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Disorders of Semantic Memory

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Disorders of semantic memory

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SUMMARY

It is now established that selective disorders of semantic memory may arise after focal cerebral lesions. Debate and dissension remain on three principal issues: category specificity, the status of modality-dependent knowledge, and the stability and sufficiency of stored information. Theories of category specificity have focused on the frequently reported dissociation between living things and man-made objects. However, other dimensions need theoretical integration. Impairments can be both finer-grain and broader in range. A second variable of importance is stimulus modality. Reciprocal interactive dissociations between vision and language and between animals and objects will be described. These indicate that the derivation of semantic information is constrained by input modality: we appear to have evolved separable databases for the visual and the verbal world. Thirdly, an orthogonal distinction has been drawn between degradation disorders, where representations are insufficient for comprehension, and access deficits, in which representations have become unstable. These issues may have their parallel in the acquisition of knowledge by the developing child.

1. INTRODUCTION

Semantic memory is a construct that now has wide currency in theories of developmental, neuropsychological and normal functioning. Sometimes it is easy to forget that the differentiation of memory into episodic and semantic subtypes is relatively recent: it was introduced by Tulving in 1972 and first applied to neuropsychological case studies by Warrington in 1975. It is now 12 years since Elizabeth Warrington discussed the evidence for disorders of semantic memory in a Royal Society forum. Our aim in this paper is to give a progress report on the investigation of disordered semantic memory in neurological patients. We shall focus on three of the major issues that have emerged as central in the intervening period, namely category specificity, modality specificity, and the distinction between disorders of access and disorders of representation.

2. CATEGORY SPECIFICITY

Neuropsychological disorders of semantic knowledge are frequently selective to particular categories of semantic information. Even when the possible role of confounding variables such as stimulus familiarity, frequency or visual complexity is taken into account, substantial category-specific effects remain to be explained (Farah *et al.* 1991; De Renzi & Lucchelli 1994). Such dissociations of knowledge appear to offer important clues to the cerebral organization of meaning. The most widely documented of the various category-specific effects is the selective impairment of knowledge of stimuli drawn from biological categories (such as animals, plants and foods) with sparing of knowledge of man-made objects (Warrington & Shallice 1984; Sartori & Job 1988; Silveri & Gainotti 1988). Patients typically lose the ability to differentiate between many members of the affected category, usually knowing that they are living beings but not which specific type of living being, and have difficulty in specifying whether they are large or small, pink or brown, tame or ferocious, foreign or domestic. As initially described by Warrington (1982), the converse dissociation has also been documented in several single cases affecting the patient's knowledge of man-made objects and sparing their knowledge of the biological world (Warrington 1982; Warrington & McCarthy 1983, 1987; Hills & Caramazza 1991). This classical example of a double dissociation effectively rules out the possibility that such category effects are merely a product of the inherent difficulty or complexity that arises during assigning meaning to certain categories of information.

The distinction between biological categories and artefacts by no means exhausts the range of category-specific disorders that have now been reported. The profiles of dissociation are both finer in their grain and broader in their range than this simple dichotomy implies. We consider first the evidence for a finer-grain profile of dissociation. In one patient (YOT) with disordered knowledge of objects compared with animals, we were able to establish evidence for finer specificity of impairment (Warrington & McCarthy 1987). In clinical testing, it is usual to examine patients' ability to comprehend (i.e. identify and/or

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Table 1. *Category specificity* (*YOT*)
Word–picture matching: percentage correct ($n = 60$).

small manipulable objects	large man-made objects	foods
58	78	83

name) readily available small man-made objects. YOT, like other cases of impaired artefact knowledge, was gravely impaired on such tests, failing to point to familiar named items such as a cup, pen, or plate. However, by using word–picture matching techniques we were able to show that YOT was relatively spared in her knowledge of large man-made objects such as forms of transport and types of building (see table 1).

