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Neurocognitive Processes of Human Memory

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Introduction

Psychologists and other brain scientists have been studying memory for over a hundred years now. By far the most unexpected, yet compelling, 'discovery' to emerge from these studies is that memory is extraordinarily complicated. The complexity of memory that we now know is greater by many orders of magnitude than even the wisest student of memory could have imagined a century ago. And today, the fractal tree of memory, in which each new finding and insight opens up a host of new questions and problems, keeps growing vigorously, with no plausible end in sight.

This kind of complexity is good news for science and scientists of memory. Complexity breeds fascination and excitement. My purpose in this article is to share with the readers some of the excitement in memory research today. The title of the article, 'Neurocognitive Processes of Human Memory', serves only to orient the reader rather generally towards the kinds of things I will talk about. 'Neurocognitive' suggests that we are interested in the interaction between brain and mind. 'Processes' serves to remind us that an indispensable precondition of progress in the study of memory is decomposition of memory into more elementary component processes. And, the explicit reference to human memory points to memory processes at their highest level of complexity, processes that have evolved most recently and that may be, or assumed to be, uniquely human.

This article consists of three main parts. First, I distinguish between two large classes of memory in terms of the temporal orientation of their function. Most forms of memory are future-oriented, and only one,

episodic, is past-oriented. Future-oriented forms of memory are evolutionarily older, and the past-oriented episodic memory is more recent.

Second, I summarize the findings from positron emission tomography (PET) studies that show different brain regions involved in retrieval from semantic and episodic memory, and different brain regions involved in encoding and retrieval processes in episodic memory. One interesting finding is the hemispheric asymmetry in retrieval: Retrieval of general factual information (semantic memory) activates cortical regions primarily in the left hemisphere, whereas, retrieval of information about recent happenings, such as having studied an experimentally presented word (episodic memory), activates cortical regions predominantly in the right hemisphere. The hemispheric asymmetry is particularly striking in the frontal lobes, referred to as the 'hemispheric encoding/retrieval asymmetry' (HERA) model, but it also extends to more posterior cortical regions.

The third part of this article concerns some of the theoretical lessons that the PET data have taught us about episodic memory. One of the more interesting of these lessons is that various kinds of intentional or orientational 'sets' play a more important role in remembering than may have been appreciated previously. The PET data suggest that in remembering past events, a great deal of neural 'computing' capacity is expended in the maintenance of a variety of such 'neurocognitive sets'. These sets represent general 'background' determinants of the 'local' processing of incoming and other online information. I suggest that the maintenance of one such set, referred to as 'episodic retrieval mode', centered on the prefrontal cortex, subserves a special kind of conscious awareness ('autonoetic' awareness) that is uniquely associated with episodic remembering.

Memory and Time

Many organisms, including human beings, begin life with biologically useful behavior patterns, or with the potential of postnatal maturation of such patterns that are 'released' in appropriate situations. These innate capabilities can be very complex, as is the case of what is probably the most thoroughly studied human 'instinct', namely, language (Pinker, 1994). All these 'instincts', effective ways of behaving in one's environment, are built into the nervous systems of organisms independently of experience. For example, very young children, like the very young of many other species, do not crawl off a 'visual cliff' when given an opportunity to do so, but cling to the safe side of the divide, even during the very first test. We understand the genetic basis of this behavior when we think of what happened to the offspring of those who, before they matured, did not 'know' that it is unsafe to step into empty space. Numerous other examples could

be given on how the organism's genome can serve as an excellent source of information as to what, and what not, to do in a given situation.

Learning for the future

Learning is another effective source of such information. Learning something now that is useful for surviving in the future, but what is unknown innately, makes good evolutionary sense in situations that have not been around for eons. Because young children lack innate knowledge about hot stoves, they must learn, through actual experience or vicariously, about what are good and bad things to do around hot stoves. Despite the differences in their origin, acquired knowledge can be as effective as innate knowledge in helping an organism to reach the reproductive age and, if possible, beyond.

