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Part I

Semantic Memory: Building Models from Lesions

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Semantic refractory access disorders

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Every individual has a vast thesaurus of conceptual knowledge. The cerebral organization of this knowledge base has intrigued philosophers for centuries and experimental psychologists for decades. By studying patients with brain lesions, neuropsychologists have been able to provide a powerful and direct source of evidence of the properties and organization of this conceptual knowledge base. This thesaurus is multifarious, encompassing words, objects, facts, people, places, and much more. In this chapter we will examine one particular neurological syndrome, "semantic refractory access dysphasia," and hope to demonstrate that patients with this disorder can provide a window on the organization of conceptual knowledge.

The original studies of semantic memory impairment were concerned to establish the selectivity of the deficit, especially with regard to the integrity of other cognitive systems. The boundaries with episodic memory, propositional language, and perceptual systems were all explored (Warrington, 1975). However, these early studies of semantic memory impairment did not attempt to differentiate between impairments of access to an intact knowledge base and damage to or loss of stored conceptual knowledge itself. "Storage" deficits are attributed to damage to the central representations of concepts, resulting in a static/stable, consistent, item-specific, loss of knowledge. Such storage deficits can be contrasted with what are termed "access" deficits, which reflect the temporary unavailability of stored representations. We wish to clarify at the outset that the term "access" is not used to refer to impairments of transmission of input between different cognitive domains but rather to the instability of activation within a system. The cardinal property of a semantic refractory access disorder (one subtype of access disorder) is sensitivity to temporal factors, resulting in an inconsistent performance. Response accuracy is improved when an interval is introduced between a response and the presentation of a subsequent stimulus. Such refractoriness has been defined as the reduction in the ability to use the system for a period of time following activation (Warrington & McCarthy, 1983, p. 874).

1.1 Description of the syndrome

The syndrome termed semantic refractory access dysphasia was first described in a patient (VER) who had sustained a major left hemisphere infarction (Warrington & McCarthy, 1983). Clinically this patient's propositional speech was gravely impaired and her comprehension of the simplest verbal instructions appeared to be all but absent. When asked to point to one of two objects she frequently succeeded with the first probe, only to make an error with the next. As a consequence, it was of interest to establish how long a delay was necessary between successive probes for VER's response accuracy to improve. The patient was tested on a picture vocabulary test (Dunn *et al.*, 1979) in which a series of words of increasing difficulty had to be matched to one of four pictures. The task was administered under both a fast (2 s) and a slow (30 s) presentation rate condition. Unexpectedly introducing a delay between making a response and presenting the next stimulus item (the response—stimulus interval, RSI) improved her performance significantly. This suggested that her comprehension vocabulary was much more extensive than was apparent clinically. In a series of further experiments using spoken word to picture matching it was shown that her performance with a 15 s RSI was consistently better than with a 3 s RSI. Furthermore, VER's performance on spoken word to written word matching tests was qualitatively very similar, suggesting again that under optimal conditions VER possessed a much more extensive written word vocabulary than might have been expected using standard assessment techniques. Although performance on word—picture matching tests comprising arrays of phonologically similar items (e.g. *cat*, *hat*) was no different than for random item arrays (e.g. *cat*, *leg*), her performance with arrays of semantically related items (e.g. *cat*, *dog*) was less accurate.

Despite subsequent single case studies reporting broadly congruent results on tests of spoken word, written word, and picture comprehension (e.g. Warrington & McCarthy, 1987; McNeil *et al.*, 1994), the theoretical validity of the distinction between refractory access and storage deficits was brought into question (Rapp & Caramazza, 1993). Such criticisms led to a more direct comparison of access dysphasics with patients with semantic storage deficits in an effort to provide a solid empirical base for the refractory access/storage distinction and, thereby, to delineate the criteria that identify a refractory semantic disorder (Warrington & Cipolotti, 1996). In this series of experiments word—picture matching tests were used to assess the residual comprehension skills of two patients with semantic refractory access deficits (consequent to either tumor or vascular damage) and four patients with semantic storage deficits (resulting from neurodegenerative disease). Typically the patients were presented with arrays of four or six items and asked to point to the named target. Each item in the array was probed repeatedly (three or four times) in a pseudorandom order. The performance of the two groups of patients gave rise to four factors which enable the delineation of refractory access and storage impairments of semantic processing.