In addition to such evidence for finer-grain category-specific disorders, there is evidence for patterns of impairment that go beyond the bounds of the empirical 'biological vs. artifacts' dichotomy. One such fractionation is the selective impairment of action names and verbs. Failure to retrieve action names has been reported in group studies of patients with non-fluent aphasic disorders (Miceli *et al.* 1984); in one single case study we were able to go somewhat further and demonstrate that failure in retrieving the names of actions was underpinned by a more fundamental disorder of comprehending action names. ROX was a patient with focal degeneration of anterior regions of the cerebrum. He was investigated in detail because of his severely agrammatic spontaneous speech (McCarthy & Warrington 1985). His attempts at sentence construction contained a sophisticated and low-frequency noun vocabulary but his spontaneous production of verbs was restricted to have, make and be. We documented an above-average confrontation naming vocabulary on tests of common and proper noun retrieval, including items such as sextant, centaur, King Canute and Virginia Woolf (McKenna & Warrington 1980). However, ROX was quite unable to name actions, even those that are known to children three years old (such as drop carry, walk and jump (Renfrew 1966)). For example 'The man is a sack of potatoes' (target: carrying); 'The woman is a cup of tea' (target: drinking); 'The child was laddering' (target: climbing); 'The daughter is chairing' (target: sitting).

We investigated whether ROX's difficulty in retrieving action names was at a semantic level by asking him to perform actions in response to single spoken commands: he confused items such as opening and closing and sitting and standing. We turned to word–picture matching tasks to sample a wider-ranging vocabulary of action names. Pairs of semantically related verbs and semantically related nouns were presented to ROX and he was asked to match one item from the pair to a spoken word. The materials were selected to incorporate very common action verbs; nouns targets were selected to span the frequency range (e.g. coming–going, drinking–eating, horn–antler, draughts–chess) (see figure 1). ROX

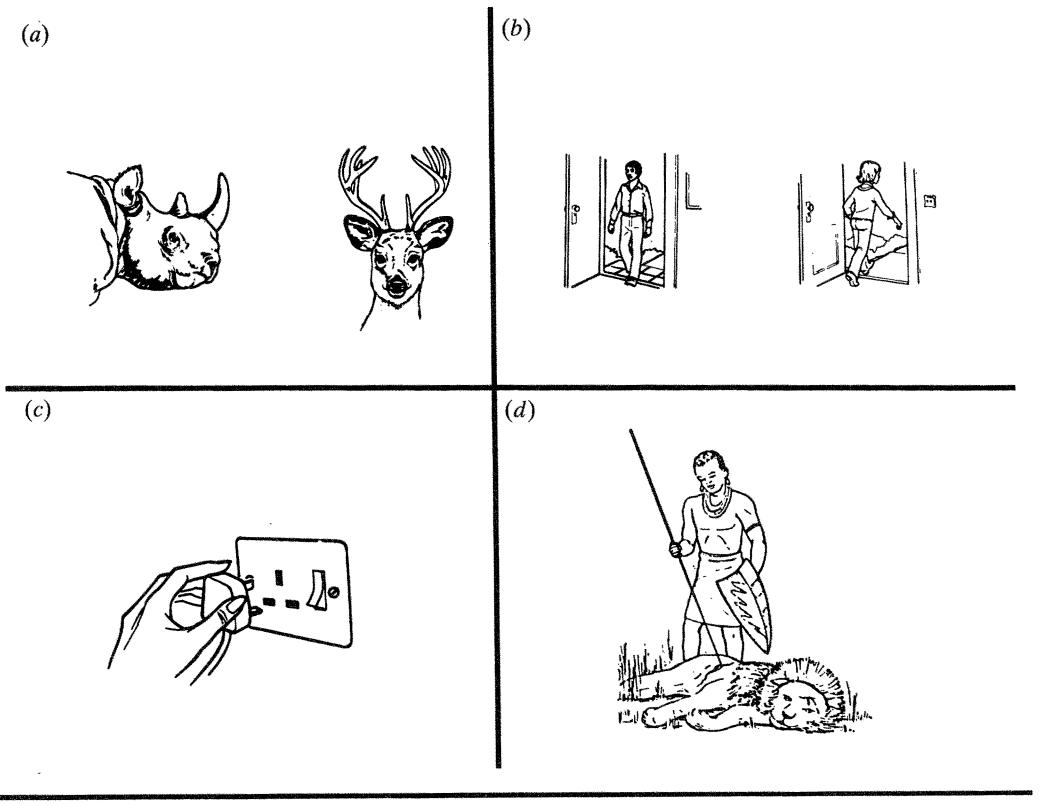

Figure 1. Examples of semantically related nouns and verbs, and of word–picture matching stimuli. (*a*, *b*) Examples of noun and verb (horn–antler and coming–going). (*c*, *d*) Interactive picture matching stimuli (plug–socket and killing–dying).