Although memory may take many different forms, all of them, with a single exception, serve the same function as do the 'instincts': They provide the organisms with means of behaving more effectively than would be possible in the absence of the relevant acquired knowledge or skill. It is not surprising, therefore, to realize that for all forms of learning and memory, with a single exception, the time's arrow points in one direction—to the future. The experience at Time 1 serves the important function of allowing the organism to respond more adaptively at a subsequent Time 2. From the point of view of the problem of survival of the organism, the important thing is what happens at Time 2 and not at Time 1. What matters is the actual behavior at Time 2, not the source of the information that guides that behavior. Whether, or not, the relevant information is there because of the inherited genes or an earlier experience is immaterial from the point-of-view of the organism's survival, or its happiness.

Forms of learning and memory involving experiences whose effects 'look' forward in time could be referred to as 'proscopic' (forward-looking). With a single exception, all forms of learning and memory that are known throughout the whole animal kingdom are proscopic. From sensitization and habituation, through simple and complex classical and instrumental conditioning, through the learning of perceptual-motor and cognitive skills, through various forms of 'implicit' memory, such as priming, through the imitative learning that occurs in higher animals, all the way to the immense quantities of concrete and abstract knowledge of the world that adult human beings have accumulated throughout their lives, memory is proscopic: It is important solely because it shapes and effectively enhances the organism's interaction with its future environment. This basic truth holds as much for the *Aplysia* learning to withdraw its gill to a conditioned stimulus, the mouse learning the location of the sunken platform in a Morris water maze, the monkey remembering the location of the peanut in a delayed nonmatching-to-sample task, the child avoiding

touching the hot stove, the pitch-hitter hitting the ball out of the ballpark, the Scrabble player coming up with a clever word that astounds the opponents, the scientist thinking of a new kind of a distinction that is important in the study of the brain/mind, and so on, and on, essentially *ad infinitum*.

In none of these future-oriented memory situations does knowledge, or conscious awareness, of what has happened in the past matter. What matters is the efficacy of the current behavior. The particular source of the acquired skills and knowledges that support current behavior is as inconsequential as the source of innately determined skills and knowledges.

Thus, despite the traditional association between memory and the past, the remembering of the past, in the sense of conscious recollection of what happened on an earlier occasion, can be said to be epiphenomenal in proscopic memory. The circumstances surrounding the origin and creation of knowledge that guides effective behavior may be of interest to the scientist studying such behavior, but to the behaving organism it makes no difference.

The important temporal concepts in all proscopic (nonepisodic) forms of memory are the present, Time 1 (time of acquisition or 'encoding'), and the future what is going to be Time 2 (time of using what was acquired) and Time 3 (time at which the behavior at Time 2 'pays off'). The organism can benefit from this sequence of happenings independently of its awareness of time, whether past or future. The individual need not be consciously aware of what has happened in the past in order to make effective use of existing knowledge and skills here and now. The child does not remember where and how she touched the hot stove in the past, but she knows how to treat the stove now; the amnesic patient does not remember that the examining physician hid a pin in his hand while shaking the patient's hand an hour ago, but she knows that it is not good to shake the doctor's hand now; the contestant in a TV show does not remember when, where or how, she acquired the knowledge that Hannibal is associated with elephants, but she answers the question correctly and profitably now. Because all these people rely on their proscopic memory, remembering the past is irrelevant.

Memory for the past and the future

The singular exception to all this—the ubiquity and evolutionary significance of memory that serves the future without bothering about the past—is episodic memory. Episodic memory does exactly what the other forms of memory do not and cannot do—it enables the individual to mentally 'travel back into her personal past'. It differs from all proscopic forms of memory in that it does allow us to remember (consciously recollect) what happened in the past. Remembering, or recollecting, are terms we