1.1.1 Temporal factors

A sensitivity to temporal factors is a cardinal feature of refractory access syndromes. As noted above in the original description of patient VER, this can be demonstrated by varying the response–stimulus interval (RSI). It should be noted that an effect of temporal factors can be elicited without rushing the subject; typically a natural response pace is compared with longer delays. In Warrington and Cipolotti's study, a fast rate (1 s RSI) was compared with a slow rate (15 s RSI). Introducing this short interval between each response and the presentation of the next stimulus improved the accuracy of the access patients dramatically; however, no equivalent facilitation was observed for the degenerative cases (see Figure 1.1). This contrast, between the access cases and the degenerative cases, in their sensitivity to temporal factors was replicated in a subsequent investigation involving one access patient and three individuals with degenerative conditions (Crutch & Warrington, 2005).

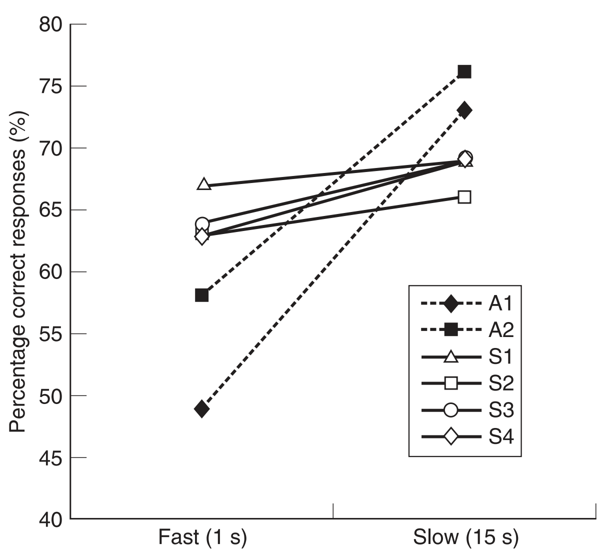

Figure 1.1. The effect of temporal factors upon the word–picture matching response accuracy of patients with refractory access disorders (A1, A2) and static storage disorders (S1, S2, S3, and S4) of semantic processing (Warrington & Cipolotti, 1996; Experiment 2).

1.1.2 Response consistency

A second critical distinction between refractory access and storage deficits lies in the degree of response consistency which emerges when subjects attempt to comprehend stimuli which are presented repetitively (Warrington & Cipolotti, 1996; Crutch & Warrington, 2005). In refractory access patients, this behavioral characteristic is integrally linked to their sensitivity to temporal factors: the occurrence of refractoriness, which has been defined as the inability to utilize the system for a period of time following activation, inevitably results in inconsistency of response. Such patients respond inconsistently to specific items, whilst storage patients who appear to have an item-specific deficit do not. Furthermore, the accuracy of refractory access patients has been found to decline with repeated probes of the same items in an array, resulting in characteristic serial position curves. Serial position effects have not though been observed in patients with degenerative conditions, who tend to make consistent errors with each successive probe (see Figure 1.2).

1.1.3 Frequency

Stimulus frequency is a very powerful determinant of performance at all stages of cognition. In individuals with storage deficits of semantic knowledge (who comprise the majority of patients reported in the neuropsychological literature), massive word frequency effects are often observed. However, in refractory access cases frequency effects have been reported to be either minor or absent.

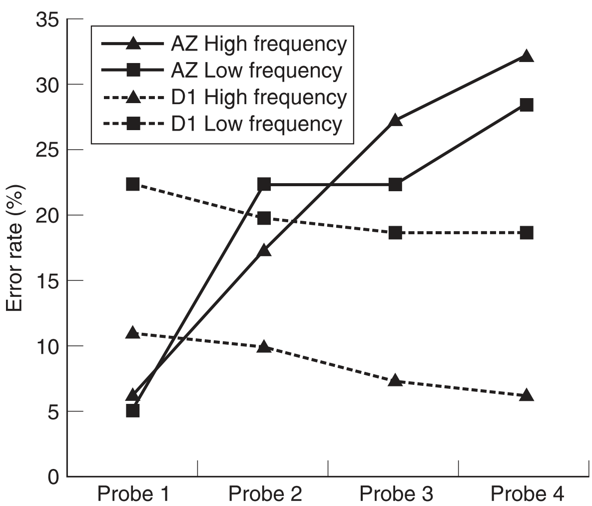

Figure 1.2. Serial position curves showing the percentage error rates of a refractory access patient (AZ) and a static storage patient (D1) on each probe of stimuli in a spoken word–picture matching task (Crutch & Warrington, 2005; Experiment 1).

