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## MULTIPLE MEANING SYSTEMS IN THE BRAIN: A CASE FOR VISUAL SEMANTICS

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**Abstract**—In this study we report our investigations of a category specific visual associative agnosia. The patient D.R.S.'s spoken language skills were excellent. Although he could name objects from their description, he was unable to name them by sight nor was he able to mime their use. On visual-visual matching tasks his performance was impaired and affected by semantic proximity. In two tasks his knowledge of visual objects was demonstrated to be significantly more impaired than his knowledge of visual living things. It is argued that these findings support a multiple knowledge base hypothesis.

**Key Words:** visual agnosia; semantic memory; category specificity; clinical study; cerebral vascular disease.

### INTRODUCTION

The issue of whether knowledge bases for visual and verbal domains are fully integrated, or in some sense separable, has profound implications for cognitive and neuroscientific theory. Patients with selective preservation or selective loss of knowledge in one domain, sparing knowledge in the other have provided evidence consistent with the multiple knowledge base hypotheses [11, 17, 19, 21]. By and of themselves, the frequently reported category specific dissociations between living things and objects do not necessarily contribute to the debate as to whether there is a unitary all-purpose knowledge system [1, 2, 5, 18, 28]. Indeed parallel category effects in two modalities have been held to favour the unitary hypothesis rather than the less parsimonious formulation that these reflect parallel deficits in two separate knowledge bases. We will argue it is the co-occurrence of disorders that are category specific and modality specific that are of critical significance.

In the classical syndrome of visual associative agnosia, patients' semantic knowledge of many visual objects is gravely compromised [9, 13]: objects, to quote Teuber [20], are "percepts stripped of their meaning". The analogous syndrome in the verbal domain is observed in patients with one subtype of transcortical sensory aphasia. For these patients, it is the spoken word that is stripped of its meaning [e.g. 6, 26]. A lack of concordance between verbal and visual knowledge does not necessarily provide conclusive evidence for separable meaning systems. There are two main problems: First, the patient's deficit may be due to a peripheral disorder of visual or auditory perception, second there may be a failure of

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communication between early sensory processing systems and a unitary central knowledge base.

However, in cases where there is evidence of a domain specific deficit confined to one semantic category then it becomes less plausible to ascribe the deficit to impaired sensory or perceptual processing [e.g. 7, 8]. Problems in communication between input systems and semantic knowledge have been less straightforward to differentiate from a primary deficit within the knowledge base itself. Once again, we can appeal to evidence of category specificity to rule out most variants of a disconnection hypothesis. For a deficit to be specific to a specific semantic category, some semantic analysis must have been carried out by the system. We consider it a contradiction to suppose that a doubly dissociated category specific deficit can arise at a pre-semantic level of processing.

We have previously described a patient in whom category and domain specific deficits co-occurred [14, 15]. Although TOB's visual knowledge of both animals and objects was preserved, his verbal knowledge of animals but not objects was impaired. We argued that T.O.B. provided evidence for categorically organised domain specific meaning systems in the brain. The fact that the disorder was specific to the category of living things implicated semantic processing; the fact that the disorder was confined to the spoken word indicated that there was a separation between visual and verbal semantics. In this report we describe a further critical case that contributes to this debate. The patient had a visual associative agnosia that appeared to be disproportionately severe for common objects. His verbal knowledge appeared to be entirely intact.

#### CASE REPORT

D.R.S. was a 59-year-old physical scientist who was referred to the National Hospital for further investigations of his cerebro-vascular disease. On examination there were no neurological signs other than a right-sided hemianopic field defect. His corrected visual acuity was 6/9 and his colour discrimination was good (James, unpublished). A CT scan revealed bilateral but asymmetric infarcts in the right parietal lobe and inferior left occipito-temporal region.

D.R.S. was investigated in the Neuropsychology Department over a 10-day period in December 1987. On a shortened form of the WAIS he obtained a Verbal IQ of 121 and a Performance IQ of 72 [25]. His recognition memory for both words (43/50) and faces (42/50) appeared to be intact [22].

His performance on a range of tests of visual competence and visual perception was adequate. On the Efron Squares test [3] of form perception his score was normal (19/20 correct) on the hardest discrimination (see Fig. 1). On a figure detection task [24] his performance, 16/20 correct, was creditable (see Fig. 1). On tests of perceptual analysis his performance was good. There was no effect of an angle of view manipulation insofar as having obtained the poor score of 12/20 correct [23] on the Unusual Views there was no gain on the Usual Views (12/20 correct). On a demanding object-decision task (see Fig. 1) he obtained a normal score of 17/20 correct.

