gases, aerosols, and clouds—are determined simultaneously within the same air column. A set of such measurements at various geographical locations during all seasons in combination with sophisticated radiation codes will lead to the necessary parametrization of radiatively relevant aerosol properties. This systematic reduction of free parameters was impeded in the past because adequate methods for the analysis of the aerosols were missing. Ice particles obviously have radiative properties different from those of soot particles, but they cannot be distinguished simply by particle counting, nor can a collection of both species easily be brought to the ground for investigation in a laboratory.

Second, another and maybe even more compelling argument in favor of in situ aerosol MS is the necessity for process studies that go beyond an accurate characterization of a static situation. Polar stratospheric clouds serve as a good example. It is widely accepted that these clouds, which consist of micrometer-sized particles, are a prerequisite for the Antarctic ozone hole (*3*), as well as for the ozone loss in the Arctic, which seems to become stronger each year (*4*). Although the bulk of these cloud particles consists of only three species—sulfuric acid, nitric acid, and water—it is still a riddle how the particles freeze (*5*). Although the thermodynamics of aqueous $H_2SO_4$-$HNO_3$ droplets has been established within the last 3 years and the thermodynamics of the frozen hydrates has been known even longer, transitions between these phases are not well understood at all. Aerosol MS would help the understanding of these kinetic processes, in particular when combined with accurate size measurements, as in Noble and Prather's experiment, to test predicted but yet unproven composition-size correlations (*6*). Such instruments ought to be applied on a carrier that traverses the clouds on a quasi-Lagrangian flight path, that is, flying with the particles and observing their behavior as function of time.

A general caveat of the methods developed so far is that even identical particles can cause a scatter in spectroscopic signal intensity of 50% and more. This is a result of the unknown ionization efficiencies in the plasma of the pulsed laser focus. A grouping of large data sets for sufficiently identical particles can significantly reduce the uncertainties in concentrations, as has been described in the survey on aerosol MS by Johnston and Wexler (*7*). At the same time, general rules on how to construct an optimal particle grouping under field conditions are still missing.

To perform field experiments with these methods, in particular under hostile upper tropospheric or lower stratospheric conditions, is, of course, easier said than done. Not only is it difficult to find a carrier that is able to fly through stratospheric clouds in a quasi-Lagrangian manner, more importantly, instruments adapted to the prevailing temperature and pressure conditions do not yet exist. Furthermore, the requirement of light and compact instrumentation renders such measurements enormously ambitious. Nevertheless, effort is currently directed into this direction: Murphy and Thomson (*8*) have used a portable ground-based aerosol MS in the field, and further miniaturization is conceivable. Another approach is being taken by Mauersberger and Schreiner (*9*) especially for stratospheric purposes. They use a sophisticated particle lens system based on a development by McMurray and co-workers (*10*), which significantly increases the particle-to-air ratio available for MS, and a thermal desorption system replaces the laser. An accuracy of better than 20% in concentrations is envisaged; of course, this improvement is at the expense of individual particle resolution.

In situ chemical and physical analysis of aerosol particles remains a challenging scientific task. As Spurny wrote in 1986 (*11*, p. 5), "Nevertheless, this is a realistic dream which might be fulfilled before the end of our century."

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# Refining the Taxonomy of Memory

Trevor W. Robbins

Memory has a distinct taxonomy, with its various forms defined by their nature and time course. The classifications of memory have long been debated by cognitive psychologists, but some of the clearest evidence comes from the study of a famous patient with epilepsy, known by his initials as H.M. Because of the severity of his epilepsy, the medial temporal lobes of H.M.'s brain were removed to prevent nearly constant seizures. As a result of this neurosurgery, H.M. is profoundly impaired in the acquisition of certain forms of information. He cannot consciously recollect new events in his life or new facts about the world, a form of memory that has been labeled "declarative memory." However, H.M. (and similar patients) retain the ability to remember other types of information. For example, H.M. can learn new visuomotor skills—such as reading in a mirror after several practice sessions—even without awareness of having been tested previously. The selectivity of H.M.'s amnesia suggested the existence of two forms of learning and memory—declarative and skill—presumably governed by different neural systems that can operate in parallel on the same input. A report in this issue by Knowlton *et al.* (*1*) strengthens the distinction between different forms of memory and describes a double dissociation: A pattern of deficits similar to those of H.M. in patients with amnesia and a pattern complementary to that of the amnesics in patients with Parkinson's disease, a neurodegenerative disorder leading to loss of dopamine from the striatum (Fig. 1). The patients with Parkinson's disease have impairments in nondeclarative memory, but their declarative memory is normal.

Previous attempts to show deficits for various forms of skill learning and intact declarative memory in patients with Parkinson's disease have foundered, because such patients often have globally impaired performance and because there is variability in determining the extent (and therefore the exact brain lesion) of the disease. Likewise, it has proven difficult to obtain unequivocal evidence from functional brain imaging studies of normal individuals that structures such as the striatum are selectively utilized when skills are learned. The successful approach now reported by Knowlton *et al.*

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stems in part from a research tradition which posits that some of the complex learning capacities of humans are similar to fundamental associative mechanisms in other animals. Thus, the ability of a monkey to recognize a visual stimulus presented a short time previously (perhaps analogous to declarative memory) can be profoundly impaired by damage to part of the medial temporal lobe; but this procedure leaves intact the monkey's capacity to learn gradually to discriminate between two visual stimuli, one of which is accompanied by a food reward (that is, associative learning) (*2*). This result has led to suggestions that in humans the learning of appropriate motor choices between the visual stimuli depends on a distinct neural system for memory that encompasses portions of the temporal cortex and their neuronal connections with the striatum (*3*) (Fig. 1). Neural activity in the striatum may be modulated by a "reinforcement" or "teaching" feedback signal from the dopaminergic neurotransmitter system (*4*), likely the same system that is dysfunctional in Parkinson's disease.