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responded promptly and accurately and scored at ceiling on the nouns task; by contrast he was hesitant and inaccurate in matching such simple action verbs as climb and jump or swim and dive (see table 2).

Verbs can also be 'similar' in terms of their thematic roles: labels such as buying and selling; giving and taking; leading and following; or killing and dying can each be legitimately applied to a single interactive episode. The exact choice of verb depends on the focus of the discourse (the agent or theme). ROX was presented with simple interactive scenes and asked to point with a pencil to the individual in the transaction that was appropriate to the action name (see figure 1). To control for interactivity and stimulus complexity, a comparable set of two-component interactive scenes was produced that included two nouns (e.g. plug and socket, truck and car). There was a very significant effect of stimulus category: ROX was again near ceiling with the noun stimuli but was at chance with the verbs (see table 2).

ROX's difficulty in pointing to named actions under these conditions indicates that he is no longer able to compute a precise meaning for verbs. We argued that this deficit was at the basis of his verb 'anomia' and was sufficient to account for his agrammatic speech. His agrammatism was not a disorder of syntax, but the manifestation of his attempt to communicate using his residual vocabulary: a form of circumlocution.

We were able to support this argument during an attempt at rehabilitation. We found that was possible to retrain ROX's ability to retrieve action names under very limited circumstances; he could be taught to associate a verb name with a specific picture. Thus, he could be taught that the verb 'dropping' was appropriate for a picture of a waiter dropping a tray. However, consistent with the semantic interpretation of ROX's deficit, we found that he could not spontaneously generalize this same label to an alternative, unambiguous representation of the same action (such as a picture of a woman dropping a flower vase). After training, ROX was able to generate competent and syntactically correct sentences to many of the trained picture set, such as 'the waiter has dropped the tray'. These results show evidence of adequate (even normal) control over grammatical skills such as word order, syntax and morphology, but inadequate semantic ability as demonstrated by his failure to generalize the label ('the woman is a break-down').

The evidence from Gleitman (this volume) has served to emphasize just how different verbs are from other types of lexical knowledge in the processes of language acquisition. This distinction appears to be mirrored in neuropsychological dissociations that suggest that verbs are represented and computed by specialized neural systems.

Table 2. *Category specificity: verbs vs. nouns* (*ROX*)
Word–picture matching: percentage correct ($n = 20$).

	trial 1	trial 2
related nouns	100	98
related verbs	80	68
interactive nouns	95	83
interactive verbs	55	63

3. CATEGORY SPECIFICITY: THEORETICAL IMPLICATIONS

The catalogue of category-specific dissociations is now large and appears to be growing. Among the fractionations that have been reported is that of abstract vs. concrete nouns, proper names vs. common nouns, places vs. people, etc. (for reviews see, for example, McCarthy & Warrington 1990; McKenna & Warrington 1993). Although some of the reported category-specific deficits appear bizarre, they are not arbitrary. They appear to be replicable (cross-culturally and cross-linguistically), they follow from similar pathological antecedents (left temporal lobe injury), and they frequently co-occur as part of a discernible syndrome cluster. Thus a deficit in comprehending man-made objects is often accompanied by impaired knowledge of body parts; disordered knowledge of animals is often associated with poor recognition of musical instruments. Such patterns of deficit association do not necessarily compel a cognitive explanation; they could arise because of the adjacency of the neuronal substrata. However, a cognitive and computational explanation of associated deficits is one that is worthy of consideration at this stage.

How are we to account for category-specific dissociations? By 1982 it was apparent that any simple division of the semantic knowledge base into animate and inanimate subdomains was probably inadequate and that any satisfactory theory had to provide some clues as to the computational basis of dissociation. A distinction between sensory and functional categories was hypothesized (Warrington 1982). Things learned in terms of their sensory properties, such as animals, foods and other 'biological' categories, might be encoded and stored differently from things known in terms of their functional attributes, such as man-made objects. Thus, in learning to distinguish between a leopard and a tiger, sensory properties including stripes and spots would be crucial. However, in acquiring the distinction between a scarf and a tie, colour or pattern would be less salient than associative and functional information (e.g. mostly worn by males as a matter of convention, unisex and worn for warmth). It is axiomatic that the brain has a spatial segregation of the sensory and motor processes; a semantic knowledge base that exploits information from these different sources might also have local specialization of function, and a category-specific pattern of breakdown if injury was appropriately located. This idea of a fundamental sensory–functional partitioning of semantic knowledge has the further advantage of providing a principled explanation for patterns of associated deficit: for example, it was suggested that failure on musical instruments and impaired animal knowledge co-occurred because both of these categories

