# Neurocase

## A Semantic Subsystem of Visual Attributes

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# A Semantic Subsystem of Visual Attributes

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## Abstract

We propose that the many different forms of selective semantic impairment that have been reported over the past 20 years may be classified into three general classes: semantic-category selective, modality-of-input selective, and semantic-attribute selective. Particular patients may exhibit more than one form of selectivity, i.e. there can be doubly and perhaps even triply selective semantic impairments. We then describe a patient with a singly selective semantic impairment of a form not previously described: he was unable to access visual semantic attributes in semantic memory, whereas he could access semantic attributes relevant to other sensory modalities, and could also access non-perceptual semantic attributes. This pattern of results was independent both of modality of input and of semantic category of probed item. We infer from these data the existence of a semantic subsystem specific to the storage of information about visual attributes of animate and inanimate objects. An ERP study of semantic processing in normal subjects provided further evidence in support of this claim about a particular component of semantic memory. We conclude by proposing that semantic memory is organized into subsystems of perceptual-attribute knowledge, one subsystem for each of the different perceptual modalities, plus a subsystem in which non-perceptual knowledge is represented. That subsystem is in turn categorically organized into semantic categories such as 'animate'.

## Introduction

Semantic memory (Tulving, 1972) is our store of knowledge about the meanings of words and objects, 'our whole-word knowledge, including what we know about robins, what to do in a restaurant, and the history of the Civil War' (Kintsch, 1980). Access to representations in semantic memory is needed for the performance of a wide variety of tasks: matching written or spoken words to pictures, producing names in response to definitions, producing definitions in response to names, synonym judgement, semantic attribute verification, and many others. Cognitive–neuropsychological research has revealed that brain injury or pathology can specifically degrade semantic memory whilst leaving intact domains of language such as phonology, orthography, syntax and morphology; for example, Schwartz *et al.* (1979) described a patient with a progressive brain pathology who, at a stage where she was profoundly impaired on the kinds of semantic tasks listed above, could still read aloud very well, although, of course, without comprehension. Other aspects of memory can also be intact in the presence of a semantic memory impairment: for example, De Renzi *et al.* (1987) described a patient with preserved procedural, episodic and autobiographical memory who was severely impaired on all tasks tapping semantic memory.

Most patients with semantic memory impairment have a general impairment affecting all aspects of semantic memory. Some, however, have a selective impairment; only some aspects of semantic memory are impaired. The first study of a selective impairment of semantic memory was that of Warrington (1975). She described a patient with a progressive cerebral atrophy, later verified as Pick's disease, whose difficulties in word comprehension were far worse for concrete words than for abstract words. For example, he could correctly define 'arbiter', 'supplication' and 'satirical', but not 'needle', 'acorn' or 'poster'. The reverse dissociation—poorer comprehension of abstract words than concrete words—has also been reported. This double dissociation between abstract-word comprehension and concrete-word comprehension obviously has implications for attempts to build theoretical models of semantic memory. More generally, any demonstrations of any kind of selective impairment of semantic memory will have such implications. That is one reason for the great interest in these selective impairments shown by cognitive neuropsychologists in recent years.

This interest has led to a voluminous literature documenting various patterns of selective semantic impairment. It has not, however, led to any agreement concerning what

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these patterns of impairment tell us about the nature of semantic memory. In our view, what will be helpful for attempts in the future to link data with theory in this domain is to appreciate that the many different recorded patterns of selective semantic impairment can be seen as belonging to one or other of three different classes of selective impairment. These classes are:
category-specific selective semantic impairments;
input-modality-specific selective semantic impairments; and attribute-specific selective semantic impairments.

## Classes of selective semantic impairments

In this section of our paper we discuss patients exhibiting each of these different classes of selective semantic impairment. Note that when we are discussing a patient under the heading, for example, of 'attribute-specific selective semantic impairments', we do not imply that the patient did not show some other form of selectivity too: some patients show more than one type of selectivity.

### Category-specific semantic impairments

We have already discussed one example of this class of selective semantic impairment: impairment related to the categorical distinction between abstract and concrete words. Some patients are impaired for only one of these semantic categories, some only for the other. Another semantic–categorical distinction which has yielded selectivity is the animate versus inanimate distinction. When semantic tasks using both animate and inanimate concepts are applied, some patients are much worse when the stimuli refer to animate concepts whilst others are much worse when the stimuli refer to inanimate concepts (for review, see Saffran and Schwartz, 1994).

Although the various patients referred to in the paragraph above had a variety of different kinds of selective semantic impairment, their patterns of impairment and preservation belong to just a single class, since all were defined in relation to specific semantic categories. So we will refer to this class of selective semantic impairment as semantic-category specific, or category-specific for short. Note that here by 'category', we are referring expressly to semantic categories. Of course, since the semantic category 'semantic category' is far from well defined, there is scope for ambiguity and even circularity here. Is, for example, 'things smaller than a telephone book' to be admitted as a semantic category?

### Input-modality specific semantic impairments

There are reports of patients whose ability to perform semantic tasks depended upon the modality of stimulus input: typically, pictures or seen objects versus (spoken or written) words. For example, McCarthy and Warrington (1988) described a patient whose ability to provide

semantic information about animals was very good when the animal was presented as a picture, but very poor when it was presented as a spoken word (as discussed below, this difference was not present with inanimate objects). For example, his response to a picture of a dolphin was 'Lives in water. They were trained to jump up and come out. In America during the war they started to get this particular animal to go through to look into ships'. His response to the spoken word 'dolphin' was 'A fish or a bird'.

We will refer to this class of selective semantic impairment as input-modality specific, or modality-specific for short. Note that here by 'modality' we are referring expressly to input modality (and not, for example, to the sensory modality of the semantic information that a task is tapping).

### Attribute-specific semantic impairments

Silveri and Gainotti (1988) and Gainotti and Silveri (1996) developed a naming-to-definition task in which the definitions were of two types. There were visually-based definitions ('A black-and-white striped horse'; 'An insect with broad, coloured, ornate wings'), and there were non-perceptual definitions ('The King of the Jungle'; 'An industrious insect that produces honey'). Their semantically impaired patient, who had suffered from a herpes simplex infection, was much better at giving the correct animal name with the non-perceptual definitions than with the visually based definitions (as discussed below, this difference was not present with inanimate objects). Silveri and Gainotti concluded from this that what had been lost was specifically visual information about animals, with preservation of non-perceptual information. Here the selectivity is related to the type of semantic attribute being probed. Questions about visual attributes caused difficulty; questions about non-perceptual attributes did not. Hence we will refer to this class of selective semantic impairment as attribute-specific.

We emphasize here the genuine distinction between attribute specificity and category specificity. One could of course regard 'having legs' either as an attribute or as a category, but the consequences for semantic impairment would be different. If it were an attribute-specific impairment, then the patient would be poor at the particular judgement 'Does it have legs?' for all kinds of objects. If it were a category-specific impairment, the patient would be poor at all kinds of judgements about objects which belong to that particular category.

### Singly, doubly and triply selective semantic impairments

Consider now a patient about whom one wants to say that there is a category-specific semantic impairment specifically affecting the semantic category of animate concepts. If the impairment is solely category specific, then it should not

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depend upon input modality, nor upon type of attribute being probed. So this patient should be poor at providing information about animals for all input modalities (pictures, spoken words, printed words); and he should also be poor at providing for animals information about all types of semantic attributes ('Does it have legs?' 'Is it dangerous?' 'Does it have a characteristic call?' 'Is it found in Australia?' 'Is it edible?'). When only one type of selectivity is present—in this example, category specificity in the absence of modality-specificity or attribute-specificity—is documented, we will refer to this as 'single selectivity'.

Does single selectivity occur in patients with selective semantic impairments? To determine this, one must study the effects of input modality, attribute type and semantic category systematically. Not all studies of selective semantic impairments have done this systematically, but some have: for example, Caramazza and Shelton (1998). Their patient EW was selectively impaired with the semantic category of animals. The patient showed no modality specificity (performance with animals was poor when the input was printed words and also when it was the sound characteristically made by the animal, which EW had to recognize). Nor was there selectivity by attribute type: visual and non-perceptual knowledge about animals were equally impaired. Hence the selectivity was single.

In other patients with selective semantic impairment, at least a double selectivity is clearly present. For example, Basso et al. (1988) studied a patient with the progressive syndrome now known as 'semantic dementia' (Snowden et al., 1989; Hodges et al., 1992). The patient showed a clear category specificity, with animate concepts impaired (35% correct on picture–word matching) and inanimate concepts preserved (95–100% correct on picture–word matching). However, when different kinds of semantic attribute were probed (in response to spoken names), this patient was much worse when visual attributes were probed than when non-perceptual attributes were probed. So, for example, with the word 'camel', the patient might be asked 'Does it live in Italy or not?' (non-perceptual attribute probe) or 'Does it have a smooth back or is it humpbacked?' (visual attribute probe). The patient scored 83% with non-perceptual probes but was at chance (50%) with visual probes. Thus this patient's ability to carry out semantic tasks in response to spoken names was influenced by two things: the semantic category of the stimulus item and the type of semantic attribute being probed. Hence, there were at least two types of selectivity influential here: category specificity and attribute specificity. Similarly, Gainotti and Silveri (1996) claimed that their patient's better performance in providing non-perceptual semantic information, relative to visual semantic information, occurred only with animate objects; performance with inanimate objects was no different for the two types of semantic attributes.

