Neurobiology

Space and time in the mental universe

Patricia Goldman-Rakic

The term 'working memory' refers to the ability to bring to mind and process limited amounts of information. The defining quality of working memory is its transient, 'on line', nature: for example, holding and processing pieces of information as we read and comprehend a line of text, recall a telephone number, plan a chess move or follow verbal instructions to locate an unfamiliar street address. Working memory provides a temporal bridge between events — both those that are internally generated and environmentally presented — thereby conferring a sense of unity and continuity to conscious experience. Advances in human brain imaging have opened a window on the anatomy of higher cognitive functions[1] such as working memory, and magnetic resonance imaging (MRI) techniques have now refined our ability to observe the timing and sequences of such functions. This is exemplified by Cohen *et al.*[2] and Courtney *et al.*[3] (pages 604 and 608 of this issue), who have looked at the temporal parameters of working memory in the human brain.

Current understanding of working memory in the central nervous system is based, in part, on psychological studies of short-term memory in humans[4,5], and neurobiological analyses of the same in non-human primates[6,7]. Single-neuron recordings in monkeys that are trained to perform working-memory tasks have identified components of a working-memory circuit in the prefrontal cortex. Here, the neuronal processes that are related to task performance can be dissociated, on the scale of milliseconds to seconds[6,7]. So, during a working-memory task, as the stimulus is sequentially registered, stored over a period of seconds and then translated into a motor response, specific neuronal populations respond in characteristic ways. For example, one class of prefrontal neuron responds to a visual stimulus as long as the stimulus is in view. In contrast, other prefrontal neurons are activated at the offset of the stimulus, and they remain active (at heightened levels) all the time that the monkey has to remember the location[6,7], or features, of an object[8]. These neurons are thought to be the cellular correlate of the transient memory trace.

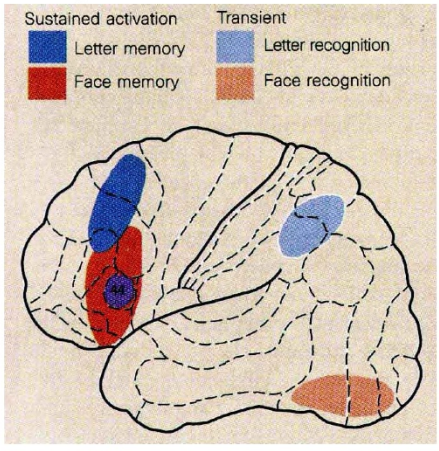

Figure 1 **Sophisticated brain-imaging techniques have allowed the areas that are associated with human working memory to be identified. Cohen *et al.*[2] asked subjects to remember whether a given letter was the same as a letter that had been presented two or three trials back in a series. Courtney *et al.*[3] set subjects a similar task that required them to recognize and remember particular faces. Specific regions of the prefrontal cortex, along with functionally related (and presumably anatomically connected) areas in the sensory-related regions of the posterior lobe, were identified as being active in each working-memory task.**

Cohen *et al.*[2] and Courtney *et al.*[3] show that the fast scan-times of imaging methods such as echoplanar functional magnetic resonance imaging (fMRI) can accurately capture the time course of the analogous human working memory. They extend the knowledge that has been gained from animal models by single-cell recording and other techniques, to show surprisingly similar phenomena in normal humans.

Functional MRI scans detect changes in blood flow and volume, which reflect local increases in brain activity. Scientists have now begun to take advantage of the temporal resolution that is possible with MRI to discriminate between different stages in cognitive processing. When the spatial resolution of MRI technology is combined with the temporal aspect, specific functions and subfunctions can be related to distinct anatomical structures in the human brain, allowing a number of unresolved issues about the functional architecture of cognition to be addressed.

One such issue concerns whether the cognitive functions of the prefrontal cortex are organized hierarchically — that is, does information processing become progressively centralized through successive stages of information flow? For example, sensory systems are anatomically segregated at early stages of cortical processing into visual, auditory and somatosensory cortical areas, and their associated pathways. According to the accepted hierarchical model of cognition, the working-memory system has two components: a 'central executive', which is non-

100 YEARS AGO

The ostrich, *Struthio camelus*, has been observed with interest from very early times; it has frequently been the subject of remark by African travellers; and it has been domesticated and farmed in the Cape Colony for some thirty years. Yet it is remarkable how little is known about it in scientific circles, and how many misconceptions still prevail as to its nature and habits. This article is founded on personal observations made during nine years of uninterrupted ostrich-farming in the Karroo of the Cape Colony, and during travels about the country generally. In large ostrich camps, some of which are a couple of miles in diameter, numbers of birds of both sexes run in what is practically a wild state, seldom interfered with in any way, except when rounded up to be plucked or to be fed in a drought. The habits of birds thus farmed differ in no way from those of native wild birds, except perhaps that monogamy is more difficult. ... The ostrich hen lays every other day, and the egg weighs about three pounds; it is a tasty and nutritious food however prepared, very rich, and excellent for making pastry and cakes. It is generally computed to be equal to two dozen fowls' eggs; but this must be on account of its superior richness, for, from personal experiment, the empty shell of a fairly large one exactly held the contents of eighteen fowls' eggs. It takes about forty minutes to boil an ostrich egg hard. The period of incubation is about six weeks.

From *Nature* 8 April 1897.

50 YEARS AGO

An account has been received from Mr. S. Duvdevani, of the Palestine Meteorological Service, of an optical method of estimation of dew which he has developed at the Dew Research Station, Pardess Hanna Agricultural School, Karkur, Palestine. The need was felt for a much quicker and less costly method than that of direct weighing of the dew collected on a standard surface, so that a network of voluntary observing stations could be organised for a country-wide study of the amount of dew in the different seasons. In a dry climate such as that of Palestine, the success of certain crops is largely dependent upon the amount of dew... .

From *Nature* 12 April 1947.