depend critically on sensory attributes; a deficit in knowing body parts (although biological) might co-occur with impaired knowledge of objects because both classes of information have functional properties. If the semantic processing substrata of the brain were locally specialized, injury to particular subregions could lead to a category-specific clinical presentation (provided that the damage was sufficiently focal or restricted).

However, a subdivision of the semantic processing substrate into dichotomous sensory and functional subregions cannot account for finer-grain dissociations such as those documented in YOT, or indeed for wider-ranging category effects such as those documented in ROX. We have hypothesized that particular subdomains of sensory, functional and associative knowledge may make differential contributions to the way that the semantic system is locally organized (Warrington & McCarthy 1987). It was proposed that differences in the way that particular categories were acquired in childhood might determine the way that they were stored and encoded by the brain. Thus, the dissociation between large man-made objects and small manipulable things might reflect their differing dependencies on stored information from proprioceptive and efferent motor commands, besides functional and associative inputs. In effect, we argued for further 'localization' of semantic processing within the broad sensory and functional subdomains of processing.

Because this account traces category-specific effects to factors operating at the time of acquisition, it is encouraging to note that category specificity has indeed been documented in developmental studies of word retrieval. For example, recent data from McKenna (1994) has documented different growth functions for items from the biological and object domains in children between three and ten years of age (see figure 2).

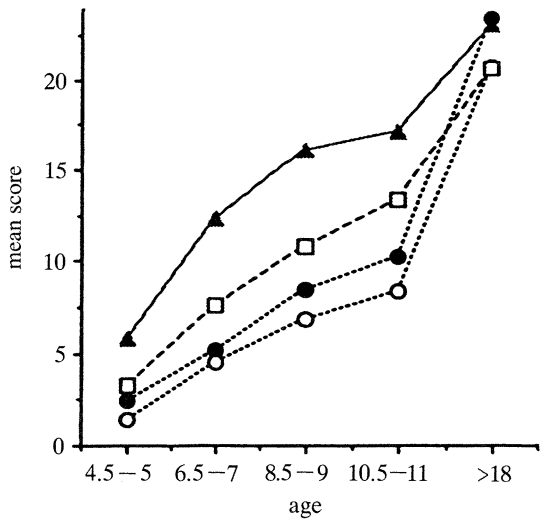

Figure 2. Performance of children and adults on four category naming tasks. Filled triangles, animals; open squares, fruit and vegetables; filled circles, manipulable objects; open circles, non-manipulable objects.

4. MODALITY SPECIFICITY

The developmental literature also indicates that there is no simple or direct mapping between the processes by which the child learns to know the visual world and the way she learns lexical or verbal concepts (see, for example, Mandler, this volume; Bowerman, this volume). Somehow, the visual and verbal domains must become easily co-referential in the adult: we can talk about what we see, and see what we talk about. Does this mean that the two domains are integrated within a unified core semantic representation? Until comparatively recently, the consensus was in favour of unity. However, evidence from neurological patients has suggested otherwise: visual and verbal knowledge may be computed independently.

Striking evidence for a dissociable substrate for visual and verbal knowledge comes from cases who have a category-specific disorder that is confined to one primary channel of information processing. The first such case was TOB: a patient with a progressive disorder of semantic memory that affected his ability to comprehend the spoken names of animals, but spared his knowledge of named objects (McCarthy & Warrington 1988). Most remarkably, TOB was able to give good definitional and associative information about visually presented stimuli, irrespective of their semantic category (see table 3). TOB was only able to give superordinate information about words that he failed to comprehend ('it's an animal but I've no idea which one'). He was also remarkably consistent in his vocabulary: the same items were lost to his vocabulary and the same ones were spared over 3 and 6 month testing intervals.

