatomy of semantic dementia would suggest, it should be possible for these patients to employ such

mechanical problem-solving strategies to achieve a considerable degree of appropriate object use (Sirigu *et al.*, 1991). As emphasized earlier, the nine patients with semantic dementia achieved a largely flawless performance in the novel tools task.

Given evidence for preserved problem solving, it may seem a little surprising that the patients only occasionally employed a 'trial and error' process in an attempt to work out the correct use of real objects. We suggest, however, that two additional considerations make this observation less surprising. The first and perhaps critically important point is that effective problem solving demands a goal or intention. In contrast to the novel tools task where the examiner provides the goal ('Use one of these tools to lift the cylinder out of its base'), demonstrating the use of an isolated object in response to the instruction 'show me how you would use this' requires a self-generated goal. The ability to conceive the appropriate goal for which the object typically is used may, in turn, depend upon conceptual knowledge of the object that is degraded in patients with semantic dementia. The second and somewhat related point is that, even setting aside the conventionally correct use for an object, the ability to work out a plausible function for it often requires knowledge of its properties that may be impaired in semantic dementia. Suppose that, in the absence of a screwdriver, you needed to tighten a screw, and the objects within reach were a piece of heavy card and a coin. Both would fit into the head of the screw but you would choose the coin because you know that coins are hard and inflexible. Unless the coin's appearance 'affords' inflexibility (and/or the card announces itself as flexible), it is not clear that semantically impaired patients still have access to this kind of feature.

As must be clear by now, our conclusion is that there is no need to postulate a separate action component of the semantic system. The key finding of our study is the dramatically high correlation between the degree of impairment to *non-action* aspects of conceptual knowledge and the ability of these patients to demonstrate the use of common objects in isolation. To the extent that other patients reported in the literature (Buxbaum *et al.*, 1997; Lauro-Grotto *et al.*, 1997), or indeed these same patients under other circumstances (in the service of hobbies and sports), achieve levels of object use beyond that predicted by this close function relating knowledge to use, we argue that factors such as affordances, problem solving, available context, etc. may provide an amply sufficient explanation.

The findings of the present study are germane to debates concerning the two visual processing streams, originally characterized in terms of a ventral 'what' and a dorsal 'where' pathway (Mishkin and Ungerleider, 1982). On the basis of extensive assessments of a patient with severe damage to the ventral system, Goodale and colleagues have argued that the role of the dorsal stream could be reformulated as providing on-line guidance of motor action computed according to position, axis length and orientation of objects in space (Goodale *et al.*, 1991). It should be noted, however, that the

critical studies in their patient involved the grasping of single objects or making appropriate orienting movements of the hand and wrist, rather than execution of complex movements related to object use. For skilled and appropriate object use, Milner and Goodale (Milner and Goodale, 1995) have suggested that the processing achieved by the dorsal stream must be combined with the products of processing in the ventral 'what' pathway. This proposal is supported by recent functional imaging studies in normal subjects: Decety and colleagues (Decety *et al.*, 1997) concluded that, although the dorsal occipito-parietal pathway in conjunction with premotor cortex is sufficient for programming of complex movements, ventral networks are co-activated whenever the movements relate to actual object use. Patients with semantic dementia have extensive temporal lobe pathology (Mummery *et al.*, 2000) with profound disruption to the ventral object identification pathway. Under these circumstances, the functioning of the (intact) dorsal pathway must become increasingly isolated, leaving the patients still able to solve mechanical problems such as the novel tool task, but gradually depriving them of the normal ability to use familiar objects in the conventionally correct, conceptually determined, fashion.