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In the investigation that compared directly these two syndromes, the performance of the access patients was equally compromised for both a high- and a low-frequency vocabulary, whereas the expected robust frequency effects were observed in the degenerative patients. Indeed there was a cross-over in performance: the individuals with degenerative conditions were superior to the access cases with the high-frequency vocabulary but the converse held for the low-frequency vocabulary. This contrast was subsequently replicated in an experiment comparing an access patient with an Alzheimer's disease patient who had a storage deficit (Crutch & Warrington, 2005). These individuals were presented with high- and low-frequency three-item picture arrays, for which the identity of each item was probed four times in a pseudorandom order using a spoken word—picture matching technique. As in the Warrington and Cipolotti study, only the patient with a storage deficit showed any sensitivity to item frequency (also see Figure 1.2).

1.1.4 Semantic relatedness

The semantic relatedness of stimulus arrays can vary greatly, ranging from semantically very distant arrays containing items which cross broad category boundaries (e.g. *slipper*, *tiger*, *cherry*), to arrays with items from within a broad category (e.g. man-made artifacts: *slipper*, *knife*, *stool*), to arrays with items that are semantically closer in that they are drawn from a subordinate category (e.g. clothes: *slipper*, *pyjamas*, *socks*) or even a very narrow category (e.g. footwear: *slipper*, *sandal*, *stiletto*). By comparing "close" and "distant" within-category arrays, it was shown that semantic relatedness had a strong deleterious effect for the access cases but less so for the degenerative cases. However, when performance on close arrays was compared with performance on distant arrays containing items that crossed major category boundaries, a significant semantic distance effect was observed in the degenerative cases (Warrington and Cipolotti, 1996).

In a subsequent investigation by Crutch and Warrington (2005), the basis of the semantic relatedness effect was explored in more detail by contrasting the effects of semantic similarity in the two types of patient. Specifically, we observed an interaction of word frequency with semantic relatedness in the degenerative cases such that a semantic similarity effect was observed with middle-frequency items but not with the high- or low-frequency items. By contrast, the access patient tested showed clear semantic distance effects with high-, medium- and low-frequency stimuli (see Figure 1.3). It was suggested that the weak semantic relatedness effect observed in the degenerative patients could be accounted for by relative preservation of superordinate information which could serve to mediate responses in the semantically distant arrays but would be ineffective in the semantically close arrays. By contrast, we attributed the semantic relatedness in

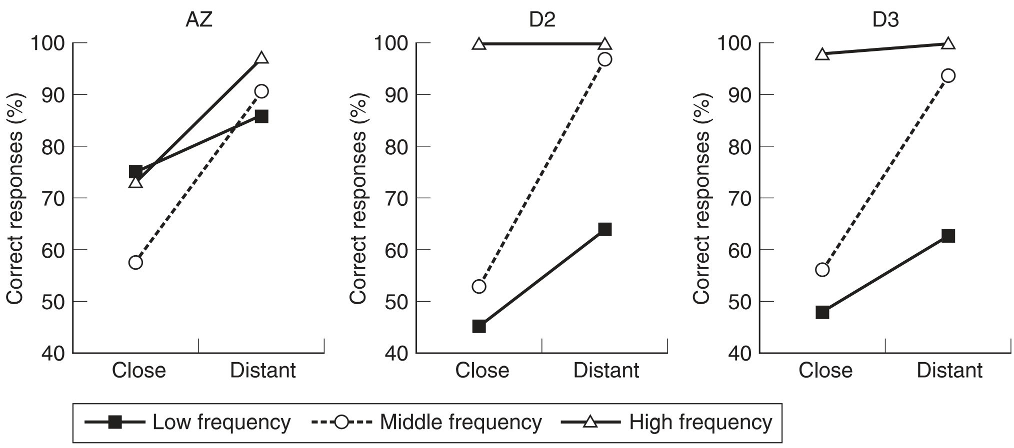

Figure 1.3. The interaction of semantic relatedness and item frequency. Percentage correct responses are shown for the performance of one refractory access patient (AZ) and two static storage patients (D2 and D3) on a spoken word–picture matching task involving semantically close and distant arrays comprising low-, middle- and high-frequency man-made artifact stimuli (Crutch & Warrington, in press; Experiment 2).