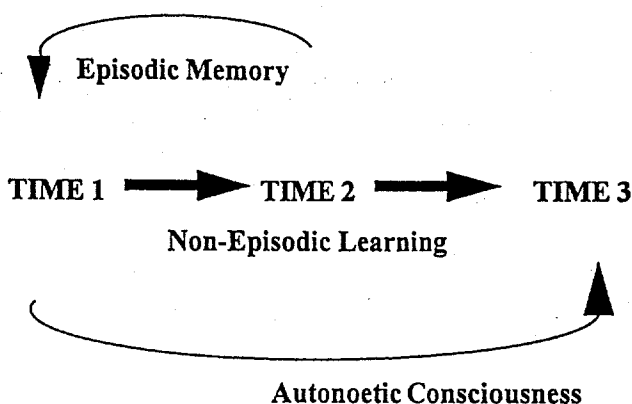


Fig. 1. A schema of time relations in memory. All forms of nonepisodic learning are oriented from the present to the future: What happens at Time 1 influences what happens at Time 2. Episodic memory is oriented from the present to the past: At Time 2, one can mentally 'travel back' to what happened at Time 1, as well as from Time 1 to the future Time 3.

use to denote the kind of mental activity in which the individual *now* becomes consciously aware of something that she witnessed or observed on an earlier occasion. A child remembers what happened at a friend's birthday party the day before, a young lover remembers the expression on the beloved's face in the moonlight, the scientist remembers the first time when a speaker at a conference mentioned her name and work, and so on, and on, almost *ad infinitum*.

Episodic memory has evolved from other forms of memory and obey the basic time relations of its constituent mileposts: The individual does something at Time 1 and remembers it at Time 2. But, episodic memory differs from all others in that at Time 2, its time's arrow is no more an arrow, it loops back to Time 1. The influence of Time 1 at Time 2 expresses itself in a mental return to the past: The individual has a conscious awareness of re-experiencing here and now something of the experiences of the earlier time. Figure 1 illustrates the situation schematically.

It is this backward past-oriented loop from Time 2 to Time 1 that is absent in all other forms of memory and makes episodic memory unique. Whereas the consciously experienced past (Time 1) can be totally inconsequential in nonepisodic (proscopic) memory, it is the very essence of episodic memory. Moreover, perhaps an even more astounding feat of the evolution is that the 'looping arrow' of episodic memory can loop once more at the remembered Time 1 forward to the imagined Time 3 that is going to follow Time 2. Episodic experiences of our personal past become a foundation for our expectations about our personal future, and we can speak of individuals 'remembering' the future (Ingvar, 1985; Wheeler

al., 1997). The time's arrow of proscopic memory becomes the time's circle of episodic memory.

We can think of episodic memory as 'palinscopic' (backward-looking) memory. An individual who 'possesses' palinscopic memory can, at Time 2, 'mentally travel back' to Time 1. However, because no other forms of palinscopic memory are known, I use only 'episodic memory' in what follows.

The mental time travel back into one's past occurs in a form of conscious awareness that is referred to as 'autonoetic'. Autonoetic consciousness is a defining feature of episodic memory: Episodic memory cannot operate in the absence of autonoetic consciousness (Perner and Ruffman, 1995; Tulving, 1993; Wheeler *et al.*, 1997).

The scenario as outlined above leads us to expect that specific brain regions are involved in mediating autonoetic episodic remembering, brain regions that are not used for the support of proscopic memory processes. Because we now have techniques available for identifying regional differences in brain activity, we can test this expectation empirically. We now turn to examine some available evidence.

PET Studies of Episodic Memory

The relation between brain and mind has fascinated and frustrated brain scientists interested in memory for a long time. A popular way of posing the problem has been in terms of 'localization of function', and a popular form of putting the question has been, 'Where are the memories in the brain?' The account of how Karl Lashley spent many years of his creative life looking for the engram, and how he finally failed, is one of the best known stories in our science. When he ruefully admitted that, "I sometimes feel, in reviewing the evidence on the localization of the memory trace, that the necessary conclusion is that learning just is not possible" (Lashley, 1950), he probably could not even imagine how it would ever become possible to relate brain activity to memory. And yet it is possible.

Today, we find ourselves at a stage where the recently developed techniques of functional brain imaging are telling us a great deal about the relation between brain and memory. Because a half-century has passed since Lashley, we do not ask any more, 'Where are the memories in the brain?' We now think of multiple forms of memory, each one not only similar to but also different from all the others, and we think of memory processes and their interactions, rather than, or at least in addition to, localization of memory traces. Although neuroimaging research on memory is only a few years old, and still clearly in its early infancy, we already have available a respectable amount of PET data concerning the identity of brain regions that are involved in encoding, storage, and re-

trieval processes of episodic memory (Buckner and Tulving, 1995; Cabeza and Nyberg, 1997; Fletcher *et al.*, 1995a).

