The sub-plot that mitochondrial sequences can evolve rapidly is just as exciting. Although the two brothers share the same heteroplasmy, they presumably inherited from their mother very different proportions of the C and T at position 16169. Further, the type T mitochondria must have segregated to homoplasmy within the four generations from the Tsar's mother to Xenia. This royal documentation of rapid mitochondrial evolution in humans will prompt some serious thinking about the mechanisms of mitochondrial selection and transmission. But for those of us in the audience watching the progress of human genetics it also perhaps indicates that we may have too simplistic a view of the inheritance of human characteristics as being solely down to the genetics of the nucleus. The subcellular population drifts of mitochondrial genetics through the generations may yet have a surprise or two in store for those beavering away on the Human Genome Project. □

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NEUROPSYCHOLOGY

The brain's dictionary

Alfonso Caramazza

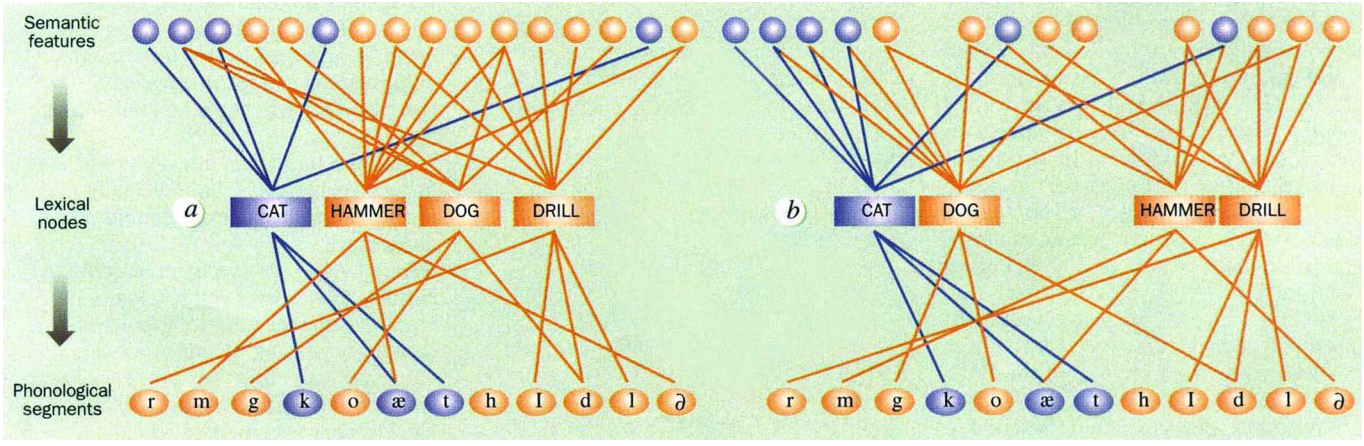
How is knowledge of words organized in the brain? Hanna Damasio and her collaborators (page 499 of this issue[1]) may have provided part of the answer to this complex question. They report evidence that suggests that lexical knowledge is organized by category in distinct areas of the left temporal lobe. Their proposal distinguishes among three neural systems: one represents the conceptual content (the meaning) of words; another represents the phonological elements (sounds) that compose words; and the third, mediating between the first two, represents modality-independent lexical knowledge. It is this third system that Damasio and her collaborators have localized to the left temporal lobe.

This proposal contains the basic claims that there is a level of lexical representation that mediates between conceptual and phonological knowledge of words; that knowledge of words is organized categorially; and that the part of word knowledge that is organized categorially in the left temporal lobe is the lexical level and not the conceptual or phonological levels. The first two claims are widely accepted and are supported by various sorts of experimental evidence. The last claim is new, and is the subject of Damasio and colleagues' study.

Cognitive scientists have long maintained that, in speech production, word retrieval involves two stages of processing: representations at the conceptual level are initially used to select modality-independent lexical representations; these lexical representations are then used to select specific phonological forms. In other words, it is thought that there are abstract lexical representations mediating between conceptual knowledge and the phonological form of words (*a* in the figure). These representations are said to be abstract or modality-independent because they specify the words of the language without directly providing information about their phonological or orthographic forms. There is compelling experimental evidence in support of this hypothesis[2,3].

Similarly compelling is the evidence that semantic categories (that is, categories such as furniture, birds, fruits and tools) play a crucial role in the organization of word knowledge in the brain. The neuropsychological literature contains sporadic references to the existence of category-specific deficits at least since 1936, when Nielsen[4] described one patient who had much more difficulty in naming living than non-living things, and another who had the reverse problem. But it was not until Warrington's[5] seminal work on semantic memory, published in 1975, that such deficits were explored in enough detail to permit firm conclusions about their significance for theories of the organization of word knowledge in the brain. Since then, a large number of detailed reports have conclusively demonstrated that brain damage, for instance as the result of a stroke, can result in highly selective deficits of semantic memory involving specific conceptual categories. For example, there have been many reports of selective impairment[6] or 'sparing'[7] in use of words in the category 'animals'. Other semantic category-specific deficits (for example for tools, proper names, fruits and vegetables, and so on) have also been described[7]. Furthermore, it has been shown that the category effects are not due to extraneous factors such as the relative familiarity or complexity of one or another semantic category.