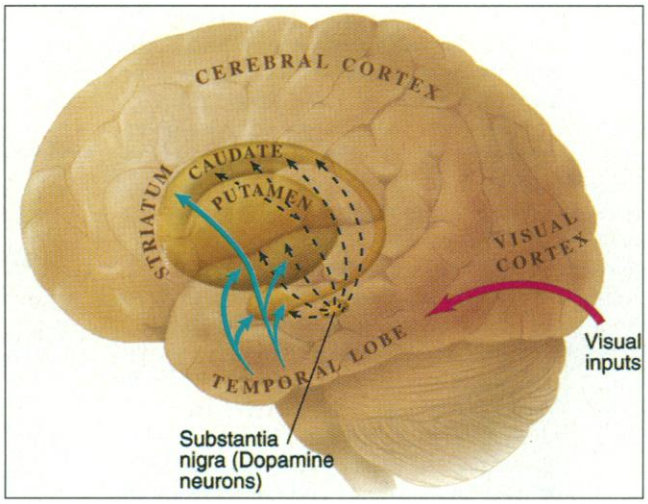


**Fig. 1. Species of memory.** Declarative memory (such as visual recognition) depends on the medial temporal lobe, whereas gradual, reinforcement-based discrimination learning depends on the striatum (the caudate and putamen). The striatum receives projections from all over the brain. The dopamine projections (broken lines), damaged in Parkinson's disease, are required for discrimination learning.

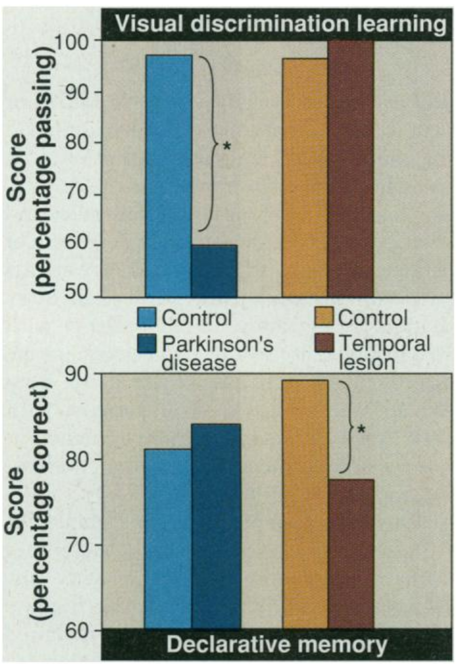


**Fig. 2. Earlier work.** (**Top**) Unmedicated patients early in the course of Parkinson's disease do not learn a battery of visual discrimination tasks as well as control subjects, whereas patients with temporal lobectomies perform the tasks as well as controls. (**Bottom**) The reverse pattern of impairments for visual recognition memory, an index of declarative memory. *, $P < 0.01$. [Reproduced from (*5, 6*)]

In earlier studies (*5, 6*), patients with Parkinson's disease were compared to patients with neurosurgical lesions of the temporal lobe by using a test of visual recognition memory and a battery of visual discrimination learning tasks (Fig. 2). Whereas temporal lobe lesions impaired recognition, patients early in the course of Parkinson's disease—those yet to receive medication with L-dopa—had deficits in discrimination learning. However, the patients could potentially solve these discrimination learning tasks by using a declarative memory system—conscious memories of the outcomes of previous trials—and could thus depend less on gradual, reinforcement-based learning than associative tasks learned by animals with temporal lobe lesions. Knowlton *et al.* (*1*) have designed a different and elegant task, a probabilistic discrimination paradigm, presented as a somewhat perverse "weather forecasting" game. The subjects predict the weather (as shown on a computer screen) based on the images on four cards, but there is only a probabilistic relation between the cards and the weather outcome. (For example, a particular cue is associated with sunshine 75, 57, 43, or 25% of the time). This task retards considerably the capacity of subjects to rely on declarative memory for its solution, thus unmasking the associative memory impairment in Parkinson's disease.

In the version of the task used by Knowlton *et al.* there is initially little opportunity to remember consciously whether previous particular choices were correct or not. Learning occurs at first in the absence of subjective awareness of the complex rules governing performance until the subject gradually gains some feel for them. This finding presumably explains why the patients with Parkinson's disease eventually achieve the same level of performance as the control subjects, although the rather low (less than 70% correct) asymptote reached by all of the groups will eventually need explanation. The goal now will be to identify the different processes underlying probability classification learning and determine its exact place in the taxonomy of memory. Like more conventional forms of learning, probability classification learning may require gradual or incremental changes in associative processes that can potentially be modeled in connectionist networks (*7*).

The main implications of the study for students of memory are that visual information processed in the temporal lobe may be handled in different ways according to the type of learning required. The results of this learning (that is, the memory) may be distributed to different neural systems with distinct functions, some of which depend on anatomical connections to specific portions of the striatum (*8*) (Fig. 1).

The selective deficits exhibited by patients with Parkinson's disease cannot easily be accounted for by global sensorimotor, cognitive, attentional, or affective impairments. Indeed, the discrimination deficits of the type shown in Fig. 2 are apparently ameliorated by L-dopa medication (*9*), indicating that the impaired dopamine system is the critical deficit underlying the memory loss. Exactly how this system participates in probability classification will have to be assessed in further studies. Patients with Parkinson's disease have nonstriatal forms of pathology that may contribute to their cognitive deficits. Alternatively, the key contribution of the dopamine system may be related to its role in the mechanism of synaptic plasticity in the striatum (*10*).

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