the access patient to refractoriness that affects not only the repeated items but also other concepts whose representations partly share semantic space. Indeed, refractoriness has been shown to spread not only between target items and distractors but also to previously untested items (Forde & Humphreys, 1995).

Thus the concept of semantic refractory access disorders was evoked to unify these four identifying criteria. All four characteristics are held to reflect a semantic system in which there is a reduction in the ability to access concepts for a period of time following activation. More specifically, response inconsistency and serial position effects are considered to be direct consequence of such refractoriness, whereas semantic relatedness effects are held to reflect the spread of refractoriness between items that share semantic space. Furthermore, a number of empirical investigations suggest that low- and high-frequency semantic concepts become equally refractory. Having established the criterion by which semantic refractory deficits may be identified, we now move on to consider how such deficits have been harnessed to investigate the organization of semantic knowledge in more depth than can be achieved by investigating patients with static category-specific deficits.

1.2 Semantic refractory access category dissociations

The categorical organization of an individual's semantic knowledge base is well established for broad classes of information. The evidence for the most part rests on the documentation of category-specific impairments and category-specific preservations observed in patients with cerebral structural damage. The double dissociations between knowledge of abstract and concrete concepts (e.g. Warrington, 1975; Sirigu *et al*., 1991; Breedin *et al*., 1994), animate and inanimate stimuli (e.g. Warrington & Shallice, 1984; Caramazza & Shelton, 1998; Capitani *et al*., 2003 [review]), and proper nouns and common nouns (e.g. Semenza & Zettin, 1988, 1989; Miceli *et al*., 2000; Lyons *et al*., 2002) have been replicated in many centers. Refractory access deficits also have the potential to reflect dissociations if refractoriness can be shown to affect or spare a particular semantic category. In such cases we would suppose there was a degree of independence of the neural structures supporting those respective semantic fields. By contrast, evidence of semantic distance effects would be considered to indicate the organization of concepts within a semantic field.

In the original semantic refractory access patient described above (VER; Warrington & McCarthy, 1983), an artifacts deficit was observed. Comparing word–picture matching performance on two- and five- item arrays of food items with man-made artifacts at two presentation rates, VER's performance on comparable conditions was shown to be impaired for the nonliving items. In a further experiment that compared her ability to identify items within picture arrays of flowers, animals and man-made artifacts, her performance was significantly worse with the artifacts than with the other two categories. Thus it appeared that the activation of nonliving object conceptual representations was more likely to elicit a refractory state than the activation of concepts supported by other areas of semantic space.

This dissociation between living and nonliving items was replicated in a second case (YOT; Warrington & McCarthy, 1987). This patient was unable to speak and had very limited comprehension after suffering an occlusion of the left middle cerebral artery. Apart from establishing a living/nonliving dissociation, YOT's comprehension of multiple categories was explored using spoken word–written word and spoken word–picture matching procedures. These investigations yielded several findings. First, a dissociation was demonstrated *within* the broad category of inanimate objects. YOT had significantly more difficulty with arrays of manipulable objects than with arrays of large man-made artifacts. Secondly, her comprehension of proper nouns was remarkably well preserved. This contrasted with her exceptionally poor comprehension of common Christian names. Thirdly, YOT's comprehension of certain abstract concepts was explored and these items appeared to be of middling difficulty for her. This pattern of preserved and impaired categories was subsequently replicated by Forde and Humphreys (1995, 1997) in a patient who also showed a greater build-up of refractoriness for nonliving than living items and for common proper names than famous proper names. Furthermore, McNeil *et al.* (1994) described a global dysphasic patient with the defining characteristics of a semantic refractory access deficit who appeared to have the selective preservation of famous person names.

