

semantic attributes of numbers must be stored in the adult parietal cortex in order to explain the pattern of dissociation and association observed after a brain lesion. The current debate about category-specific impairments is mainly devoted to the question of the relative importance of visuo-semantic attributes in the processing of living and nonliving entities. If one turns towards numbers, it appears that, rather than being defined by visual or functional attributes, numbers are better defined by other numbers. In fact, numbers share a series of very specific semantic attributes: they pertain to the same ordered sequence, they represent a quantity, and this quantity can be defined as the sum of the preceding number and 1, when 0 and 1 have been defined (Russell 1921). Furthermore, numbers are subject to specific semantic manipulations such as subtraction, multiplication, parity judgment, and so on. In this respect, one might suggest that numbers are represented in an autonomous semantic store located in specific cortical areas; a true categorical account (TCA). In such perspective, most if not all, of the attributes of numbers must be stored in the same region, and all must be specific to numbers. However, in apparent contradiction with the TCA is the fact that numbers are also involved in the definition of other concepts (e.g., a dog has got four legs, there are 60 seconds in one minute, etc.). Another potential explanation of the category-specific deficit or preservation for numbers might be that they emerge as a category in the semantic system because they share some particular properties implemented in distinct brain regions; a reductionist account (RA). One such property could be that numbers are organised in an ordered sequence. At the semantic level, this means that each number must be linked to the following one by a "plus-one" link, and to the preceding one by a "minus-one" link (Thioux et al. 1998). The observation that, in both NM and CG, the categories of numbers, days, and months were conjointly spared or impaired fits with the hypothesis that these concepts have this important property in common. Nonetheless, a RA might have difficulty in explaining why different aspects of number meaning (e.g., order and magnitude) were conjointly spared or preserved in CG and NM. At first glance, this suggests that different meanings of numbers are grouped together in the same cortical areas.

In this respect, a RA can hardly be distinguished from a TCA, the only difference being that in the latter the critical areas are assumed to be involved in the storage of all the semantic attributes of the concepts, and only those. The fact that bilateral parietal areas are involved in eye movement, visuo-spatial representations, grasping, time estimation, as well as in magnitude estimation gives so many opportunities to justify one and the other account. In fact, all these abilities might have been important in the development of a fully integrated representation of number meaning, but also, each of these abilities might rely on a specific area within the parietal lobe.

## Concepts and categories: What is the evidence for neural specialisation?

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**Abstract:** Humphreys and Forde argue that semantic memory is divided into separate substores for different kinds of information. However, the neuro-imaging results cited in support of this view are inconsistent and often methodologically and statistically unreliable. Our own data indicate no regional specialisation as a function of semantic category or domain and support instead a distributed unitary account.

Humphreys & Forde's (H&F's) Hierarchical Interactive Theory (HIT) of object recognition makes important claims about the organisation and processing of semantic knowledge. In this com-

mentary, we concentrate on two main issues: (1) the authors' interpretation of the neuro-imaging data as support for their claim that semantic knowledge is divided into separate stores and that there is top-down activation of visual information in naming, and (2) the relation between the organisation of semantic knowledge and the internal structure of concepts.

H&F suggest that "the concept of a semantic system in any unitary sense may be one of the victims of an attempt to define the nature of our stored knowledge in more detail" (p. 6). They argue for multiple substores, concentrating on the separation between stored structural descriptions and "stored functional and inter-object association information." Much of the motivation here comes from the analysis of the neuroimaging literature (see sect. 5.1) where H&F interpret existing studies as supporting the claim for anatomical differences in the representation of different categories or types of knowledge. However, close inspection of the neuroimaging data suggests a more complex and less coherent picture than is implied in their review. Instead of a consistent set of regions being activated in response to either living or nonliving things, across studies many different regions are activated. For example, Perani et al. (1995) report activation in the left fusiform and the left lingual gyrus for natural kind concepts. None of these regions overlap with those activated in Mummery et al. (1996) which reports activation in the left anterior temporal pole, right anterior temporal pole and right inferior parietal lobe. This discrepancy is typical across the board, with perhaps the exception of the left posterior middle temporal gyrus which has been activated in a number of studies in response to tools (Damasio et al. 1996; Martin et al. 1996). However, even this region is not robustly activated within individual studies.