The logic of PET

The logic of PET 'activation studies' of memory is straightforward. PET provides information about the differences in blood flow in every one of a large number of sites that occur because of the differences in the behavioral/cognitive demands of different tasks. Because changes in blood flow are known to be correlated with neuronal activity, their patterns (maps) provide information about neuronal activity in different brain sites that reflect such demands (Posner and Raichle, 1994; Raichle, 1994).

Traditionally, PET data are presented in the form of 'brain maps'. A brain map reflects differences in the patterns of regional blood flow associated with two different tasks, A and B. The tasks are usually selected to differ from one another with respect to readily specifiable cognitive processes. A brain map shows regions in which blood flow and, hence, neuronal activity, was higher in Task A than B, regions in which the level of blood flow could not be distinguished between the two tasks, as well as regions in which the level of blood flow was lower in Task A than B. The logic of PET studies holds that these 'activation' maps reflect the differences between the two comparison tasks. The experimental challenge in such a situation is to describe the correlation between the functional neuroanatomy and the cognitive processes in a disciplined, systematic and theoretically meaningful fashion.

Encoding and retrieval

Let me illustrate the logic of PET studies of memory with an example from a study done in Toronto, in which healthy university students served as subjects (Cabeza *et al.*, 1997b; Kapur *et al.*, 1996). Scanning was done under two conditions. In one, subjects were shown pairs of words, such as PENGUIN-TUXEDO, and were instructed to think of some meaningful relation between the words of each pair. They were also told that their memory for these pairs would be tested. Two processes occur in this situation. First, subjects make use of their semantic knowledge (general 'knowledge of the world') in relating the paired words to each other, that is, they engage in semantic-memory retrieval. Second, the presented information is encoded and stored in episodic memory: Subjects can remember later that such and such word pairs occurred in the study list. In the other experimental condition, subjects again saw pairs of words, such as PENGUIN-TUXEDO, but now they had to decide whether, or not, the pair had appeared in the study list. This is an episodic-memory retrieval (recognition) condition. Note that the perceptual display presented

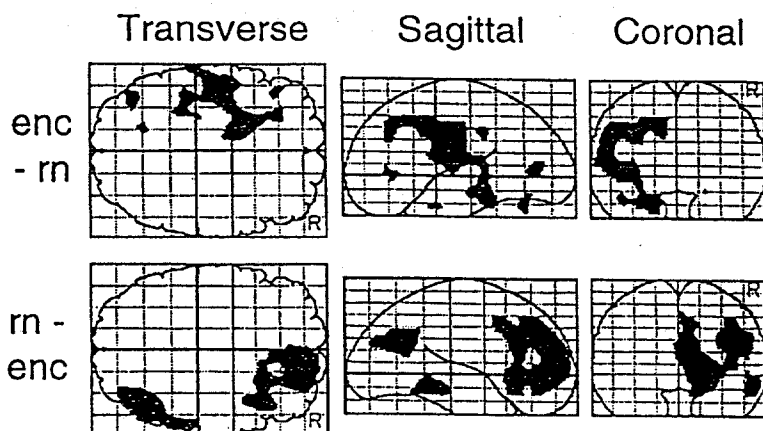


Fig. 2. Brain maps showing regions that are more active during encoding (intentional study) than during retrieval (recognition) of pairs of words (upper bank), and regions that are more active during retrieval (recognition) than during encoding (intentional study) of the same information (lower bank). Average data for 12 young healthy subjects. (Based on Kapur *et al.* 1997; Cabeza *et al.*, in press. Figure reprinted from Nyberg *et al.* (1996), with permission.)

to the subject (pairs of words), the behavioral form of the response that the subjects made (spoke the second single words), as well as other variables (e.g. pacing of presentation of the stimuli), were held constant in both conditions. Only the cognitive task demands differed.

Figure 2 shows the results of this study. The blood flow data were averaged over all 12 subjects. The brain maps in the upper bank were obtained by the subtraction of the retrieval activations from the encoding activations; they show regions that were more highly activated during encoding than during retrieval. The brain maps in the lower bank were obtained by the subtraction of encoding activations from the retrieval activations; they show brain regions that were more highly activated during retrieval than during encoding.