Because TOB's disorder was confined to one semantic category, we would argue that spoken words had been processed up to the level of semantic analysis. The difference in his comprehension of spoken words and pictures therefore seems to indicate a separation between the semantic subsystems that are accessed by words and pictures. We argued that category specificity and modality specificity were orthogonal variables. Of course, with any single dissociation, alternative explanations are possible. One possibility is that visual input might access semantic information about animals more powerfully or directly than verbal information (Caramazza *et al.* 1990; Farah & McClelland 1991). Further dissociations are critical to distinguish these possibilities. If the semantic systems accessed by visual and verbal routes can be distinguished, then it might be possible to document complementary patterns of category specificity in both visual and verbal domains.

Table 3. *Category by modality interaction (TOB)*

Picture and word identification: percentage correct ($n = 48$).

	pictures	words
living things	94	33
inanimate objects	98	89

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Two recent cases are directly relevant to this issue. The first patient, DRS, was a highly intelligent research physicist who sustained several vascular episodes leaving him with a dyslexia and difficulties in recognizing visually presented objects (Warrington & McCarthy 1994). However, his comprehension of spoken words remained above the 95th percentile and his ability to recognize faces remained at a normal level. In view of his difficulty in recognizing objects, he was tested for his perceptual processing by using an object decision task (VOSP) (Warrington & James 1991). His performance on this test (85% correct) and on a test of tactile object identification (82% correct) was considered to be normal. He was not merely unable to *name* visually presented objects (58% correct) he was also unable to generate a pantomime in response to visually presented objects that he was not allowed to touch (58% correct). By contrast, he was flawless in generating actions in response to names of the very same objects when spoken by the experimenter.

We explored DRS's knowledge of other visually presented categories. On a visual–visual 'synonym' matching test (figure 3) he showed a significant difference between his good ability to match animal exemplars (80% correct) and his poor ability with object exemplars (45% correct). The category-specific effect was replicated in a follow-up study in which word–picture matching was employed. DRS showed a selective impairment of his ability to point to a named object (63% correct) as compared with a named animal (93% correct) or even a named flower (93% correct). In view of his excellent verbal abilities we would attribute the category-specific profile of failure on this task to DRS's difficulty in the visual identification of objects.

A second case has recently been investigated whose pattern exactly complements DRS. PHD sustained a severe closed head injury 17 years previously, leaving him with a disproportionate impairment in recognizing visually presented animals (McCarthy & Laws, in preparation). PHD's performance was normal on the VOSP object decision test and on tests of visual and perceptual processing up to the level of semantic interpretation. However, on the visual–visual 'synonym' test (described above) he was at chance with animals but normal for objects. PHD's knowledge of animals and other biological categories was further explored by asking him to define pictures and spoken words. The results indicated a fine-grain pattern of category specificity that was also modality-specific. PHD has a modality-specific impairment of semantic knowledge that is more significant for biological categories than for objects. However, he also shows a fine-grain dissociation of knowledge, being relatively better at identifying or defining visually presented foods than he is at identifying animals (see table 4, Kitchener & McCarthy).

5. MODALITY SPECIFICITY: THEORETICAL IMPLICATIONS

We argue that category specificity and modality specificity are orthogonal variables. The present

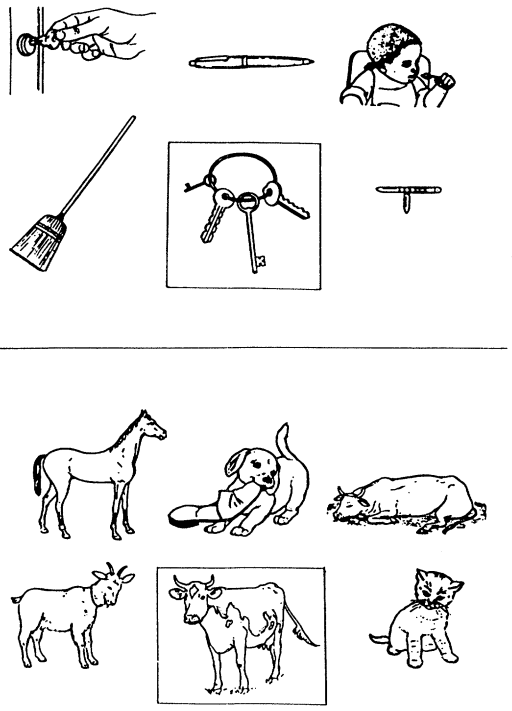

Figure 3. Examples of animate and inanimate visual–visual synonym matching test.