Double selectivity was also revealed in the performance of the patient studied by McCarthy and Warrington (1988), to whom we have already referred above. As we mentioned,

this patient was poor at providing semantic information in response to spoken words whilst being good at providing semantic information in response to pictures. But this was true only for animate concepts. When the stimulus referred to an inanimate concept, e.g. 'lighthouse', the patients performed well regardless of input modality. Thus this patient's ability to carry out semantic tasks was influenced by two things: the semantic category of the stimulus item and the modality of input. Hence there were at least two types of selectivity influential here: category specificity and modality specificity.

A fourth example of double selectivity comes from the patient described by Warrington and McCarthy (1994). This patient's auditory comprehension was intact, but his comprehension of pictures was impaired; and this impairment of picture comprehension was significantly worse for one semantic category (manipulable common objects) than for another (animals). The double selectivity here is again one of modality by category; note that the modality effect is in the other direction to that shown by the patient of McCarthy and Warrington (1988).

What about triple selectivity? This has never been reported, but the relevant type of investigation has often not been carried out. For example, if Basso et al. (1988) had probed knowledge of semantic attributes using pictures as stimuli versus using spoken words as stimuli, they might have found that their patient was poor at supplying visual information about animals only for one input modality; that would represent a triple selectivity. Similarly, if McCarthy and Warrington (1988) had probed separately for visual and non-perceptual semantic attributes, they might have found that their patient was poor at providing semantic information about animals in response to pictures only when what was being probed was non-perceptual information; that also would represent a triple selectivity.

Our aim here is not to review the entire literature on selective semantic impairments. That would be far beyond the scope of this paper. Instead, we aim to make a case for the idea that such impairments can be classified into three general classes, and that there is evidence that examples of each of these classes have actually been observed. If we are correct, then this classificatory framework may be a useful guide in future research on semantic impairment—and may even help us achieve some success in linking data from semantically impaired patients to theories about the nature of semantic memory.

In the rest of this paper, we focus on just one class of semantic-memory impairment: attribute-specific impairment. This is the least studied of the three classes. To the best of our knowledge, there have been only six previous studies of the particular topic with which we are concerned. That topic is the selective impairment of semantic information about visual attributes with preservation of semantic information about non-perceptual attributes.

Studies of this topic have been impeded by the use of the term 'visual semantics'. As various authors, from Riddoch

*et al.* (1988, pp. 4–7) to Caramazza and Shelton (1998), have pointed out, it has not been apparent to many working in the area of semantic impairment that different authors have used this term in quite different ways. For Warrington and colleagues, 'visual semantics' means the store of semantic knowledge that is accessed from vision (i.e. from seen objects and pictures); see, e.g. Warrington and McCarthy (1994, pp. 1466 and 1472). For others (e.g. Farah *et al.*, 1989), 'visual semantics' means that part of semantic memory in which knowledge of visual attributes is held. So, for example, the phrase 'selective impairment of visual semantics' refers to a modality-specific impairment if the first sense of the term 'visual semantics' is being used, but refers to an attribute-specific impairment if the second sense of this term is being used. This kind of confusion can be seen, for example, in Farah and McClelland (1991, p. 339); 'semantic memory could be subdivided by modality of knowledge, such that one component is responsible for visual information about objects . . . the losses appear to be tied to specific modalities, resulting in impaired recognition of objects in just one modality'. Here the term 'modality' is first used to refer to type of semantic attribute, and then used to refer to channel of sensory input.

To avoid such potential for confusion, we will avoid using the term 'visual semantics' altogether.

Another terminological distinction that is potentially confusing is 'perceptual' versus 'conceptual' semantics (see, e.g. Flores d'Arcais and Schreuder, 1987). We originally used this terminology ourselves, but the problem with it is that it conflicts with the terminology of the distinction between 'lexical semantics' and 'conceptual semantics' (see, e.g. Bierwisch and Schreuder, 1992). 'Conceptual semantics' when used in the latter sense includes, rather than is contrasted with, 'perceptual semantics' used in the former sense (see Schreuder and d'Arcais, 1989, p. 424). We have therefore adopted the terminology 'non-perceptual semantics' (to refer to semantic information that does not describe any perceptual properties of the object in question) and 'perceptual semantics' (within which one can if necessary make subdistinctions based on particular perceptual modalities: visual semantic information, auditory semantic information, etc.)

## Dissociation between knowledge of visual attributes and knowledge of non-perceptual attributes in patients with semantic impairment

We have already briefly referred to some of the previous studies of this dissociation. We will now consider all of them in some detail, since they are directly relevant to our own study. We should also point out that Caramazza and Shelton (1998) have made a number of criticisms of the claims of selective impairment of visual attributes in these cases, particularly noting the frequent failure to match visual and non-perceptual attribute tasks on relative difficulty.

## Michelangelo (Sartori and Job, 1988; Sartori et al., 1993, 1994)

This patient had suffered from a herpes simplex infection. With animals, he was worse at providing visual semantic information than non-perceptual semantic information; this was not the case for inanimate objects. His drawing to dictation was adequate for inanimate objects but very poor for animals. In an object decision task (distinguishing between drawings of real animals or objects and drawings of possible but non-existent animals or objects), he performed well for inanimate objects but was impaired for animals.

## Basso et al. (1988)

Ten-alternative picture–word matching tasks were administered to this patient (who was suffering from a semantic dementia). Comprehension was good for inanimate objects (19/20), means of transport (20/20) and body parts, but bad for animals (7/20), fruits and vegetables (7/20) and musical instruments (10/20). This alignment of musical instruments with the animate category and body parts with the inanimate category is of course commonly found in studies of selective semantic impairment.

Then the 38 items with which he had failed in this picture-word matching task (36 of which were animals, fruits, vegetables or musical instruments) were used in subsequent forced-choice comprehension tests. The two that are relevant here is a test for knowledge of non-perceptual attributes (Basso *et al.* refer to these as functional attributes, and give as an example probe 'Does it live in Italy or in the desert?') and knowledge of perceptual attributes (example: 'Does it have a smooth back or is it humpbacked?') Performance was good with non-perceptual attributes (25/29 correct) but at chance with perceptual attributes (10/20 correct).

Basso *et al.* do not indicate whether all the perceptual attributes they used were visual, or whether some had to do with other perceptual channels; so one cannot distinguish here between a loss of visual attributes and a more general loss of all kinds of perceptual attribute. However, the patient was also impaired at matching environmental sounds to pictures (11/20 correct; controls 18.8/20 correct).

## Silveri and Gainotti (1988) and Gainotti and Silveri (1996)

This patient, LA, had suffered a herpes simplex infection. She was relatively poor at naming pictures of animals, fruits, flowers, vegetables, food and musical instruments, and almost normal at naming pictures of inanimate objects and body parts.

The authors created two types of definition (stressing perceptual attributes versus stressing functional properties) for two types of item (animals and inanimate objects).

These definitions were used in two tasks: (a) naming to definition and (b) sentence verification. With functional properties, LA was worse on both tasks with animals than with inanimate objects, but in neither case was this effect significant. With perceptual definitions, she was significantly worse with animals than with inanimate objects on both tasks.

She was also worse with animals than with inanimate objects on other perceptual tasks, such as (a) hearing the names of two objects of similar shape and describing in what ways their shapes differed; (b) giving the colour of a named object; (c) classifying coloured drawings as appropriately or inappropriately coloured.

Although she was impaired at recognizing environmental sounds, there was no category-specificity here, i.e. no difference between animals and inanimate objects.

## Farah et al. (1989)

This patient, who had suffered a head injury, was given a forced-choice comprehension test in which semantic category of item (living versus non-living ) and type of semantic attribute (visual versus non-visual) were orthogonally varied. The patient was only worse than a normal control group when asked about visual attributes of living things.

## Hart and Gordon (1992)

This patient, with diffuse mild brain inflammation attributable to a paraneoplastic syndrome, was asked questions about various animate and inanimate items. The questions concerned visual properties or non-perceptual properties. She performed flawlessly when the items were inanimate objects, fruits, vegetables or vehicles. When the items were the names of animals, she was almost perfect at the non-perceptual questions (Land/air/sea?; Woods/farm/jungle?; Edible?; Pet?) but made many errors when the questions probed perceptual attributes (What colour? Four legs or not? Size?). This is the pattern shown by the patient of Farah *et al.* (1989).

Unsurprisingly, the patient was also poor at spoken or written naming of animals. He was also poor at naming animals in response to characteristic non-verbal sounds (such as a dog's bark) but could perform this task for inanimate objects; and it is particularly surprising that he could name the parts of animals (even though he was poor at naming the animals themselves), could match heads to bodies, could point to animal parts on command, and could sort line drawings of animals into those correctly coloured and those wrongly coloured.

## De Renzi and Lucchelli (1994)

This patient had suffered a herpes simplex infection. Her naming of inanimate objects was within normal limits, but she was poor at naming fruits and vegetables, and particu-

larly poor at naming animals. Her definitions of animals lacked visual detail, which was not the case for her definitions of inanimate objects. She was impaired at matching environmental sounds to pictures, but equally so with animate and inanimate items.