There are three observations to make about the data in Fig. 2. First, there are striking differences between the brain maps of encoding and those of retrieval. We can assume that there are common regions as well, activated during both encoding and retrieval, although they do not appear in Fig. 2, because they are 'subtracted out' in the analysis. Nevertheless, the differences are surprisingly extensive. Second, the two sets of activation are heavily lateralized in the two hemispheres: Encoding activations are all in the left hemisphere, and retrieval activations in the right hemisphere. This kind of a stark dichotomy is not always observed, of course, but it does illustrate a kind of functional hemispheric laterality that seems to be real. Third, it is useful to keep in mind that because of the design

of this particular study, the left hemisphere activity reflects the combined effects of both semantic retrieval and episodic encoding.

Hemispheric encoding/retrieval asymmetry (HERA)

The data in Fig. 2 nicely complement the data yielded by many other PET studies, including the very first ones designed to investigate encoding and retrieval processes in episodic memory. These studies were done at the Hammersmith Hospital in London, England (Fletcher *et al.*, 1995a,b; Shallice *et al.*, 1994), at the Washington University in St Louis (Squire *et al.*, 1992; Buckner *et al.*, 1995), and in Toronto (Kapur *et al.*, 1994a, 1994b; Moscovitch *et al.*, 1995; Tulving *et al.*, 1994a, 1994b). Taken together, the data from these studies suggested a surprising empirical regularity: Left prefrontal cortex seemed to be differentially more involved than right in encoding information into episodic memory, whereas, right prefrontal cortex seemed to be differentially more involved than left in episodic memory retrieval.

This pattern is referred to as HERA in the frontal lobes (Tulving *et al.*, 1994a). Although initially unexpected and, therefore, greeted sceptically (Roskies, 1994), the HERA pattern is now well established and indeed represents one of the most robust facts of the PET-memory literature. Figure 3 presents a schematic summary of the results from 25 different PET studies, available in May 1996, that reported relevant data (Nyberg *et al.*, 1996). The pattern of the data depicts the asymmetry: Episodic-memory encoding (intentional or incidental study) is associated with the activation of the left prefrontal cortex, and not with the right. Episodic-memory retrieval (recognition or recall) is associated predominantly with the activation of the right prefrontal cortex. Because in many cases episodic encoding involves semantically based judgments about the to-be-remembered information, the left frontal activation associated with such encoding also reflects semantic memory retrieval. This is why the HERA model associates semantic-memory encoding also with the left frontal lobe.

The overall HERA pattern can be economically described in terms of the interaction among three pairs of concepts: (i) Encoding vs. retrieval; (ii) episodic vs. semantic memory; and (iii) left and right frontal lobes. This overall regularity is largely unaffected by specific conditions of the relevant experiments. Available evidence suggests that it holds equally for verbal and nonverbal materials. For instance, encoding of human faces has been shown to activate the left prefrontal cortex, in the absence of comparable activation on the right, while recognition of previously studied faces has been shown to activate the right prefrontal cortex, in the absence of comparable activation on the left (Grady *et al.*, 1995; Haxby *et al.*, 1996; see also, Andreasen *et al.*, 1995). Similar observations have been made with

The HERA Model

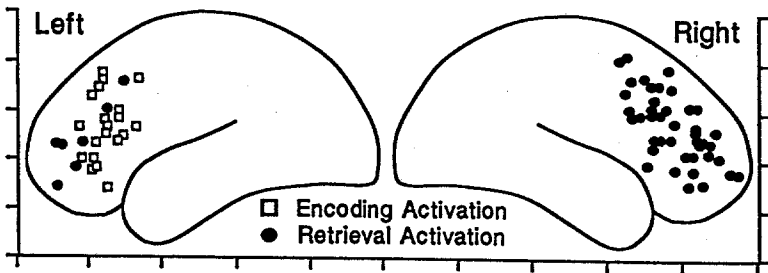


Fig. 3. A schematic summary of PET data from 25 different studies illustrating the HERA pattern in the frontal lobes. Episodic-memory encoding (intentional or incidental study) is associated with the activation of the left prefrontal cortex, and not with the right. Episodic-memory retrieval (recognition or recall) is associated predominantly with the activation of the right prefrontal cortex. (Detailed data presented in, and the figure reproduced from, Nyberg *et al.* (1996), with permission.)