data are consistent with a model in which semantic information can be computed in dissociable, modality-specific meaning systems. However, these modality-specific semantic systems appear to show some similar category effects and may, therefore, have comparable organizational characteristics. Such similarities in organization are unlikely to reflect a simple duplication of knowledge across visual and verbal domains. These domains may differ because they are required to be different for normal function. They 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: see Bowerman, this volume). It therefore makes computational sense for the visual and verbal systems to have the potential for a considerable degree of autonomy. 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. One possibility is that the verbal semantic system initially develops by mirroring the organization of the visual semantic processor. Thus, the ontologically primitive segregation of knowledge into 'biological' (sensory) and 'non-biological'

Table 4. *Category by modality interaction* (*PHD*)

Picture and word identification: percentage correct.

	pictures	words
animals	33	77
foods	100	96

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(functional) protoconcepts might be carried over as a blueprint for organizing verbal knowledge. This seems an eminently sensible way for the semantic system to develop and would maximize the potential for transfer of relevant conceptual structures, while minimizing interference caused by differences in semantic scope and specificity.

6. ACCESS AND DEGRADATION

An important contrast has been drawn between the quality and quantity of stored knowledge and the complex operations or procedures involved in its access. Is it possible to differentiate empirically between the conceptually distinct notions of knowledge representation and the dynamics of information retrieval? Two classes of semantic impairment are directly relevant to these issues. In one subgroup of patient, failure to understand the precise meaning of words (and/or pictures) is highly stable and replicable. Exactly the same items appear to be irrevocably lost or degraded in their content when tested many months (or even years) later. By contrast, there are other patients whose knowledge seems inherently variable: on one occasion they may know the meaning of a word, but seconds later they may be unable to access it. If testing conditions are optimal their performance may approach normal levels; however, their semantic systems are unstable and a subtle variation in conditions may reveal a substantial impairment (Warrington & McCarthy 1983, 1987). These two classes of patients are considered to show disorders of 'semantic storage' and 'semantic access', respectively.

Three empirical variables appear to be important in distinguishing between access and storage disorders: the effects of testing rate; the effects of semantic relatedness between a target and any distracters; and word frequency. Most contrasts between patients with these different characteristics have been carried out retrospectively and the methods of testing and materials have been confounded (Rapp & Caramazza 1993). However, Warrington & Cipolotti (in preparation) have recently carried out a systematic study comparing these three variables in access and storage cases using exactly the same testing methods and test stimuli; preliminary results are presented here. Two patients with vascular disease, who appeared to have variable access to their knowledge base, and three patients with degenerative conditions, who appeared to have a stable but depleted knowledge base, were assessed. Word–picture matching tests were used with both types of patient. The subjects were presented with arrays of four stimuli and asked to point to named targets. Each array was sampled repeatedly (three times per target) so that a direct measure of the stability of the patient's knowledge could be obtained.

The effects of testing rate were varied by comparing a brief (1 s) interval between the subject's response and the presentation of the next target with a longer (15 s) interval. The results are shown in figure 4*a*. The patients diagnosed as having an access deficit were highly sensitive to the rate manipulation. These findings replicate earlier work in showing a deterioration in the subjects' ability to point to a named item unless they are allowed a brief rest in between trials (Cipolotti & Warrington 1995; Forde & Humphreys 1995). The three patients with degenerative conditions show no effects of testing rate. Semantic relatedness was varied by comparing across single category arrays of very closely related items (apple, pear, orange, banana) and less closely related items (cabbage, grape, potato, cherry). The patients who were sensitive to testing rate also showed a substantial effect of semantic proximity. By contrast, those patients unaffected by the manipulation of rate were also unaffected by semantic relatedness (see figure 4*b*). The third variable of interest was word frequency. Arrays of high- and low-frequency targets were presented, again using the word–picture matching paradigm. Once again there was a significant difference between the two classes of patient. However, with this manipulation it was the storage cases who showed a frequency-dependent loss of information; the access cases were not adversely affected (see figure 4*c*).