This general lack of consensus across studies is due to many factors, some methodological and some statistical. H&F acknowledge that some differences may "reflect variations in scanning procedures or in the task requirements." We believe that the problems are even more wide-ranging than this, and warrant greater caution in the interpretation of results. For example, sets of stimuli are not always controlled for factors such as familiarity, imageability, and letter length (for words) and visual complexity or structural similarity (for pictures) although these variables can generate spurious differences (e.g., Funnell & Sheridan 1992). Problems also arise because in many studies statistical maps are not corrected for multiple comparisons between voxels. Using uncorrected alpha levels over large numbers of contrasts increases the probability of obtaining a high proportion of false positives. Thus, many of the reported significant activations may, in fact, be false positives. Indeed, some studies include little statistical support for apparent differential activations. Chao et al. (1999) for example, do not report full statistical information, such as *z* scores and their accompanying significance values (nor do they correct for multiple contrasts), yet H&F interpret their finding of lateral fusiform activation for questions about living things as strong support for their claim that specific forms of knowledge are drawn on to different degrees when accessing knowledge about living and non-living things.

When we try to avoid these problems by controlling for nuisance variables and correcting for multiple statistical comparisons, we find that there is no neural specialisation as a function of category or domain of knowledge (Devlin et al., in press; Tyler & Tovaes, in press). In three PET studies using different tasks (lexical decision and semantic categorisation) we found an extensive network in L fronto-temporal regions which was reliably activated for semantic processing of words and pictures. However, there were no domain or category effects in either study. We only found differences between natural kinds and artefacts at an uncorrected level of significance and these activations were generally inconsistent across the experiments.

H&F also rely on neuroimaging results to support the idea of re-entrant activation of visual information in the naming task. Their argument is as follows: (1) left inferior and posterior temporal lobes are more involved in object naming than in naming the

colours of non-objects (Price et al. 1996), (2) if inferior and posterior temporal regions are linked to stored visual knowledge, then this shows that naming known objects involves extra recruitment of visual knowledge over and above simply recognising those objects (i.e., re-entrant activation). The basis for assuming that these regions are linked to stored visual knowledge is that they are activated to a greater extent for animals than tools. However, as we have argued above, the support for this claim is inconsistent at best. Moreover, even if these regions are more activated for animals than tools, it seems circular to assume that this is because of the greater demand on visual processing for these concepts. Thus, although we agree that interaction among the different stages of the hierarchy may be more plausible than the strictly feed-forward cascade model, the specific support cited for this claim is not clear cut.

Thus, the neuroimaging data do not provide compelling support for neural specialisation as a function of either category or domain. Indeed, they appear to be more compatible with the kind of distributed account of conceptual knowledge which we have been developing (Durrant-Peatfield et al. 1997; Tyler & Moss, in press; Tyler et al. 2000). In this account, concepts are represented as sets of overlapping features – some distinctive and some shared across concepts. Frequently co-occurring features (has-legs, has-ears) support each other and are thus more resistant to damage. Since their distribution differs across categories, some categories are more susceptible to semantic damage than others, leading to category-specific semantic impairments (Moss & Tyler 2000; Tyler et al. 2000). On this account, there is no anatomical differentiation by semantic content. Concepts are represented in a distributed neural system including frontal, temporal, parietal, and occipital regions. The components of this highly interactive system will be more or less involved, depending on a number of factors – the nature of the input, specific task, and the additional non-linguistic cognitive demands required.

This leads to our second point. H&F discuss our account of conceptual structure, and agree that “the differences between shared and distinctive features and the degree to which these features correlated with the function of the object are likely to be important contributing factors in category-specific deficits.” We acknowledge that such models need to be elaborated further and set within a framework for object recognition (and language comprehension). In fact, we have always assumed (implicitly, at least) that there is a structural description system (or some form of low-level object processing) necessary for object recognition. We differ from H&F in assuming that perceptual properties of objects are not only represented at this level – in a modality specific store of “templates” for object recognition – but that they are also represented along with other kinds of semantic property within a distributed semantic system. One reason for this is that structural descriptions seem to consist of only a subset of the perceptual properties of an object – essentially its shape – leaving other perceptual properties such as colour, size, surface texture, and pattern unaccounted for. Second, how are correlations among the perceptual and functional properties of objects captured if these properties are stored independently in modular subsystems? H&F appear to be in agreement with an approach that emphasises the internal structure of concepts – yet it is not clear how they are proposing these inter-feature relations are to be instantiated across the different information stores.

Thus, while disagreeing with some of their conclusions, we support H&F’s efforts in laying the groundwork for a thorough discussion of the issues involved in constructing a cognitive and neural account of object recognition.