other nonverbal materials and line drawings of objects (Buckner *et al.*, 1996; Köhler *et al.*, 1995; Moscovitch *et al.*, 1995; Owen *et al.*, 1996). The encoding activations on the left have been observed under conditions of both intentional and incidental learning; the retrieval activations on the right have been observed in both recall and recognition tasks.

Although the general left/right encoding/retrieval pattern is remarkably consistent, as shown in Fig. 3, it is important to note that within this general regularity there exists considerable variability in localization of function, depending on particular conditions of the different studies. This variability invites more detailed analyses of the data. Such analyses have begun (Buckner, 1996), and the results are promising: It is possible to identify specific prefrontal regions that are involved in encoding and retrieval of particular aspects of the information.

Encoding/retrieval asymmetry in other brain regions

Focusing on the encoding/retrieval asymmetry in the frontal regions ignores the many activations in posterior brain regions, found in PET studies of encoding and retrieval. We already saw an example of these in Fig. 2, where these posterior activations were also lateralized. How general is this tendency?

The answer is, pretty general. A recent review of the relevant studies shows that in a large majority of cases, intentional encoding in episodic memory activated the left, but not the right, temporal regions (Fletcher *et al.*, 1995a). As to retrieval, several studies found increased activation in the

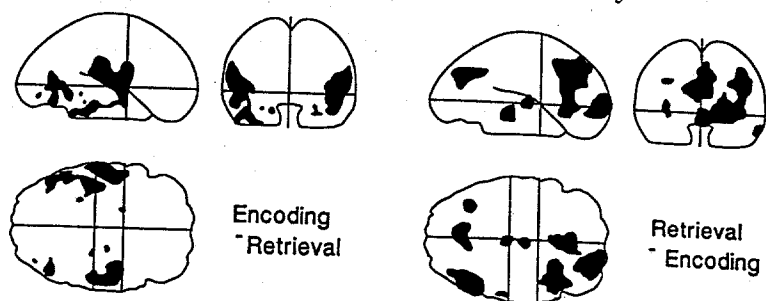


Fig. 4. The left panel shows brain regions that are more active during encoding than during retrieval: Temporal lobes bilaterally, left fusiform gyrus and perirhinal cortex in the medial temporal lobe, right parahippocampal gyrus and entorhinal cortex bilaterally. The right panel shows brain regions that are more active during retrieval than during encoding: Right prefrontal cortex, anterior cingulate cortex, thalamus, brainstem and midline parietal regions near cuneus and precuneus. Data were pooled from four different PET studies in which a total of 48 young healthy subjects participated. (Reprinted from Tulving and Markowitsch (1997), with permission.)

parietal lobes. In some cases, the activation has been bilateral (e.g., Schacter *et al.*, 1996b; Tulving *et al.*, 1994b). In other cases, unilateral activation has been observed, and in these cases it has been located predominantly on the right side (Grady *et al.*, 1995; Kapur *et al.*, 1995; Kapur *et al.*, 1995; Moscovitch *et al.*, 1995).

The data in Fig. 4 (reprinted from Tulving and Markowitsch, 1997) further illustrate the hemispheric asymmetry between episodic encoding (together with semantic retrieval) and episodic retrieval. Similar to the data in Fig. 2, these data were provided by a direct within-subject comparison of encoding and retrieval condition. The data were pooled from four different studies, each involving the testing of 12 young healthy subjects. Kapur *et al.* (1996) was one of them; another was a study similarly involving intentional study and recognition of word pairs, but conducted with older subjects (Cabeza *et al.*, 1997a). The third involved the study and recognition of single words (Nyberg *et al.*, 1996), and the fourth study involved encoding and recognition of line drawings of objects and their location in a visual display (Köhler *et al.*, 1998). We reasoned that such pooling minimizes the changes in blood flow that are attributable to the features by which the four studies differed (such as the study and test materials), and maximizes the changes correlated with the features shared by all four studies, namely, the encoding vs. retrieval processes.