In a task requiring her to say how two objects (presented as spoken names) differed visually, she was in the normal range for inanimate objects but poor with fruits and vegetables and very poor with animals. The same was true for the object decision task, for giving the typical colours of objects (except here she was worse than normals with inanimate objects), and for drawing to dictation. Her knowledge of non-perceptual (functional/encyclopaedic) properties of animals was much better than her knowledge of visual properties.

It is striking that in all six of these patients, that is, in every patient so far studied with an attribute-specific selective semantic impairment affecting semantic knowledge of visual attributes, there is also a category-specific selective semantic impairment affecting the category of animals. What might this mean? It is not to do with aetiology because, although three of these patients had the same aetiology (herpes simplex infection), the other three had quite different aetiologies: a progressive brain atrophy, a head injury, and a cerebral inflammation.

. One account is that offered by Farah and McClelland (1991), who argued that animal concepts depend strongly upon visual attributes, and inanimate concepts depend strongly upon functional (non-perceptual) attributes, so that selective damage to visual attributes will always cause selective difficulty for knowledge about animals relative to knowledge about inanimate objects. Indeed, they argued that the apparent category-specificity here is artefactual, being due to the association between type of attribute that is important and semantic category.

On the other hand, of course, cognitive neuropsychological orthodoxy counsels us not to devote much time to thinking about what this association of symptoms might mean, since it is a mere association. It may be telling us nothing about the functional organization of semantic memory, having arisen instead because of an accident of brain geography that has no functional consequences.

In this paper, we report two studies aimed at learning more about how visual and non-perceptual forms of information are represented in semantic memory. The first is a case study of a patient with a semantic memory impairment. The second is an event-related potential (ERP) study of brain activations occurring during the performance of semantic tasks by intact subjects.

## Case study

## Case report

AC, a 67-year-old right-handed clerk, presented in September 1987 with a left-hemisphere stroke affecting

predominately his language abilities but also causing ideational apraxia, minor right-sided limb weakness and a right homonymous hemianopia. Speech pathology assessment showed a moderately severe fluent aphasia with word-finding difficulties, semantic and phonemic paraphasic errors, impaired comprehension, alexia and agraphia. A CT scan performed 4 days after admission to hospital revealed an area of low attenuation compatible with a recent infarct in the territory of the left middle cerebral artery and patchy lacunar lesions and deep white matter ischaemic changes (leucoaryosis) throughout the hemispheres.

There was a long past history of cardio- and cerebrovascular disease. He had suffered from rheumatic fever as a child and was subsequently noted to have a cardiac murmur. Hypertension was diagnosed in 1966. In 1978 he was hospitalized for the first time following a single episode of short-lived amnesia presumed to be of cerebrovascular aetiology on the basis that it followed a 2 year history of recurrent episodes with features suggestive of vertebro–basilar transient ischaemic attacks (TIAs) namely ataxia, dysarthria and vertigo. Warfarin therapy was instigated at this time. He then remained well until 1981 when he was re-admitted with a 4 day history of slurred speech, ataxia, dysgraphia and mild word-finding difficulty. A minor completed stoke was diagnosed. Cardiological investigations failed to reveal a source of cerebral emboli. Aspirin was added to his drug regime.

Between 1981 and 1987 he had numerous further brief TIAs involving both the vertebro–basilar and left middle cerebral artery territories. CT scans in 1985 and 1986 revealed small lacunar infarcts in the region of the right lateral ventricle and right caudate nucleus plus generalized periventricular white matter changes compatible with long-standing hypertension. In 1985 he was noted to have a poor memory and underwent formal neuropsychological assessment and in March 1986 he had a generalized seizure following which he was commenced on phenytoin therapy. There were, however, no fixed neurological deficits until the stroke in 1987.

Our studies of AC were carried out in 1988–89 and first reported by Coltheart (1990, unpublished data).

## Preliminary general cognitive assessment

AC exhibited a variety of severe cognitive impairments.

### Reading

AC scored 0/20 on reading aloud common short (one to four letters) words. He could not comprehend single printed words, nor carry out cross-case matching or cross-case copying tasks. The problem here was not a low-level visual problem, since he could report the number of letters in the words he could not read, and he could copy letters if not required to change their case.
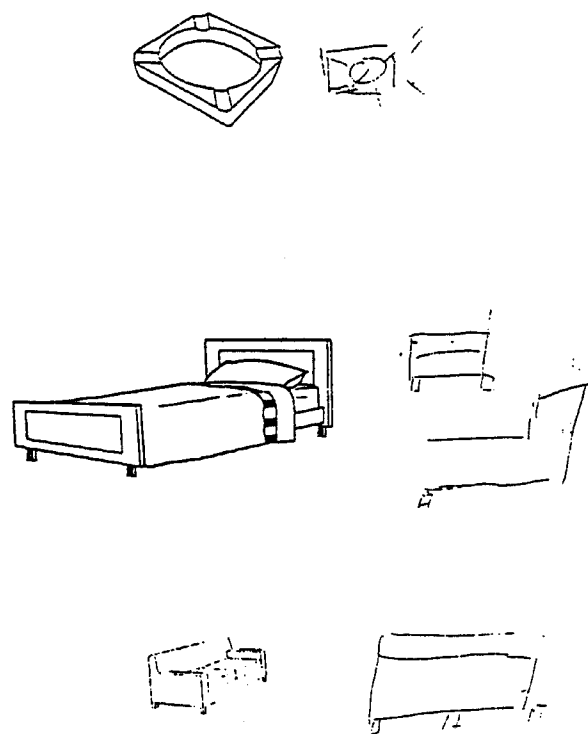


Fig. 1. Examples of AC's copying.

### Writing

AC could write no words to dictation except his name and address. He scored 12/21 in writing single letters to dictation.

### Naming

AC was profoundly anomic in picture-naming and in conversation, so anomic that picture-naming data (e.g. naming animate versus inanimate objects) could not be collected.

### Copying picture and designs

This was very poor, as the examples of AC's copying in Fig. 1 show. Features were disorganized, e.g. chair legs not joined to chair.

### Drawing to dictation

Results similar to copying.

### Gesturing object use

This was impaired, equally so when the stimulus was a black-and-white drawing of an object or a spoken verb. However, he scored 10/11 correct in obeying commands to gesture, such as 'Show me how you wave goodbye'.

## Main investigations

*1. Yes/No comprehensions of single spoken words*

In all the tests described in this section, the input to AC on each trial was a single spoken object name, and the output

required of him was simply the spoken response 'Yes' or the spoken response 'No'. Each test probed a specific single semantic attribute, and AC's task was to say whether or not the object named to him possessed that attribute or not; the percentage of items in each test for which the correct answer was 'Yes' was always exactly 50%.

We began by studying his ability to report whether animals had legs or not. Twenty common animals were chosen, 10 of which had legs (e.g. elephant, zebra) and 10 which did not (e.g. worm, whale), and presented to him as spoken names. Asked which of these have legs, AC scored 11/20. On two subsequent occasions with the same items he scored 12/20 and 10/20. Thus he was completely unable to make this judgement, his performance not differing significantly from chance on all three occasions.

Given that all patients previously reported as having an impairment in accessing information about visual attributes were only poor at this for animate objects, we next investigated AC's ability to make exactly the same judgement—does it have legs?—about inanimate objects. Twenty common inanimate objects were chosen, 10 possessing legs (e.g. table, chair) and 10 not (e.g. pencil, cup). When these were presented to him as spoken names, his performance was once again not significantly different from chance: his scores on three occasions were 9/20, 11/20 and 10/20 . Therefore his semantic impairment was not specific to the category of animals. Nor was it specific to the visual feature legs: AC also was at chance on 'does it have wheels?' (bicycle, ferry, ice skates, roller skates, etc: 15/28 and 11/24 correct with two versions of this test) and on 'does it have a tail?' (crab, elephant, lizard, etc.: 12/22 and 9/14 correct with two versions of this test). In these and other tests where AC did not perform better than chance, he most commonly produced approximately equal numbers of YES and NO responses; in a few tests he showed a strong bias towards responding NO.

Is the difficulty to do with specific shape features of objects, or does it also affect more holistic visual attributes? Clearly the latter, since AC also was at chance on 'is it round?' (bubble, needle, knife, pea, etc.: 18/28 and 13/28 correct on two occasions) and on 'is it coloured or not?' (frog, parrot, panda, crow, etc.: 15/28 correct).

Thus AC was completely unable to retrieve from his semantic memory information about a wide variety of perceptual attributes: legs, wheels, tail, shape and colour.

Was his deficit specific to perceptual knowledge? We first investigated this by probing his knowledge of non-perceptual attributes of animals. Twenty common animals were chosen; 10 were dangerous animals (e.g. snake, lion) and 10 were non-dangerous animals (e.g. oyster, canary). Most of these animals had been used in the test probing knowledge about legs. When these were presented as spoken names and AC was asked 'Is it dangerous or not?', he performed very well, scoring 18/20 correct, indicating that non-perceptual semantic knowledge was spared, at least as far as this particular non-perceptual attribute is

concerned. To establish the generality of this result we probed a variety of other non-perceptual attributes in the same way: 'is it Australian?' (lion, kangaroo, koala, elephant, etc.: 20/22 correct); 'do people usually eat it?' (oyster, elephant, asparagus, eagle, etc.: 20/22, 26/28, 16/18, 20/22 and 20/26 correct on various versions of this test); 'does it live in water?' (oyster, elephant, snake, frog etc.: 18/20 correct). With another set of animals he scored 27/30 on 'Is it a water creature ?' and on the same day with the same set of animal names scored 15/30 correct (chance) on 'Does it have legs?'.