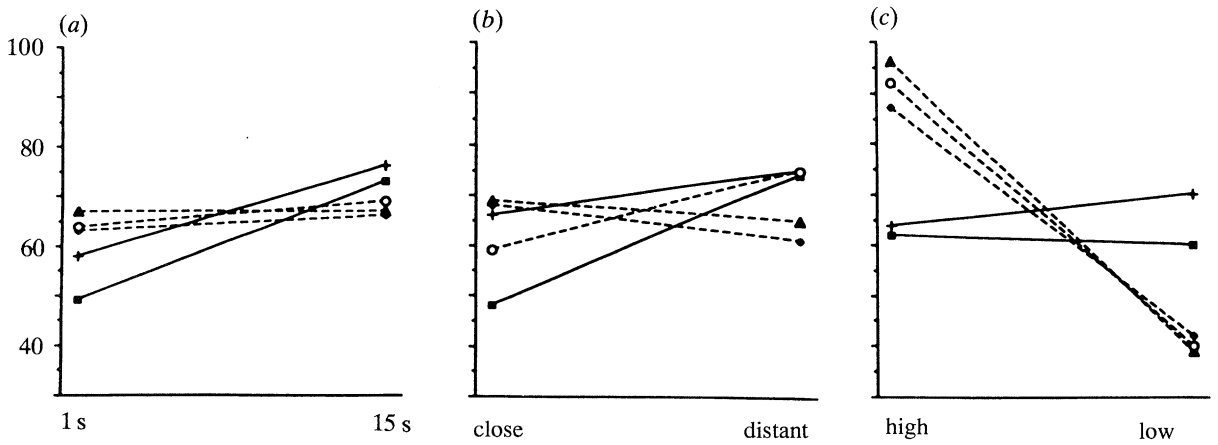

Figure 4. Performance of patients with access dysphasia (curves, filled squares) and patients with degenerative conditions (filled triangles, open circles and filled circles). (*a*) Presentation rate; (*b*) semantic relatedness; (*c*) word frequency.

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7. ACCESS AND DEGRADATION: THEORETICAL IMPLICATIONS

We have suggested that the fundamental deficit in access cases arises from instability in the activation of the semantic system. On this account, access deficits may be viewed as abnormalities in the dynamics of semantic processing and they may arise from local abnormalities *within* the system itself. Indeed, we contrast access deficits with disconnection syndromes, in which the *transmission* of input between different domains has been affected (for example, in the linkage of auditory lexical analysis with semantic interpretation).

Our proposal is that, after stimulation, the semantic system may become temporarily less able to respond to subsequent stimuli: access to the semantic representations has become refractory. In access cases, the period required for recovery is pathologically increased. In category-specific access cases, such refractoriness may be confined to a subregion of the system (Warrington & McCarthy 1983, 1987). The refractoriness hypothesis explains the effects of testing rate; by allowing the subjects a period of time for their system to recover, maximal performance is demonstrated. If we further speculate that refractoriness is not 'item' specific, but rather is common to members of a semantic field, then the effects of semantic proximity are easily explicable. So the extent to which similar information is required for computing a semantic interpretation will determine (or constrain) the 'spread' of refractoriness within the semantic system.

Under normal circumstances, semantic knowledge is accessed or computed in a context-sensitive and economical way. In the refractory phase of a semantic access disorder, subjects are restricted in their capacity to activate sufficient semantic information to allow them to distinguish between related exemplars. The absence of effects of word frequency appears to indicate that the instability seen in access cases compromises a process, or set of processes, that is independent of trace strength or the familiarity of individual representations. By contrast, those patients with a depleted semantic knowledge base who are sensitive to word frequency appear to have lost their weakest or least regularly interrogated semantic representations. Their disorder appears to have compromised the contents of semantic memory rather than the dynamics of accessing procedure (Hodges *et al.* 1992).

It remains to be established whether the instability that is characteristic of semantic access disorders reflects an exacerbation of the normal activation–inhibition process by which cognitive information is assembled from memory, or whether it is fundamentally physiological and reflects the changed responsiveness of a pool of neurons that have been subject to acute injury or deafferentation.

8. CONCLUSIONS

The study of impaired semantic knowledge has led to considerable refinements in the understanding of meaning. We have now reached a stage where there are clear correspondences between the issues, data, and theory that are applicable for the developing system and for the brain-injured individual. In particular, semantic category effects appear to provide an incisive scalpel for dissecting the organization of cognition. The structure of content, the multiplicity of systems, and the distinction between representation and computation, have all been illuminated by detailed investigation of brain-damaged patients: from disorder some order is emerging.

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