The left half of Fig. 4 shows brain regions that were more active during encoding than retrieval. They include large regions in the temporal lobes bilaterally, and left fusiform gyrus and perirhinal cortex in the medial temporal lobe. Smaller, but statistically highly significant, activations were also observed near entorhinal cortex bilaterally and the right parahip-

pocampal gyrus. The right half of Fig. 4 shows brain regions that were more active during retrieval than during encoding. These include extensive areas in the right prefrontal cortex and anterior cingulate cortex, together with the thalamus, brainstem and midline parietal regions near cuneus and precuneus.

These data paint the outlines of widely distributed encoding and retrieval 'circuits' in the brain. In addition to the traditional 'memory regions' in the medial temporal lobes, some of which showed more activation during encoding than during retrieval (Fig. 4), there are extensive neocortical areas that seem to be heavily involved in getting information into the memory store at Time 1, and other such areas involved in recovering it at Time 2.

Another observation worth noting has to do with the evidence suggesting that the cerebellum is also involved in 'purely' cognitive activities (Leiner and Leiner, 1995; Schmahmann, 1991). These include encoding and retrieval processes of episodic memory. An HERA-type asymmetry seems to be also true of the cerebellum, although with the polarity opposite to that characterizing the cerebral cortex: Cerebellar hemispheres are anatomically cross-connected to cerebral hemispheres (Barker *et al.*, 1991; Middleton and Strick, 1994). Consequently, in keeping with HERA, episodic encoding (and semantic retrieval) tends to activate the right cerebellar regions more than the left (Bäckman *et al.*, 1997; Jennings *et al.*, 1997; Pardo and Fox, 1993; Raichle *et al.*, 1994), whereas, episodic retrieval is associated with cerebellar activation mostly on the left (Andreasen *et al.*, 1995, 1996; Bäckman *et al.*, 1997; Cabeza *et al.*, 1997b; Schacter *et al.*, 1996a).

The finding of cerebellar activity in purely cognitive tasks, or in tasks in which motor components of the tasks are presumed to be subtracted out by experimental design, represents another interesting neuroanatomical discovery made possible by PET, although the nature of the contribution that the cerebellum makes to memory processes is not yet known. Students of memory are only beginning to digest the implications of the news. I mention it here primarily to underscore one of the important functions of PET, that of providing (new) information about the functional neuroanatomy of memory.

Neurocognitive Sets: Remembering and Consciousness

The data we have reviewed paint a picture of a multitude of brain regions involved in episodic encoding and retrieval processes. Thus, the emerging brain maps of 'memories in the brain' are rather different from those suggested by earlier lesion-based analyses of memory disorders that were largely limited to medial temporal and diencephalic regions (Squire and Zola-Morgan, 1991). Today, students of memory talk about widely distributed cortical, subcortical, cerebellar encoding and retrieval networks,

simultaneously activated and functionally interconnected brain regions (Andreasen *et al.*, 1995b; Fazio *et al.*, 1992; Grasby *et al.*, 1993; Heiss *et al.*, 1992; Kapur *et al.*, 1994a; Mesulam, 1990; Perani *et al.*, 1993; Shallice *et al.*, 1994; Tulving *et al.*, 1994a).

But exactly what are these networks networks of? How are we to think of the workings of, say, episodic retrieval networks that include various prefrontal cortical, anterior cingulate, thalamic, anterior temporal, medial and inferior parietal and cerebellar regions (Cabeza *et al.*, 1997b)?

We begin with the idea that 'retrieval process' is not a single process, as its label implies, but rather consists of a complex concatenation and combination of a number of component subprocesses. Moreover, we can imagine that the workings of these components subprocesses are determined jointly by (i) 'local' conditions prevailing at a given moment in time (e.g., the presentation of a particular stimulus); and (ii) general 'background' conditions that change more slowly over time (e.g. the 'context' or 'set'). This is in keeping with one of the most basic principles of behavior: An organism responds to a stimulus only if it is 'set' to respond.