Thus AC was consistently good at dealing with these various non-perceptual semantic attributes.

Was his impairment one affecting all types of perceptual knowledge, or just visual knowledge? This was determined by probing his knowledge of attributes that are perceptual but not visual. We investigated his knowledge of olfactory semantic attributes by choosing 26 common objects, 13 of which have characteristic smells (e.g. coffee, petrol) and 13 of which do not (e.g. lettuce, cloud). He performed well when presented with the spoken names of these objects and asked to judge which of these objects had a smell and which did not: 24/26 correct. And we investigated his knowledge of auditory semantic attributes by choosing 24 common objects, 12 of which make characteristic noises (e.g. bell, flute) and 12 of which do not (e.g. star, tie). Again, he performed well when presented with the spoken names of these objects and asked to judge which of these objects made noises and which did not: 21/24 correct.

His good performance on these two tasks showed that his attribute-specific semantic deficit was specific to visual semantic attributes, rather than being a more general deficit of all kinds of perceptual attributes. These results also indicate that his problem did not depend on any confounding between how superordinate an attribute is and what type of attribute it is, since clearly these auditory and olfactory attributes are equal in superordinateness to the visual attributes with which he performed so poorly.

Having established that his deficit was attribute specific but not category specific, we then investigated whether it was modality specific; in his case, was it specific to tasks where the stimuli were words? We presented AC with recordings of 46 environmental sounds (e.g. train, bird, alarm clock) and asked an appropriate visual-attribute question about each one (e.g. legs? or wheels? or wings? or tails?). AC was at chance on this task, scoring 24/46 correct. Therefore his inability to retrieve visual semantic attributes was not modality-specific.

His chance performance here did not reflect an auditory agnosia, because with the same environmental sounds he did very well at choosing which of four pictures matched each sound (20/24 correct; chance would be 6/24).

All of the results reported above are summarized in Table 1, the percentages being averaged across testing occasions when a particular type of test was given more than once. These results show that when the Yes/No task

Table 1. AC's performance on tasks probing perceptual and non-perceptual semantic attributes (chance = 50% in all cases)

| Perceptual semantic information | | Non-perceptual semantic information | |
| --- | --- | --- | --- |
| Visual | | | |
| legs (animals) | 53% | dangerous | 90% |
| legs (inanimate) | 50% | edible | 88% |
| tail | 58% | Australian | 91% |
| wheels | 50% | water-dwelling | 90% |
| shape | 55% | | |
| colour | 54% | | |
| Non-visual | | | |
| smell | 93% | | |
| noise | 88% | | |

required the retrieval of visual semantic information, AC's performance never exceeded chance, ranging from 50 to 58%. In contrast, when the Yes/No task required the retrieval of non-perceptual semantic information, or perceptual but not visual semantic information, AC did very well, his scores ranging from 88 to 93%.

It is important here to realize that a problem of stimulus matching that has bedevilled the study of category-specific semantic impairments does not crop up in our study of attribute-specific impairments. When a patient is worse at naming animals than non-animals, this effect is at least sometimes due to a failure to match the two types of picture on such dimensions as familiarity and complexity (Funnell and Sheridan, 1992; Stewart et al., 1992). In our studies, however, the tasks at which AC was bad and the tasks at which he good used many (sometimes all) targets in common, for example, the target 'shark' can be used in the legs, tail, dangerous and edible tests, and the entire set of targets for which visual knowledge was probed did not differ in word frequency or length from the set for which non-perceptual knowledge was probed. Thus AC's chance performance on the visual tests and very good performance on the non-perceptual tests cannot be an artefact of lack of control in stimulus selection.

Lastly, consider the semantic attribute size. Is this a perceptual attribute or a non-perceptual attribute? One's first reaction might be to classify it as perceptual, but we think this is not so obvious: when one forms as good a visual image as one can of an elephant, that image certainly has legs and a tail, no wheels, is appropriately coloured—but it does not have a size.

We tested AC's ability to make judgements about size by selecting 24 animals, 12 large and 12 small. We avoided any animals that have specifically visual cues to size such as relatively short but thick legs, achieving this by using matched pairs in which one animal was small and the other large and the two were structurally similar to each other (e.g. shark, trout, whale, tadpole, etc.). When AC was presented with the spoken names of these animals and asked to judge which were small and which were large, he performed well: 20/24 correct. He also scored 20/24 correct when asked to classify inanimate objects (presented as

spoken names) into the categories Large and Small. This is consistent with our claim that size is a non-perceptual semantic attribute. Also consistent with our claim is the finding that Michelangelo, a patient with a doubly selective semantic impairment affecting knowledge of visual semantic attributes of animals, could nevertheless judge with 100% accuracy which of two animals (presented as spoken names) was the larger one (Sartori et al., 1993).

We conclude that AC's semantic impairment was a singly selective impairment in which what is affected is a subsystem of semantic memory that is specifically devoted to the representation of visual attributes about objects; and therefore we take our data as providing evidence that the semantic memory system contains such a subsystem.

This conclusion might be challenged on the ground that in AC we have observed just a single dissociation, rather than a double dissociation, and so the usual arguments about the inconclusiveness of single dissociations might be raised. However, these arguments do not apply in our case, because what we have found is a large number of dissociations, not just one: colour versus edibility, legs versus dangerous, wheels versus Australian, etc. To argue that this is really just one dissociation is to say that attributes such as colour, legs and wheels belong together, and are distinct from attributes such as edibility, dangerousness and Australian, which themselves belong together; and that of course is exactly what we wish to claim.

## 2. Performance with pictorial input

The LUVS picture-word matching test (D.V.M. Bishop, unpublished) was carried out with AC. In this test, a single spoken word is presented, along with four or eight pictures. The picture set includes the correct item and distractors that are semantic, visual or unrelated. AC scored 61/80, and making nine unrelated, five semantic/visual, four semantic and one visual errors. His impairment here was not solely due to the use of spoken words as input, since he was also poor at the all-picture version of the Pyramids and Palm trees test (Howard and Patterson, 1992). In this test, three pictures are presented, and the subject is asked to choose which of the two pictures on the lower half of the card (e.g. palm tree, pine tree) goes with the picture on the upper half of the card (here, a pyramid). AC's performance was poor: 32/51 correct (normal range 49–51 correct).

Preliminary versions of Tests 7 (Minimal Feature Test) and 8 (Foreshortened View Test) from the BORB (Riddoch and Humphreys, 1993) were carried out: these tests require matching of a picture of a normally oriented object to a picture of the same object displayed from a different viewpoint. AC scored 85% correct on both tests, which, according to Caramazza and Shelton (1998) is within normal limits.

On a preliminary version of Test 10 of the BORB, an object decision task requiring him to distinguish between drawings of real objects and drawings of imaginary objects he scored 45/60 and 48/60 on separate occasions. Here

occurred the only instance of a dissociation between animals and inanimate objects in any of the tests we gave him: his scores with real and imaginary animals were 19/30 and 20/30, whereas with real and imaginary inanimate objects he scored 26/30 and 28/30.

Normal performance on Test 7 and 8 with impairment on Test 10, at least for animals, we take as evidence that AC could form an adequate visual episodic representation of pictured objects but is impaired at using this to access object representations in a visual structural description system, since Tests 7 and 8 can be performed even with drawings of non-existent (and therefore unrecognizable) objects.

His ability to deal with visual attributes, impaired when presentation was by means of spoken names, was also impaired with pictorial input. When shown pictures of animals half of which were animals with tails and half tail-less animals, with the tails of the tailed animals obscured, he averaged 0.62 over five occasions when asked 'Does it have a tail?'. Even when these items were presented with the tails visible, he was impaired, averaging 0.88 correct over four occasions. With a set of legged and non-legged animals, with the legs visible in the picture, he scored 0.85 correct with the probe 'Does it have legs?' In the same type of test with the probe 'Does it have wheels?', with the wheels always visible, his proportion of correct responses averaged 0.74 across eight testing occasions. His performance in the Visible conditions here is further evidence that AC was impaired at using visual representations to access object representations (for example, the representation of a wheel) in a visual structural description system. This could be an access-procedure problem or a problem of degradation of the representations in that system.

These difficulties with pictures remained even when the probe for a visual attribute did not refer to a part of the object, but instead to its colour. When asked to match a black-and-white drawing of a characteristically coloured object to one of four colour patches, he was at chance (3/15 correct). He was also at chance (6/20 correct) when given the spoken name of a characteristically coloured object and asked to choose one of four colour patches to match that name. And when asked to sort coloured photographs into those where the object was correctly coloured and those where it was not, he was very impaired (13/22 and 14/22 on two occasions). He was not colour-blind.

### Summary of results obtained with AC

This patient had preserved knowledge of non-visual attributes of objects, both perceptual attributes that are not visual (smell, noise) and also non-perceptual attributes (dangerousness, edibility, Australian/not Australian and habitat). In contrast, he performed very poorly when visual attributes (legs, wheels, tails, shape or colour) were probed, regardless of whether the input was spoken or pictorial.