References

- Bozeat S, Lambon Ralph MA, Patterson K, Garrard P, Hodges JR. Non-verbal semantic impairment in semantic dementia. *Neuropsychologia* 2000; 38: 1207–15.
- Buxbaum LJ, Schwartz MF, Carew TG. The role of semantic memory in object use. *Cogn Neuropsychol* 1997; 14: 219–54.
- Caramazza A, Hillis AE, Rapp BC, Romani C. The multiple semantics hypothesis: multiple confusions? *Cogn Neuropsychol* 1990; 7: 161–89.
- De Renzi E, Lucchelli F. Ideational apraxia. *Brain* 1988; 111: 1173–85.
- Decety J, Grezes J, Costes N, Perani D, Jeannerod M, Procyk E, et al. Brain activity during observation of actions. Influence of action content and subject's strategy. *Brain* 1997; 120: 1763–77.
- Folstein MF, Folstein SE, McHugh PR. 'Mini-mental state': a practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res* 1975; 12: 189–98.
- Funnell E. Objects and properties: a study of the breakdown of semantic memory. *Memory* 1995; 3: 497–518.
- Goldenberg G, Hagmann S. Tool use and mechanical problem solving in apraxia. *Neuropsychologia* 1998; 36: 581–9.
- Goodale MA, Milner AD, Jakobson LS, Carey DP. A neurological dissociation between perceiving objects and grasping them. *Nature* 1991; 349: 154–6.
- Graham KS, Lambon Ralph MA, Hodges JR. Determining the impact of autobiographical experience on 'meaning': new insights from investigating sports-related vocabulary and knowledge in two cases with semantic dementia. *Cogn Neuropsychol* 1997; 14: 801–37.
- Hamanaka T, Matsui A, Yoshida S, Nakanishi M, Fujita K, Banno T, et al. Cerebral laterality and category-specificity in cases of semantic memory impairment with PET-findings and associated with identification amnesia for familiar persons. *Brain Cogn* 1996; 30: 368–72.
- Hodges JR, Patterson K, Oxbury S, Funnell E. Semantic dementia: progressive fluent aphasia with temporal lobe atrophy. *Brain* 1992a; 115: 1783–806.
- Hodges JR, Salmon DP, Butters N. Semantic memory impairment in Alzheimer's disease: failure of access or degraded knowledge? *Neuropsychologia* 1992b; 30: 301–14.
- Hodges JR, Patterson K, Tyler LK. Loss of semantic memory: implications for the modularity of mind. *Cog Neuropsychol* 1994; 11: 505–42.
- Hodges JR, Graham N, Patterson K. Charting the progression in semantic dementia: implications for the organisation of semantic memory. *Memory* 1995; 3: 463–95.
- Hodges JR, Garrard P, Patterson K. Semantic dementia. In: Kertesz A and Munoz DG, editors. *Pick's disease and Pick complex*. New York: Wiley-Liss: 1998. p. 83–104.
- Hodges JR, Spatt J, Patterson K. 'What' and 'how': evidence for the dissociation of object knowledge and mechanical problem solving skills in the human brain. *Proc Natl Acad Sci USA* 1999; 96: 9444–8.
- Howard D, Patterson K. *The Pyramids and Palm Trees Test: a test of semantic access from words and pictures*. Bury St. Edmunds (UK): Thames Valley Test Company; 1992.
- Lambon Ralph MA, Howard D. Gogi aphasia or semantic dementia? Assessing poor verbal comprehension in a case of fluent progressive aphasia. *Cogn Neuropsychol*. In press 2000.
- Lambon Ralph MA, Graham KS, Ellis AW, Hodges JR. Naming in semantic dementia—what matters? *Neuropsychologia* 1998; 36: 775–84.
- Lauro-Grotto R, Piccini C, Shallice T. Modality-specific operations in semantic dementia. *Cortex* 1997; 33: 593–622.
- McCarthy RA, Warrington EK. Evidence for modality-specific meaning systems in the brain. *Nature* 1988; 334: 428–30.
- Mesulam MM. Slowly progressive aphasia without generalized dementia. *Ann Neurol* 1982; 11: 592–8.
- Mesulam MM, Weintraub S. Primary progressive aphasia. In: Boller F, Forette F, Khachaturian Z, Poncet M, Christen Y, editors. *Heterogeneity of Alzheimer's disease*. Berlin: Springer-Verlag, 1992. P. 43–66.
- Milner AD, Goodale MA. *The visual brain in action*. Oxford: Oxford University Press; 1995.
- Mishkin M, Ungerleider LG. Contribution of striate inputs to the visuospatial functions of parieto-preoccipital cortex in monkeys. *Behav Brain Res* 1982; 6: 57–77.
- Mummery CJ, Patterson K, Price CJ, Ashburner J, Frackowiak RSJ, Hodges JR. A voxel-based morphometry study of semantic dementia: relationship between temporal lobe atrophy and semantic memory. *Ann Neurol* 2000; 47: 36–45.

- Ochipa C, Rothi LJ, Heilman KM. Ideational apraxia: a deficit in tool selection and use. *Ann Neurol* 1989; 25: 190–3.
- Ochipa C, Rothi LJ, Heilman KM. Conceptual apraxia in Alzheimer's disease. *Brain* 1992; 115: 1061–71.
- Patterson K, Hodges JR. Semantic dementia: one window on the structure and organisation of semantic memory. In: Cermak L, editor. *Revised handbook of neuropsychology: memory disorders*. Amsterdam: Elsevier; 2000. p. 289–309.
- Raven JC. *Coloured Progressive Matrices, Sets A, AB, B*. London: H.K. Lewis; 1962.
- Raven JC. *Advanced Progressive Matrices Sets I & II*. London: H.K. Lewis; 1965.
- Schwartz MF, Marin OS, Saffran EM. Dissociations of language function in dementia: a case study. *Brain Lang* 1979; 7: 277–306.
- Sirigu A, Duhamel J, Poncet M. The role of sensorimotor experience in object recognition: a case of multimodal agnosia. *Brain* 1991; 114: 2555–73.
- Snodgrass JG, Vanderwart M. A standardized set of 260 pictures: norms for name agreement, image agreement, familiarity, and visual complexity. *J Exp Psychol [Hum Learn]* 1980; 6: 174–215.
- Snowden JS, Goulding PJ, Neary D. Semantic dementia: a form of circumscribed cerebral atrophy. *Behav Neurol* 1989; 2: 167–82.
- Snowden JS, Griffiths H, Neary D. Semantic dementia: autobiographical contribution to preservation of meaning. *Cogn Neuropsychol* 1994; 11: 265–88.
- Snowden JS, Griffiths HL, Neary D. Autobiographical experience and word meaning. *Memory* 1995; 3: 225–46.
- Snowden JS, Griffiths HL, Neary D. Semantic-episodic memory interactions in semantic dementia: implications for retrograde memory function. *Cogn Neuropsychol* 1996a; 13: 1101–37.
- Snowden JS, Neary D, Mann DMA. *Fronto-temporal lobar degeneration: fronto-temporal dementia, progressive aphasia, semantic dementia*. New York: Churchill Livingstone; 1996b.
- Tulving E. Episodic and semantic memory. In: Tulving E, Donaldson W, editors. *Organization of memory*. New York: Academic Press; 1972. p. 381–403.
- Warrington EK. The selective impairment of semantic memory. *Q J Exp Psychol* 1975; 27: 635–57.
- Warrington EK, James M. *Visual Object and Space Perception Battery*. Bury St Edmunds (UK): Thames Valley Test Company; 1991.
- Wechsler DA. *Wechsler Adult Intelligence Scale–Revised*. Test Manual. New York: Psychological Corporation; 1981.

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