Although he was unable to read, his spelling was at a high level. His propositional speech was fluent and sophisticated both in content and vocabulary. On a test of naming objects from description his performance was error-free (15/15). However, on a graded difficulty object-picture naming test he scored only 11/30 [16]: here it appeared that his difficulty was not merely one of retrieving the target name: but rather, that he had difficulty in recognising

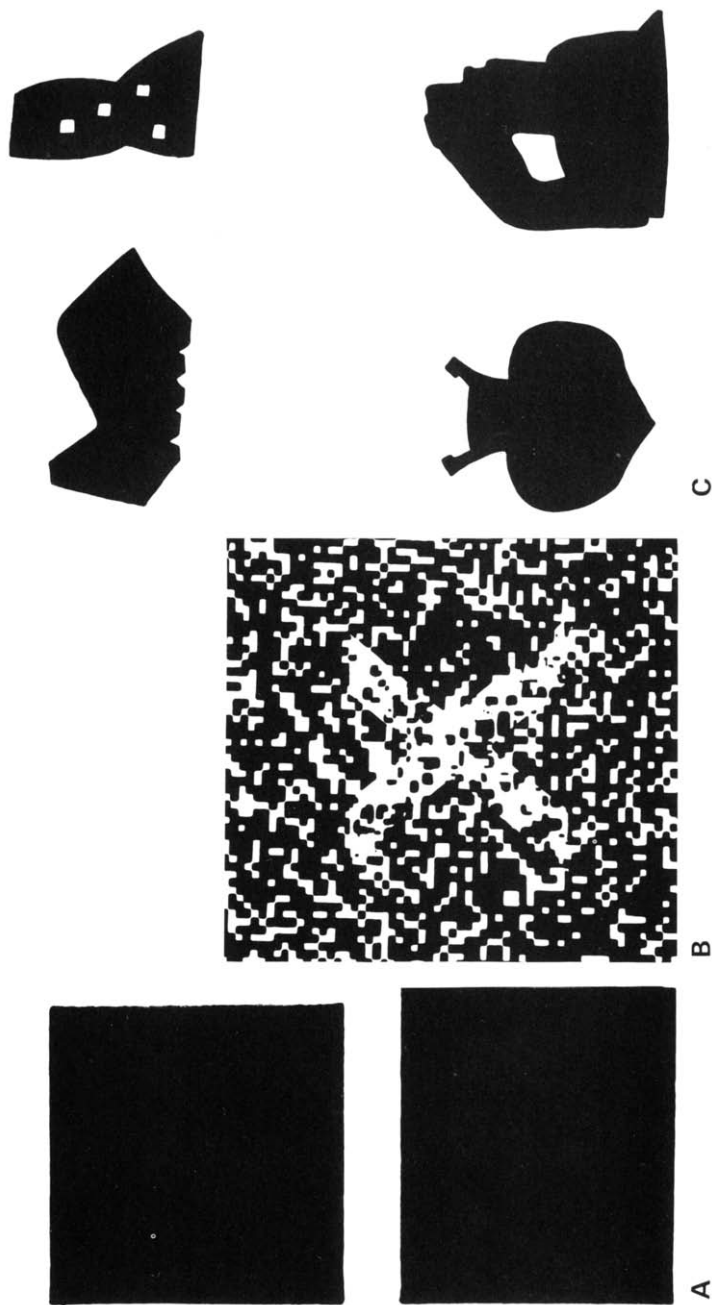


Fig. 1. (A) Example of the most difficult discrimination of the Efron squares test. In a series of randomly presented items the subject is required to identify the stimulus as a square or an oblong. (B) Example of shape detection test. The subject is required to determine whether the central "X" is present or not. (C) One example of the object-decision test. The subject is required to point to the one real object, the other three shapes being nonsense shapes.



the object (e.g. TWEEZERS “device for threading needles”). On a test requiring him to name objects and animals (distinct coloured photographs) ranging in frequency from very common to very infrequent, he named 7/20 objects and 11/20 animals (Thorndike-Lorge Mean Frequency 38.1, 19.0). Again, his errors indicated grave difficulty in identification of some very common target objects (e.g. fork → lightbulb, clock → sewing machine). His naming was tested on three further categories: occupations, sports and actions. Whilst he scored a creditable 27/30 in identifying pictures of occupations, he was somewhat weaker at naming pictures representing sports (22/32) or actions (14/22) [12]. His ability to name objects presented for identification via touch was considerably better than when the same objects were presented visually: he scored 9/11 and 3/11, respectively.