With pictures, he was even impaired when the relevant feature was visible in the picture itself.

His impairment on picture–word matching and on picture–picture associative matching also indicated some degree of visual agnosia, although note that he was well above chance on picture-word matching (0.76 correct; chance 0.19) and on matching pictures to sounds, as reported earlier (0.83 correct, chance 0.25).

## Experimental study

### Introduction

As described above, our patient AC was very good at accessing non-perceptual semantic information about concrete objects, whilst being completely unable to access visual semantic information about such objects. We have taken this as evidence that there are functionally and neuroanatomically distinct semantic subsystems for the representation of visual and non-perceptual attributes of concrete objects.

We sought converging evidence for this conclusion from an electrophysiological study of intact subjects performing a task which required the verification of a variety of visual or non-perceptual properties of concrete objects. Our aim was to determine whether the two types of attribute verification would yield different patterns of neural response in the brain, as indexed by event-related potentials (ERPs). Any such differences would support the view about the structure of semantic memory to which we have been led by the studies carried out with AC. The ERP component of most relevance is the N400, a negative component which onsets at ~200 ms and peaks at ~400 ms after stimulus onset. N400 is sensitive to the structural aspects of semantic memory (Kounios and Holcomb, 1992) and in particular, an examination of N400 scalp topographies to words has been successfully employed in the past to demonstrate that abstract and concrete words are associated with different neural systems (Kounios and Holcomb, 1994). The same strategy will be employed in the current investigation to determine whether visual and non-perceptual attributes have distinct neuroanatomical substrates.

### Materials and methods

#### Stimuli

The stimuli were 300 pairs of upper-case words consisting of a probe (e.g. LEGS?) followed by a target (e.g. LAMB or TABLE. WORM or CARPET). There were 10 different probes presented 30 times. Five of these required access to visual information: TAIL?, ROUND?, WHEEL?, LEGS?, WINGS? and five to non-perceptual information: EDIBLE?, WATER?, DANGEROUS?, SIZE?, AUSTRALIAN?. All of these probes were ones we had used with AC. There were no repeated items amongst the targets. Half of the targets following the 30 presentations of
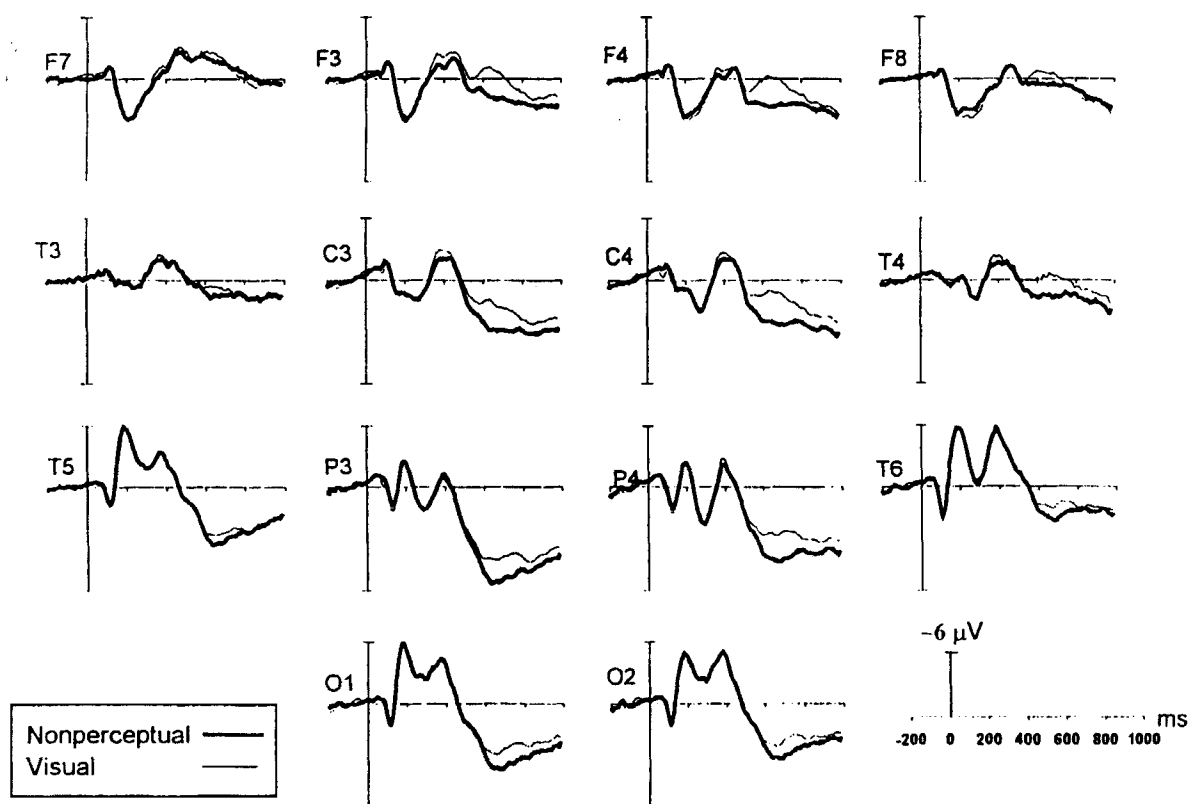
## Target ERPs



**Fig. 2.** ERPs to target stimuli in the visual and non-perceptual conditions.

each probe word required an affirmative (TRUE) response and the remainder a negative (FALSE) response. The 300 probe–target pairs were presented in a randomized order. Probes and targets were presented for 200 ms with an interstimulus interval of 1800 ms. The interpair interval was also 1800 ms.

The 150 targets in the visual condition did not differ significantly from the 150 targets in the non-perceptual condition in written or spoken word frequency (Baayen *et al.*, 1993) or number of letters.

*Subjects*

The subjects were 12 undergraduate students from Macquarie University, who served for course credit.

*Procedure*

Subjects viewed the words on a computer monitor from a distance of 1 m. They were instructed to verify whether the probe attribute applied to the target item by responding with an affirmative (true) or negative (false) response by pressing one of two buttons. Half the subjects used their left hand for affirmative responses and half used their right.

*Electrophysiological recording*

The electroencephalogram (EEG) was recorded over seven left hemisphere and right hemisphere sites (F3, F4, F7, F8, C3, C4, T3, T4, F5, T6, P3, P4, O1, O2) using an electrode cap (Electro-Cap International, Eaton, OH, USA). Each site was referenced to linked ear lobes. The electro-oculogram (EOG) was monitored via electrodes placed on the infraorbital ridge and the external canthus of the right eye. The EEG and EOG channels were amplified using a Grass Neurodata (Astro-Med Inc., West Warwick, RI, USA) (Model 12) system (bandpass 0.01–30 Hz, amplification 20 000) and continuously digitized at 200 Hz for the duration of the run. The continuous record was subsequently segmented into 1200 ms epochs beginning 200 ms before stimulus onset. Any epoch showing EOG activity > 64 μV was excluded.

*Results*

Figures 2 and 3 reveal differences in the neural processing of both target and probe words (summed over true and false items) as a function of whether processing of visual or non-perceptual attributes was required. As these effects were not restricted to particular ERP components, mean
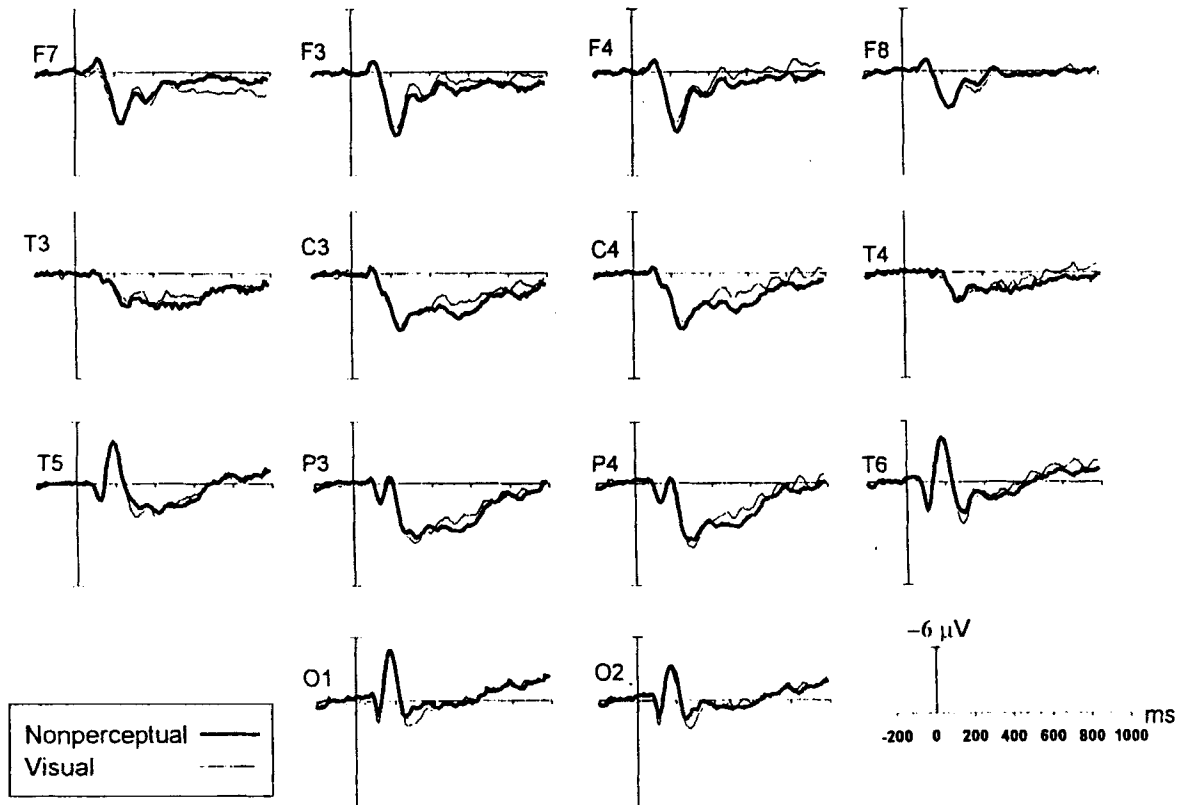
## Probe ERPs