Nevertheless, the precise interpretation of these semantic category deficits remains unresolved. One interpretation assumes that they reflect either damage to semantic properties shared by members of



a, The three levels of representation of word knowledge necessary for speech production. Semantic features (carnivorous, furry, domesticated, pet) activate lexical nodes (the word CAT) which, in turn, activate their corresponding phonological features (k, æ, t). *b*, Organization of the three levels in the form proposed by Damasio *et al.*[1]. The neural system for conceptual information consists of a distributed network involving structures in both the left and right hemispheres. These networks are connected to lexical representations in the left temporal lobe which are organized by semantic category — animals in the inferior temporal (IT) lobe; tools in the posterior regions of the IT lobe and the occipito-temporo-parietal junction. The selected lexical representation in turn activates its associated phonological features for speech production.

a particular category or damage to the pathways leading from those semantic properties to lexical representations[6,7]. Damasio *et al.*[1] propose, instead, that category-specific deficits may reflect the categorial organization of the mediating lexical representations (*b* in the figure). They base their conclusion on the results of two studies — one involving anatomo-clinical correlations, the other involving functional imaging with positron emission tomography (PET).

The principal evidence they provide is the correlation between category-specific naming deficits and sites of brain damage. To maintain that the category effects in naming disorders reflect specifically the organization of lexical (and not conceptual) representations, it must be shown that naming failures do not result from damage to the semantic system. To this end, a naming trial was scored as an error only when patients demonstrated comprehension of the object by providing an adequate description but still failed to produce the correct name (for instance when they could describe a skunk as a small, black-and-white animal that makes a nasty smell, but not actually name it). In this way, Damasio *et al.* argue, we may be sure that category-specific naming failures can be attributed to a deficit in lexical retrieval and not in semantic processing.

Using this procedure, they found that patients who were selectively impaired in producing people's names had damage restricted to the left temporal pole (TP); patients who were selectively impaired in producing animal words had damage restricted to the left inferior temporal (IT) lobe; and patients who were selectively impaired in producing the names of tools had damage to the posterior inferior temporal lobe and the temporo-occipito-parietal junction (posterior IT+) (see Fig. 2 of the paper on page 501).

Converging evidence for this conclusion came from a parallel PET study with neurologically intact individuals: significantly greater activation was found in the left TP, IT and posterior IT+ in naming people, animals and tools, respectively. The close correspondence in the results obtained in the PET and the anatomo-clinical studies provides a compelling basis for the conclusion that word knowledge is organized categorially in the left temporal lobe.

There is a pleasing elegance to the proposed theoretical framework for the organization of word knowledge in the brain. The autonomous level of lexical representation serves the important function of providing focal points for collecting the set of distributed conceptual and phonological features that constitute, respectively, the meaning and the pronunciation of words. The localization of these lexical representations to specific areas of the left temporal lobe is an important achievement. The proposal that these lexical representations are organized by semantic category is equally important, although it is not uncontroversial because other imaging studies have found maximal activation for the animal and tool categories in other areas of the left hemisphere[8]. We also cannot exclude the possibility that the category-specific deficits in Damasio and colleagues' patients involved semantic rather than lexical representations.

Further studies will be needed to resolve these potential difficulties, and to address aspects of lexical representation not tackled by Damasio *et al.* Their study was restricted to concrete concepts. Are abstract concepts — justice, evidence and ambition, for example — also represented categorially? Are they, too, represented in the temporal lobe? And what about syntactic information? Lexical representations must also serve as the focal points about the grammatical class of words and their selectional restrictions (for instance that the verb 'give' but not 'die' requires a direct object)[2,3]. It is obvious the syntactic features of words must be represented in the brain, but not how this information is organized in relation to other aspects of word knowledge.

What is clear, however, is that brain damage can result in selective deficits for individual grammatical classes of words. For example, patients have been reported with selective deficit[9] or sparing[10] in use of verbs, nouns or function words (articles, auxiliaries and prepositions). These results, like those for semantic categories, suggest some form of categorial organization at the lexical level of representation. It remains to be determined how the categorial structure for syntactic features is related to that for semantic categories, but the combined approach of anatomo-clinical and functional imaging studies provides a promising way forward. □

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DAEDALUS

Variable voltage

THE transformer, that elegant invention which steps some voltage up or down in almost every electrical or electronic system in the world, has one major drawback. It only works with alternating current — indeed, that is why all power distribution systems use a.c. Daedalus is now inventing a true d.c. transformer.

He points out that a current flows in a wire because each electron is pushed along by the repulsion of the electrons behind it. They need not be exactly behind it; even an electron behind and to one side will exert a component of its repulsion in the direction of the current. Even an electron so far to one side that it is in an adjacent wire will exert some repulsion. So, says Daedalus, a steady current in one wire should create one in another wire alongside, simply by this diagonal repulsion. This is a d.c. transformer.

Sadly, electron repulsion falls off rapidly with distance. For an electron in one wire to influence one in another, the wires would need to be almost atomically thin and adjacent. Modern monolayer-film and vapour-deposition techniques can lay down such layers quite easily. So Daedalus's d.c. transformer consists of many alternate layers of metal and insulator, each only a few atoms thick, interleaved so that a current in the input layers induces a current in the output layers between them. If each input layer is a single wide strip, while each output layer is many narrow strips side by side and connected in series, the result will be a step-up transformer. Connected in reverse, it will step a voltage down.

In step-up form, the d.c. transformer will be a wonderful saver of batteries. All batteries lose voltage as they run down. We usually discard them long before they are exhausted, simply because their voltage has dropped too low. But an adjustable d.c. transformer in the circuit could be arranged to step up the voltage automatically as fast as it declined. The last drop of power could be wrung from every battery.

The step-down d.c. transformer will make possible a new battery. Many radioactive sources emit electrons or alpha-particles of many millions of electron volts — a tiny beam of 'primary current' at very high voltage. Fired at grazing incidence past an appropriate secondary winding, it could induce a much stronger current at a usefully lower voltage. Radioactive waste, now a pure liability, could power neat and highly efficient little 'radio-batteries' that might last for decades. They would be ideal power sources for isolated areas, or unmanned relay or scientific stations, or even spacecraft. David Jones