The first attempt to give a principled account of semantic category dissociations was by the contrast of sensory and functional attributes within the domain of animate and inanimate stimuli. However, there were a number of anomalies that were difficult to encompass by this simple dichotomy: the selective impairment of action verbs, the isolated preservation of maps, and evidence of more fine-grain impairments such as fruits and vegetables. Indeed, it was the evidence of multiple selective impairments and dissociations observed in a semantic refractory access case that motivated the initial elaboration of the original sensory—functional framework (Warrington & McCarthy, 1987). It was proposed instead that there are multiple channels of processing within both the motor and sensory input systems. Differential activation or weightings of these channels during acquisition were held to provide the basis for a fine-grain categorical organization of semantic knowledge in the adult (see also Crutch & Warrington, 2003a).

1.3 Evidence for fine-grain semantic organization within broad categories

The evidence of categorical dissociations derived from refractory access patients must be interpreted with caution. Semantic relatedness effects are so robust that it is possible that an apparent category dissociation could be reduced to unequal semantic relatedness within an array. For example, it would not be appropriate to claim a living/nonliving dissociation if a patient's identification performance with arrays of five very distant animals were to be compared to performance with arrays of five semantically similar man-made artifacts. Nevertheless semantic refractory access deficits have proved to be most illuminating with regard to the organization of conceptual knowledge in the brain. Not only do specific items become refractory, but semantically related items also become refractory. For example, with repeated probes in a word—picture matching task there will be a higher error rate with a semantically related array than with a semantically more distant array. It is the ubiquity of semantic distance effects that provides the opportunity to observe the organization of an intact knowledge base or at least one that can be accessed under favorable conditions.

Before discussing the evidence for fine-grain organization of the semantic knowledge base, one procedural point will be described. Despite the relative insensitivity of patients with refractory access deficits to item frequency, it is important in assessing semantic similarity that the frequency of items being probed in each condition is carefully balanced. One procedure whereby this is achieved is to probe the same items both in a semantically close array and in a semantically distant array. This technique was first used in the investigation of YOT (Warrington & McCarthy, 1987), the patient whose comprehension of nonliving concepts was more impaired than comprehension of living concepts. Six pictures from each of six close semantic categories were selected. Each of these items was probed in a semantically close array containing items from the same category. These same items were then rearranged into semantically distant arrays each containing one item from each category. Thus by equating the array size to the number of categories or subcategories it is possible to explore semantic relatedness in depth (i.e. four categories in arrays of four items, three categories in arrays of three items, etc). Indeed, this procedure can be extended to more levels of semantic similarity by dividing each of the broad categories into subcategories (i.e. *pigeon*, *crow*, *sparrow*; *pigeon*, *goldfish*, *cow*; *pigeon*, *leek*, *shirt*). By using this procedure for constructing semantic relatedness experiments, not only item frequency but many other relevant variables such as concreteness, familiarity, and visual complexity are controlled because exactly the same stimulus items are examined under each semantic distance condition.

In our extensive series of experiments with our patient AZ we used this procedure to assess her comprehension of a very broad range of concepts within the domains of proper nouns, common nouns, parts of speech, abstract knowledge, and concrete knowledge. AZ had sustained a major left hemisphere stroke in the territory of the middle cerebral artery. Clinically, she was globally and severely dysphasic, dysgraphic, and dyslexic. However, our investigations focused upon her comprehension skills because AZ demonstrated all the core features of a semantic refractory access disorder. These characteristics can be illustrated by her performance on a "levels of semantic similarity" experiment conducted using spoken word–picture matching (Crutch & Warrington, 2005). The test stimuli were high- and low-frequency concrete items from the broad categories of animals, plants, and man-made artifacts which were arranged into three-item semantically close (e.g. *crow*, *pigeon*, *sparrow*), medium (e.g. *crow*, *dolphin*, *sheep*) and distant arrays (e.g. *crow*, *potato*, *jumper*; see Figure 1.4 for examples of low frequency items). It was observed that AZ's response accuracy was a function of semantic relatedness for both high- and low-frequency set items. Her error rate on the first probe of a stimulus item in a given array was also found to be negligible but to increase with successive probes (see Figure 1.2). Furthermore, there was no significant difference in response accuracy with high- and low-frequency stimuli. In a similar experiment, arrays containing matched sets of semantically close,