Fig. 3. ERPs to probe stimuli in the visual and non-perceptual conditions.

amplitudes over successive 50 ms intervals starting at 50 ms post-stimulus were measured. Separate analyses of ERPs at medial lateral sites (F3/F4, C3/C4, P3/P4, O1/O2) and outer lateral sites (F7/F8, T3/T4, T5/T6) were carried out.

*Electrophysiological effects of attribute type*

The aim of this experiment was to discover whether there were any differences in the ERPs generated by the target items as a function of whether visual or non-perceptual semantic information about the target item was being retrieved. Furthermore, in order to argue that distinct neural systems are responsible for any such ERP differences, we need to demonstrate that the effects of semantic attribute type can be distinguished on the basis of their scalp topography. Hence we were particularly looking for evidence of interactions between attribute type and site or hemisphere. Such interactions do not allow us to infer the location of the putative separate neural systems, but do allow the claim that different neural generators contribute to the scalp potentials in the two attribute-type conditions..

This turned out to be so. There was a small early separation between target ERPs with visual information being retrieved and target ERPs with non-perceptual being retrieved. ERPs were more negative for the non-perceptual

task than for the visual task. This early separation started at 200 ms after target onset and persisted until 400 ms, at outer lateral sites; and it was primarily restricted to the right frontal lateral site, F8, as can be seen in Fig. 2 [attribute × hemisphere × site interaction: $F(2,22)$ range 4.40–4.91, $P$-value 0.035–0.029].

At the more medial anterior sites (F3/F4, C3/C4), a separation of opposite polarity emerged later, at 300 ms, and persisted until 400 ms. This later effect of attribute type was larger over the left hemisphere [attribute × hemisphere × site interaction: $F(3,33)$ range 3.27–3.91, $P$-value range 0.033–0.027]. Although this effect overlaps the N400 component of target ERPs, it does not have an N400 distribution, being largest over left anterior sites as opposed to the typical right posterior distribution of N400.

A third more substantial and longer duration separation was evident over all medial lateral sites from 600–800 ms after target onset [attribute main effect: $F(1,11)$ range 5.09–9.07, $P$-value 0.045–0.012]. This separation was larger over anterior sites than other sites during its onset [attribute × site interaction over 550–650 ms: $F(3,33) = 4.83$, $P < 0.019$]. While these effects overlap the latency range of the parietally distributed P600, the scalp topography of the separation between visual and non-perceptual ERPs suggests that

**Table 2.** Mean reaction time in ms (upper entry) and mean response accuracy (lower entry), with standard deviations in parentheses, for true and false statements requiring visual and non-perceptual knowledge

|  | Visual | Non-perceptual |
|---|---|---|
| True | 912.4 (139.0) | 859.9 (107.4) |
|  | 82.0 (18.0) | 88.3 (12.0) |
| False | 1006.6 (126.0) | 950.8 (137.0) |
|  | 78.7 (13.3) | 82.7 (14.7) |
| Overall | 959.5 (132.5) | 905.4 (115.3) |
|  | 80.4 (15.7) | 85.5 (13.4) |

attribute type does not have a direct effect on P600, but rather on a component with a more anterior distribution.

It is clear, then, that the two attribute conditions did generate clear ERP differences, at various latencies and at various electrode sites.

*Behavioural effects of attribute type*

Subjects found the attribute verification task more difficult for visual than for non-perceptual information, reflected in longer reaction times [subject analysis: $F(1,11) = 14.10$, $P < 0.004$; item analysis: $F(1,296) = 42.5$, $P < 0.001$] and reduced accuracy [subject analysis: $F(1,11) = 12.21$, $P < 0.005$] for visual attribute verification (see Table 2). TRUE responses were faster [$F(1,11) = 41.93$, $P < 0.000$; item analysis: $F(1,296) = 96.66$, $P < 0.000$] and more accurate [subject analysis: $F(1,11) = 9.16$, $P < 0.0115$] than FALSE responses. No other effects approached significance.

*Electrophysiological effects of probe type*

It might well be expected that a probe requiring access to visual semantic information would activate the semantic subsystem containing visual information, and a probe requiring access to non-perceptual semantic information would activate the semantic subsystem containing non-perceptual information. Therefore, we also measured ERPs to the probes themselves; and indeed we did find differences in the ERPs to probes for visual information versus ERPs to probes for non-perceptual information.

Probe ERPs (see Fig. 3) revealed early differences between the visual and non-perceptual probes over the range from 200–350 ms at medial lateral sites [attribute × site interaction: $F(3,33)$ range 4.19–14.17, $P$-value range 0.032–0.001]. ERPs to visual probes were shifted positively relative to non-perceptual probes at posterior sites, but showed the reverse pattern at more anterior sites. These results are consistent with different neural generators contributing to the scalp recorded waveform during the processing of visual as opposed to non-perceptual probes. In addition, there was a later separation, from 700 ms onwards, between visual and non-perceptual probes which was most marked over left lateral frontal cortex (F7) but due to substantial individual differences, this was significant only from

700–750 ms [attribute × hemisphere at outer lateral sites: $F(1,11) = 6.06$, $P < 0.032$], although it approached significance from 800–950 ms.

## Conclusions from electrophysiological evidence

The ERP data support the claim that the representations of visual semantic information and non-perceptual semantic information have distinct neural substrates. Both probe and target ERPs showed evidence as early as 200 ms of differences in neural processing which were attributable to the type of semantic attribute being accessed. In the case of target ERPs, these effects were small although significant. However, they were followed by later more substantial differences over anterior areas during latency ranges which overlapped the N400 (300–400 ms) and P600 (600–800 ms) components, although in neither case appeared to be a modulation of these components.

Previous research has shown that P600 is reduced at posterior sites when subjects are less confident about their decisions (Ruchkin and Sutton, 1978). Given the finding from the current data that subjects found the visual attribute verification task more difficult than the non-perceptual attribute verification task, the question might be raised whether our ERP effects are due to differences in difficulty rather than differences in task. Because our two conditions yielded ERP differences at anterior sites, and because there was no modulation of P600 between the two conditions, we would argue that our ERP effects are not difficulty artefacts.

## Discussion

Our general conclusion from the neuropsychological and electrophysiological data we have reported is that there exist in the semantic memory system two functionally and neurally distinct subsystems, one containing information about the visual properties of objects and another containing information about non-perceptual properties. These two subsystems are independent of input modality (so that, for example, deciding that a lion is dangerous depends upon access to just that piece of information in the non-perceptual-semantic system regardless of whether the input is a spoken word, a printed word, a picture or a roar). These two subsystems are also independent of semantic category in that, for example, the fact that an item is dangerous is represented in the non-perceptual semantic system regardless of the semantic category of that item: knowledge of the dangerousness of a lion, of strychnine, and of lightning depends upon that semantic subsystem. That is not to say that the non-perceptual semantic system has no internal categorical organization; we believe it does, and will discuss this further below; but first we wish to say something more about the system of visual-attribute information.

In this paper, we have so far focused exclusively on the neuropsychological literature, the reason being that there is not much work on semantic memory in intact people that is specifically relevant to the topic of our paper. However, one line of work on normal semantic memory is directly relevant. Schreuder *et al.* (1984) found that lexical decision responses to printed words were primed not only by what we have called non-perceptual semantic relatedness (e.g. the word APPLE primes the word BANANA) but also by purely visual semantic relatedness (e.g. the word APPLE primes the word BALL). In contrast, when the task was to read the target words aloud, only the purely visual priming was seen; there was no effect of non-perceptual semantic relatedness.

These authors suggested that this difference between the lexical decision and reading aloud results may have occurred because lexical decision RTs are slower than word naming latencies, and perhaps access to non-perceptual semantic information is slower than access to perceptual semantic information; and further work by Flores d'Arcais *et al.* (1985) provided some evidence in favour of such differential access time. On the other hand, in our experimental study, RTs were longer when visual semantic information had to be accessed than when non-perceptual information had to be accessed. Clearly further work is needed here.