Our investigation has focused on the analysis of his visual recognition deficit.

## EXPERIMENTAL INVESTIGATIONS

### *Test 1: Naming—visual vs verbal presentation*

His ability to name objects from verbal description vs his ability to name from pictures was directly compared. Twenty low frequency three-syllable words (e.g. telescope and unicorn) and 20 low frequency one-syllable words (e.g. hoof—moat) were tested using both a verbal definition and a simple prototypical black and white line drawing. D.R.S.’ picture naming was slow, laborious and inaccurate (25/40). His naming from description was fast and efficient (37/40). This dissociation establishes a domain specific naming difficulty.

### *Test 2: Pantomime actions—visual vs verbal elicitation*

D.R.S.’s ability to produce pantomimes in response to a spoken object name or a visually presented object was assessed. The stimuli consisted of 24 common household objects and tools with an associated characteristic and distinctive action. The test stimuli were presented in sets of six items that were functionally and contextually similar (e.g. pliers, hammer, screwdriver, hacksaw, trowel, paintscraper; paintbrush, hairbrush, shoebrush, toothbrush, nailbrush, shavingbrush). Each set of objects was tested (1) for naming (2) for pantomime given the spoken name and (3) for pantomime when shown the object out of reach. The conditions were tested in a counterbalanced order, each item being sampled twice in each condition. D.R.S.’s mimes to the spoken name were flawless and unmistakable (24/24 correct). However, his performance on the miming to object task was very impaired (13/24 correct) and at the same impaired level as object naming (13/24 correct). On the miming task his performance was characterised by semantic errors (e.g. pliers demonstrated as a drill; screwdriver demonstrated as a hammer). These results establish that his deficit is not merely one of word retrieval, but affects his ability to identify common objects.

### *Test 3: Word picture matching—semantic proximity*

In order to further determine the locus of D.R.S.’s visual recognition problems he was tested on a word–picture matching test which manipulated the semantic relatedness of targets [27]. The stimuli consisted of 12 arrays of six pictures (selected from the Snodgrass and Vanderwart pool), six of the arrays consisted of visually distinct exemplars from a narrow semantic category (i.e. six items of clothing, of desktop objects, of containers, etc.). The other six arrays comprised one item drawn from each of six of these narrow categories (e.g. table, jumper, watch, pen, car, bowl). Each item was probed twice in both the close and distant array conditions. He scored 56/72 in the close arrays and 71/72 on the distant arrays. In view of his excellent verbal abilities we would infer that these findings reflect an impairment in the visual component of the task. His sensitivity to the close/distant manipulation provides further evidence that his disorder is at the level of visual object identification in visual semantics.

### *Test 4: Visual visual matching—real objects and pictured objects*

In order to confirm that D.R.S. had a deficit at the level of visual identification, two visual–visual matching tasks were devised. In these tasks the subject is required to match an object to its physically dissimilar “synonym” pair (e.g. two glasses). The stimuli in the first task consisted of three sets of four pairs of real objects. Each object in each array was probed three times (a total of 36 responses). He scored 26/36 correct. The stimuli in the second task consisted of two sets of four pairs of coloured object photographs. Each object in each pair was probed once. He scored 6/16 correct. Although he was slow and careful on these tasks his performance was nevertheless gravely impaired. His errors included confusions between common items such as a wine glass and a light bulb.

### *Test 5: Visual visual matching—category specificity*

In the previous visual visual matching task, all the items probed were common objects. D.R.S. protested vociferously when presented with these stimuli commenting “not another \*\*\*\*\* common object, I don’t recognise

those!" We therefore attempted to broaden our stimulus range and tested him on a further matching test in which we compared his performance on visual-visual and auditory-visual matching with common objects, animals and vehicles. The stimuli consisted of four arrays of five simple clear line drawings. In the visual-visual condition D.R.S. was given a physically dissimilar line drawing of one item in the array and asked to match it to its pair (see Fig. 2). In the auditory condition he was asked to match a spoken word to a target item in the array, each item in each array was probed eight times. Auditory and visual conditions were ordered in an ABBA design. The percent correct and response latency for each array is given in Table 1. By broadening the number of categories probed it appears that there is a category effect insofar as his score on visual-visual matching of manipulable common objects is significantly worse than his matching of animals ( $\chi^2=13.3$ ,  $P<0.001$ ). A similar category profile is seen in the verbal-visual matching task ( $\chi^2=9.60$ ,  $P<0.01$ ), albeit that his overall level is somewhat less impaired.