Be that as it may, the results of the two studies just discussed do support the view of semantic memory advanced by these authors: 'In the present work, we made a distinction between semantic information based on physical properties such as shape, size or colour, and information based on more abstract, functional properties' (Schreuder *et al.*, 1984, p. 340; see also Flores d'Arcais and Schreuder, 1987). That is more or less our view too, except that we would not include size amongst visual attributes and, more importantly, we have provided evidence that semantic information based on physical properties is not stored in a single semantic subsystem. Instead, there is a subsystem specifically containing visual semantic information that is distinct from systems containing other forms of perceptual information (since AC could access information about auditory or olfactory properties of objects, but not visual properties of objects).

### The role of the perceptual-semantic subsystems in object recognition

Flores d'Arcais and Schreuder (1987) and Schreuder and Flores d'Arcais (1989) argue that a seen object directly activates its visual-semantic features but only indirectly activates its non-perceptual semantic features (via its directly-activated visual semantic features): 'a very specific assumption is that perceptual pattern analysers (other than word-recognition systems) are connected to P (perceptual semantic) elements. These analysers can activate systems that deal with information about shape, colour, motion patterns, etc.' (Schreuder and Flores d'Arcais (1989, p. 425).

Riddoch *et al.* (see, e.g. Riddoch and Humphreys, 1987 and Sheridan and Humphreys, 1993) have made the same proposal: that the structural description system that is used for recognizing seen objects and the semantic subsystem that is used to answer visual-attribute probes such as 'Does an oyster have legs?' are the same system. Damage just to that system would therefore produce not only a visual agnosia but also an attribute-specific selective semantic deficit.

That is the view we will also take here. We contend that it is the same body of visual knowledge about objects that we use (a) when we recognize a visually presented object or picture (b) when we are answering questions about the visual attributes of objects, even when these questions are posed verbally and (c) perhaps also when we are generating visual information about objects i.e. drawing to dictation or drawing spontaneously. Damage to representations within that body of knowledge will thus produce a visual agnosia, an impairment of the ability to answer spoken questions about visual attributes of objects, and an impairment of drawing.

This does not mean that every patient with a visual agnosia must also show impaired knowledge of visual attributes and impaired drawing. There are of course many forms of visual agnosia. A patient with aperceptive agnosia has a deficit prior to the system of visual knowledge, and so is impaired at accessing that system; but the system itself, and retrieval from it, can still be intact. Take, for example, the agnosic patient CK (Behrmann *et al.*, 1992) whose drawing from memory was excellent; these authors characterized his agnosia as follows: 'His errors indicate that, like some other visual agnosic patients, he proceeds in a piecemeal fashion, reconstructing elements of the stimulus rather than recognizing the object as a meaningful whole'. It is reasonable to argue that this patient had a deficit in construction of an adequate visual episodic representation of pictured objects, rather than of the representations of objects in a structural description system; if so, his intact drawing ability is to be expected.

We see no reason not to make the same proposal with regard to every sensory modality. In the case of audition, for example, we suggest that it is the same body of auditory knowledge about objects that we use (a) when we recognize an environmental sound (b) when we are answering questions about the auditory attributes of objects, even when these questions are posed verbally and (c) perhaps also when we are generating auditory information about objects, as in responding to commands such as 'Imitate a duck'. Damage to representations within that body of knowledge will thus produce an auditory agnosia, an impairment of the ability to answer spoken questions about auditory attributes of objects, and impaired mimicking of environmental sounds.

Even if there are distinct bodies of modality-specific perceptual information about objects, the content of those bodies of knowledge does not exhaust what we know about objects, since of course some of the things we know about

objects are not to do with their sensory properties. We have been using the term 'non-perceptual information' to refer to such knowledge. Consequently, our claim is that in addition to the various systems of perceptual information about objects there is also a system of non-perceptual information—and it seems clear that this system has an internal categorical organization, which is the reason why impaired knowledge about objects can be semantic-category specific. Allport (1985) has previously proposed a view of the organization of semantic memory very similar to the one we are proposing here.

Consider now patient EW (Caramazza and Shelton, 1998), a particularly clear case of category-specific semantic impairment, the impaired category being animals (not living things in general, since fruits and vegetables were spared in her case). She was impaired at naming animals from pictures and from their sounds: we argue that this is because the only route from any of the perceptual identification systems to phonological (or orthographic) output is via the non-perceptual knowledge system, and representations of animals are impaired there. She was also equally, and severely, impaired at answering visual-attribute and non-perceptual-attribute questions about animals. Since in our view visual attribute knowledge is stored elsewhere than in the non-perceptual knowledge system, visual attribute knowledge about animals could be intact in EW (though see below), but even if it were, it would not be accessible from speech, since the pathway from speech to the visual-attribute knowledge system is via the non-perceptual knowledge system.

Our term 'non-perceptual knowledge system' corresponds to the term 'conceptual knowledge' as used by Caramazza and Shelton (1998), and their views about its categorical organization, and how that organization can give rise to semantic-category specific deficits after brain damage, are views to which we would subscribe.

But now consider EW's performance on certain non-conceptual tasks. Object decision is one such task: EW showed category-specificity here, being normal with in-animate objects stimuli and poor with animal stimuli (as was the case with Michelangelo; see Sartori *et al.*, 1993). If the only source of category specificity were an impairment of the non-perceptual knowledge system (because that is the only system that is organized by semantic category), why should a visual task such as object decision show category specificity?

Caramazza and Shelton (1998) suggest that this must mean that the visual object recognition system is also organized by semantic category, whilst acknowledging as a problem for such a view the fact that no cases of category-specific agnosias for the categories of animate and inanimate categories have been reported.

An alternative explanation which avoids this particular problem is the proposal that the various object recognition systems and the non-perceptual knowledge system are linked in an interactive activation way. In that case, if an object's

representation in the non-perceptual system has been abolished, there will be no top-down support for activation of that object's representation in any of the object-recognition systems, and so even if the latter systems are intact the object may not be recognizable. That would impose a category-specific deficit upon object recognition tasks, even though the object recognition systems themselves are not categorically organized. This explanation too is problematic: it predicts that all patients with a category-specific deficit affecting animals should also perform worse with animals than with inanimate objects on the object decision task, and whilst this is clearly so in some cases (e.g. Sartori *et al.*, 1993), there are also clear counter-examples in which the prediction about object decision is not supported (e.g. Sheridan and Humphreys, 1993; Samson *et al.*, 1998).

Finally, what about the interpretation of our patient AC? Given what we have argued about the organization of object knowledge, his lesion would not be prior to the visual attribute system (i.e. the visual object recognition system or structural description system) since that would not prevent information from being retrieved from that system in response to verbal probes and should also compromise performance on the Minimal Feature and Foreshortened View tests, which he did well.

One possibility is that the deficit is within that visual object recognition/structural description system: for AC, representations in the system are degraded or absent, and such representations are needed to answer visual-attribute questions. Since such a deficit would also lead to an impairment on the visual object decision task, to an impairment of drawing to dictation, to impaired performance on the LUVS and Pyramids and Palm trees tests, and to failures to recognize wheels, legs etc. in drawings, all of which he showed, we adopt this interpretation of AC.

## The relationship between visual semantic attributes and the semantic category 'animal'

Warrington and McCarthy (1983, 1987) and Warrington and Shallice (1984) argued that perceptual attributes are especially important for the semantic category of living things, with functional attributes being especially important for the semantic category of inanimate objects. Flores d'Arcais and Schreuder (1987, p. 155) on independent grounds made a similar suggestion: 'These arguments give us the basis for distinguishing two classes of object categories, for which we will tentatively use the term 'perceptual' categories as opposed to 'conceptual' categories ... A perceptual category (e.g., BIRD) is a category that is defined predominantly in terms of perceptual attributes of its members, while a conceptual category (e.g. KITCHEN UTENSILS) is defined more by functional attributes of its members.'

Farah and McClelland (1991) pursued this idea further, claiming that the inference from the observation of patients with selective semantic impairment for animate objects to

the view that semantic memory is organized categorically is fallacious, because this apparent semantic-category-specificity of semantic impairment is an artefact. Animate concepts depend heavily upon the representation of visual attributes, and so, if there is a selective impairment of visual attributes in semantic memory, animate concepts will suffer more than inanimate concepts, even though semantic memory is not organized in a way that respects the categorical distinction between animals and non-animals. Warrington and McCarthy (1987, p. 1273) offer a similar view: 'different weighting values from multiple sensory channels will be important in the acquisition of different categories of knowledge and ... such differential weightings could be the basis of the categorical organization of systems in the brain subserving semantic knowledge'.

This claim by Farah and McClelland makes two very clear predictions. Both of these predictions have been falsified in studies of patients with neuropsychological impairment of semantic memory.

The first prediction is that all patients with a selective impairment to visual semantic attribute knowledge will perform worse with animals than with inanimate objects in tests of semantic memory. Our results falsify this prediction. AC clearly had a very severe loss of the representation of visual semantic attributes in semantic memory; therefore, on the Farah–McClelland view, he should have performed much worse with animals than with inanimate objects in tests of semantic memory. However, he did not; his performance was the same with animate and inanimate objects on a wide variety of tests of semantic memory.

The second prediction from the Farah–McClelland view is that all patients with a selective impairment of semantic knowledge about animals, relative to knowledge about inanimate objects, will show a selective impairment of knowledge about visual semantic attributes, relative to knowledge about non-perceptual semantic attributes. This too is not so. Laiacona et al. (1993, 1998) have described four different patients all of whom had a selective semantic memory impairment for living things, relative to inanimate objects. None of these patients was worse in tests tapping knowledge of visual semantic attributes than in tests tapping knowledge of non-perceptual semantic attributes.

We agree with Farah and McClelland, of course, that there is a semantic subsystem for specifically visual information; what we disagree with is their claim that it is damage to this system, or damaged access to it, which is the explanation for the form of category-specificity in which animals are worse than non-animals.

We therefore claim that apparent category-specificity of semantic impairments in which performance is worse with animals than inanimate objects cannot be dismissed as an artefact of attribute-specificity, and that at present there is no evidence inconsistent with the view that both types of specificity occur and that each can occur independently of the other. AC showed attribute-specificity in the absence of category-specificity. The patients described by Laiacona

et al. (1993, 1998) showed category-specificity in the absence of attribute-specificity.

## How do doubly selective impairments arise?

We are claiming that there are three classes of selective impairment of semantic memory, and that these three classes of impairment can occur independently. By 'independently' here we mean, for example, that whatever the form of brain damage is which causes an attribute-selective impairment (say, for visual attributes), and whatever the form of brain damage is that causes a category-specific impairment (say, for animals), there is nothing to prevent some patients from suffering just one of these forms of damage, whilst others suffer both forms of damage.

What would the semantic performance of patients with both forms of damage be like? With non-animals, visual attributes would be impaired and non-visual attributes spared. With non-visual attributes, performance with animals would be impaired and performance with inanimate objects would be spared. In addition, knowledge of visual attributes of animals would be doubly impaired. Thus of the four cells in the 2 × 2 table here, performance would be normal in only one, in patients with doubly selective semantic impairments.

That is the pattern shown by the patient DRS (Warrington and McCarthy, 1994, Table 1) whose double deficit was for pictorial input and the semantic category of small manipulable objects: he was worst at tasks involving pictures and small manipulable objects, averaging 45% correct, performing at an intermediate level at tasks involving pictures of items that were not small manipulable objects (78%) or spoken input and that category of small manipulable objects (74%), and did best (although in the absence of control data, one cannot know whether performance was actually normal here) when there was spoken input of items that were not small manipulable objects (89%). His response latencies also showed this pattern.

This ordering of difficulty can also be seen in the data reported by McCarthy and Warrington (1988) for their patient TOB, whose double deficit was for verbal input and the semantic category of animals, although the effects are much smaller: verbal input of living things 33% correct, verbal input of objects 89%, pictures of living things 94%, and pictures of objects 98%.

The patient described by Silveri and Gainotti (1988,) and Gainotti and Silveri (1996) had a doubly selective deficit affecting perceptual semantic attributes and the semantic category of animals. She was impaired on tasks probing visual semantic attributes even with non-animals and impaired on tasks probing non-perceptual semantic attributes even with animals, but in both cases less impaired than on tasks probing perceptual semantic attributes of animals. Whether she was least impaired on tasks probing non-perceptual attributes of animals is, as
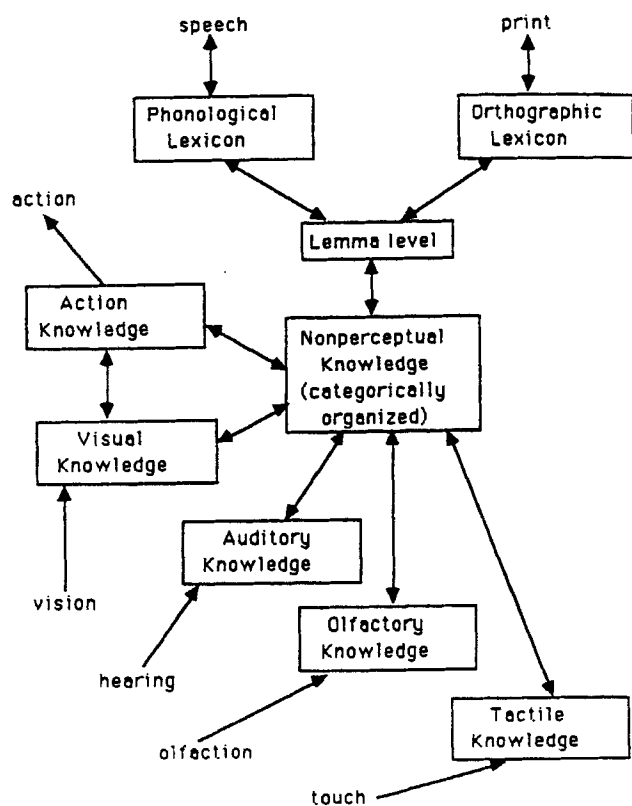
Fig. 4. A hypothesis about the representation of object knowledge.

the authors note (Gainotti and Silveri, 1996, p. 369), difficult to determine because of differences across these conditions shown by intact control subjects.

The last of the four patients showing a doubly selective deficit that we discussed earlier in this paper is the patient described by Basso *et al.* (1988); and that paper does not report data relevant to the ordering-of-conditions issue we are discussing here.

Hence, our view that patients with doubly selective deficits have two semantic impairments is reasonably well supported by the data. Note that this is not the only logically possible interpretation of such patients. Some authors have advanced the hypothesis that there are distinct semantic systems for different input modalities such as pictures and words, with duplication of representations in these two systems (e.g. Warrington, 1975; Warrington and McCarthy, 1994). If that were the case, then doubly selective patients could be found who were intact on tasks tapping only one of their deficits. For example, a patient with impaired knowledge of animals in the verbal semantic system could still show perfect knowledge of animals when these were presented as pictures plus perfect knowledge of the meanings of spoken words provided these did not refer to animals. Such patients have not been reported.

In conclusion, we offer Fig. 4 as a summary of our views about the mental representation of object knowledge. In this scheme, each perceptual domain has its own distinct knowledge base, which not only functions as a recognition

system for objects presented in that perceptual modality but also is the locus from which information is retrieved when questions about perceptual properties in that domain are posed. In addition to these perceptual knowledge bases, there is a store of non-perceptual object knowledge, and a store of action knowledge. The sum total of what we know about any object is distributed across this set of knowledge bases.

Amongst the theoretical commitments (or perhaps over-commitments) made in this scheme are the following:

(a) Following Allport and Funnell (1981), we have made no distinction between input and output lexicons; others (e.g. Patterson and Shewell, 1987; Ellis and Young, 1988) do make that distinction. This is a matter of current controversy [see, e.g. Weekes and Coltheart (1996) for further discussion of this issue].

(b) Following Levelt *et al.* (1998), we propose that the word-form systems (lexicons) are interfaced with semantic systems via a lemma level. Arguments against the postulation of a lemma level may be found in Caramazza (1997) and Caramazza and Miozzo (1997). An alternative for us would be simply to have direct connections from the lexicons to the non-perceptual knowledge system.

(c) In the syndrome known as optic aphasia (see, e.g. Coslett and Saffran, 1989), objects can be named from non-visual modalities such as touch, but not from vision; but this is not due to a failure of visual recognition, since the optic-aphasic patient can make appropriate gestures in response to seen objects. The intactness of tactile naming shows that the pathway from non-perceptual knowledge to phonology is intact. Hence in any scheme like ours, the deficit in optic aphasia must involve the links from vision to non-perceptual knowledge. If the only way in which action knowledge could be accessed from vision were via the non-perceptual knowledge system, or if action knowledge were simply part of the non-perceptual knowledge system, optic aphasia could not exist. Hence, we propose that action knowledge is represented in a distinct system, and that visual object recognition communicates directly with that system, thus enabling correct gesturing to seen objects even in the absence of correct naming.

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# A semantic subsystem of visual attributes

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## Abstract

We propose that the many different forms of selective semantic impairment that have been reported over the past 20 years may be classified into three general classes: semantic-category selective, modality-of-input selective, and semantic-attribute selective. Particular patients may exhibit more than one form of selectivity, i.e. there can be doubly and perhaps even triply selective semantic impairments. We then describe a patient with a singly selective semantic impairment of a form not previously described: he was unable to access visual semantic attributes in semantic memory, whereas he could access semantic attributes relevant to other sensory modalities, and could also access non-perceptual semantic attributes. This pattern of results was independent both of modality of input and of semantic category of probed item. We infer from these data the existence of a semantic subsystem specific to the storage of information about visual attributes of animate and inanimate objects. An ERP study of semantic processing in normal subjects provided further evidence in support of this claim about a particular component of semantic memory. We conclude by proposing that semantic memory is organized into subsystems of perceptual-attribute knowledge, one subsystem for each of the different perceptual modalities, plus a subsystem in which non-perceptual knowledge is represented. That subsystem is in turn categorically organized into semantic categories such as 'animate'.

## Neurocase Reference Number:

O124

## Primary diagnosis of interest

Multi-infarct

## Author's designation of the case

AC

## Key theoretical issue

● Selectivity of semantic impairment

*Key words:* semantics; comprehension; category-specificities; visual semantics

## Scan, EEG and related measures

CT scan

## Standardized assessment

None

## Other assessment

Reading, writing, naming, copying, drawing, comprehension

## Lesion location

● Numerous small brain lesions

## Lesion type

Numerous small brain lesions

## Language

English