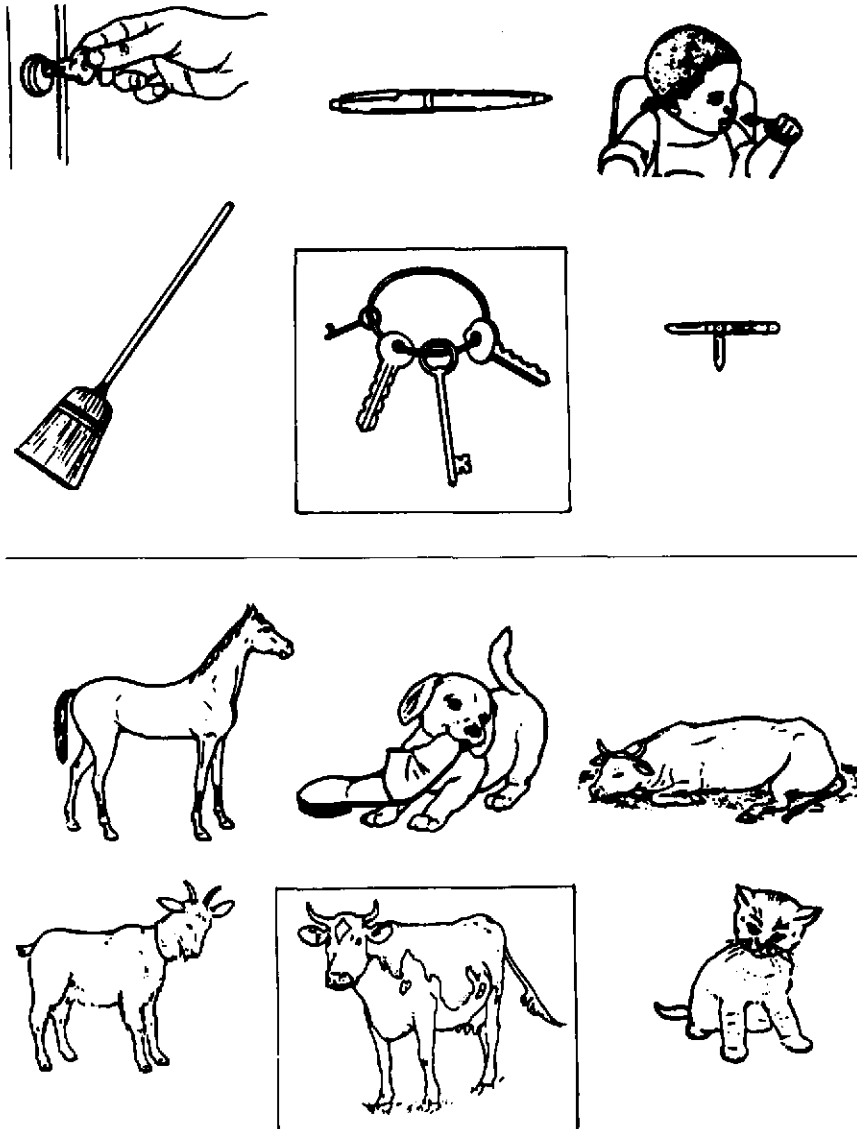


Fig. 2. Examples of visual-visual matching test. The subject is required to point to the stimulus item in the array that has the same "identity" as the singly presented test item (i.e. the key on the door, the lying down cow).

*Test 6: Word-picture matching—category specificity*

In order to explore the category effect further we turned to a verbal-visual matching test that has previously been found to show category effects [27]. The stimuli consisted of three arrays of distinctive coloured drawings of five items each: five flowers, five common objects and five animals. He was tested in blocks of 20 trials in which each item was probed four times. Each of the three arrays was tested three times using a Latin Square design. His scores were as follows: Objects 38/60; Animals 56/60; Flowers 56/60. His score on the objects condition was significantly worse than on the other two ( $\chi^2=6.0$ ,  $P<0.02$ ). These findings both replicate and extend the findings of category specificity documented in Test 5.

Table 1. Percent correct and mean latency of response for each condition.

	Visual-visual	Auditory-visual
Common objects 1 <i>N</i> = 40	60% 17.4"	80% 5.7"
Common objects 2 <i>N</i> = 40	30% 29.2"	68% 5.6"
Vehicles <i>N</i> = 40	75% 13.0"	83% 5.8"
Animals <i>N</i> = 40	80% 8.1"	95% 4.5"

## DISCUSSION

In this investigation we have documented a patient with a category-specific visual agnosia. Although D.R.S. had excellent and very high-level verbal skills, he was impaired in identifying visually presented common objects. His deficit was entirely within the visual domain. The major feature of interest in this visual agnosic syndrome was its category specificity. D.R.S. had grave difficulty in identifying common objects such as cups and saucers or knives and forks but he could, nevertheless, identify a wide range of stimuli drawn from other semantic categories. His performance was particularly competent with living things. In this discussion we shall focus on the importance of this hitherto undocumented dissociation.

First, it is important to establish the component of the visual information processing system that is implicated by these impairments. We wish to argue that D.R.S.'s deficits are accounted for by a disorder at the level of assigning meaning to a structured visual input. In order to support this analysis, it is important to eliminate any sufficient causes of the disorder arising at earlier stages in the visual information processing system: specifically at the stages of sensory processing or structured perception. D.R.S. was competent on tasks requiring him to detect, discriminate and group visual sensory input. In particular, his performance on tests of figure-ground discrimination and form discrimination were adequate. These results indicate that a deficit in the early stages of object processing cannot explain D.R.S.'s disorder. Moreover, his ability to derive structural information from drawings and pictures was good. D.R.S. did not appear to be differentially affected by presenting stimuli in a visually complex or degraded format or in the context of perceptually similar discriminanda. He was not additionally disadvantaged by presenting stimuli in a foreshortened view and he

performed within the normal range on a difficult object decision task. These results effectively eliminate the possibility that his agnosia can be attributed to a deficit in deriving a volumetric structural description; the stage of information processing that is compromised by some right parietal lesions (e.g. [23]).

The locus of D.R.S.'s deficit therefore appears to lie either within those components of the processing system that are responsible for assigning meaning to a structured percept, or in access to them. Since D.R.S.'s deficit is also category specific we can go somewhat further with our analysis. We wish to argue that his impairment is not merely a disconnection between perceptual input systems and semantic processing but rather, that it implicates a functionally distinct visual semantic system [e.g. 13]. Category specificity appears to implicate a disorder within the procedures required for computing meaning rather than in those processes that relay information from one level of coding to another.

There have been two other attempts to account for category by modality interactions that merit discussion here. First, Caramazza and his colleagues [2] have proposed that there is a central categorically organised semantic system. On their framework, the sparing of visual living things (documented in our previous case, T.O.B.) was attributed to privileged activation of this system from vision. However, asymmetries that favour the verbal domain over the visual domain, as documented in the present case, D.R.S., pose a serious problem for this position. They would seem to refute it.

Secondly, Farah and McClelland [4] have proposed that knowledge is organised in two parallel sub-systems, one organised for sensory information and one for functional information. They suggest that the locus of the category by modality interaction arises prior to addressing the full semantic representation. Thus, in the case of our previous case T.O.B., they argued that input from peripheral verbal systems to a visual/sensory semantic processor was disconnected. The same formulation could, of course, be applied to D.R.S.: input from a peripheral visual system might be disconnected from a functional/associative semantic subprocessor.

While acknowledging that virtually any argument for a representational deficit might be countered by a complex combination of disconnections interacting with differential trace or connection strengths, we prefer a simpler interpretation. We propose that semantic information can be, and is, computed in dissociable modality-specific meaning systems. The fact that these modality-specific semantic systems appear to be sensitive to similar independent variables (e.g. the distinction between sensory and functional semantic categories) suggests that they may have comparable organisational characteristics. In essence, our hypothesis is that processing domain (e.g. visual semantics vs verbal semantics) is *orthogonal* to category specificity.

Similarities in organisation across visual and verbal domains are unlikely to reflect a simple duplication of knowledge. These domains may differ because they are required to be different for normal function. They do appear to have a different time course in development; synonymy and equivalence relations are different for vision and language and visual and verbal knowledge may partition the world along different lines (and in different ways depending on the characteristics of specific languages). It therefore makes computational sense for the visual and verbal systems to have the potential for a considerable degree of autonomy since they have different inputs, often have different outputs, and typically differ in their requirements for stimulus generalisation and equivalence. We want to understand what we see without interference with what we say—but to have the option of making the two domains co-referential.



This account is testable: it predicts that two further dissociations ought to be observed, namely failure to recognise visual animals and failure to comprehend named objects. We do not think the story is likely to stop there. Indeed, given the complexity and range of the current catalogue of category specific effects this framework appears to be the most easily extended to accommodate finer grain and broader ranges of deficit.

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