A great deal of evidence, from a wide variety of sources, suggests that the brain can respond to any particular kind of incoming information, and process any kind of online information in many different ways, depending on the currently present background factors that we can refer to as 'neurocognitive sets'. Neurocognitive sets are patterns of coherent neuronal activity that determine the kind of processing performed on incoming and online information, and inhibit the many other kinds of processing that the brain is capable of performing on the same stimuli. In human cognition, they are the *active neural* correlates of mental states and processes that have been studied under various rubrics, such as attention, intention, orientation, set and readiness. We can think of neurocognitive sets as a clever stratagem of nature that enables the brain to do a great deal of task-relevant processing of a stimulus *before* the stimulus occurs.

One well-known background factor, a neurocognitive set, in episodic retrieval is 'episodic retrieval mode': Holding in mind, in the field of sustained attention, a past segment of one's life of which certain aspects become consciously accessible, and others are held in a special state of readiness. Three things happen when the rememberer's brain/mind is in the episodic retrieval mode: (i) The rememberer keeps 'thinking back to' a smaller or larger segment of her subjective past; (ii) she treats presented stimuli as retrieval cues, as queries about the 'contents' of one or more previously experienced episodes; and (iii) the product of successful ecphory (retrieval) is auto-noetically experienced as remembering a past event. Auto-noetic consciousness is the brain/mind capacity that allows individuals to apprehend their subjective experiences throughout time, and to perceive the present moment as both a continuation of their past and a prelude to their future (Tulving, 1993; Wheeler *et al.*, 1997).

Until recently, it was possible to contemplate the concept of retrieval mode only as an abstract idea (Tulving, 1983). Now, thanks to functional neuroimaging techniques, we can actually 'see' the episodic retrieval mode in the brain. Relevant evidence has been provided by Kapur *et al.* (1995), Nyberg *et al.* (1995) and Schacter *et al.* (1996b) (see also, Rugg *et al.*, 1996). The logic is simple: In a PET study we (i) hold constant the retrieval mode, by asking the subject whether, or not, he can recognize presented test items as those he encountered in the earlier study phase; and (ii) by manipulating the nature of test items, vary the extent to which the subjects can actually succeed in recovering the stored information.

The question is: 'Are there brain regions that show activation during intentional retrieval attempts regardless of the degree of success of such retrieval, or success of ecphory?' If yes, we can think of these brain regions as involved in the maintenance of neurocognitive set that we call 'episodic retrieval mode'.

The available data suggest that the answer to the question is 'yes', and that the brain areas thus identified with the episodic retrieval mode are regions in the frontal lobes, especially in the right hemisphere (Kapur *et al.*, 1995; Nyberg *et al.*, 1995). The results showed that when subjects were in the episodic retrieval mode, trying to recognize test items as having occurred in a previously studied list, but were unsuccessful in remembering, because the experimentally presented test items do not match the studied items, large regions in the right prefrontal cortex were nevertheless activated. The extent of activation was very similar to that observed in other scans, in which subjects succeeded to recognize (retrieve) many previously studied words.

It is tempting to speculate that autonoetic awareness, through which episodic retrieval is expressed, is also critically dependent on the integrity of the right frontal lobes and its connections with other brain regions (Wheeler *et al.*, 1997). There is some evidence that patients who have suffered right anterior brain damage have difficulty in autonoetically reminiscing about their premorbid personal experiences (Calabrese *et al.*, 1996; Markowitsch *et al.*, 1993; Markowitsch, 1995). We can think of the frontal episodic retrieval mode as an activated state (neurocognitive set) in which experiences of successful ecphory are autonoetically treated as remembering. If so, the set determines the general nature of the experience (remembering) *before* any specific instance of the experience occurs. That is, the autonoetic awareness is intrinsic to the operations of episodic retrieval mode.

To summarize, we have some evidence suggesting that the frontal lobes are involved in the establishing, maintaining, and switching of a specific neurocognitive set. This set is episodic retrieval mode. Other data, not reviewed here, suggest that actual 'storage sites' of engrams, that are ecphorized ('activated') at retrieval lie in posterior neocortical areas (Ny-

berg *et al.*, 1996). Once the neuroimaging data have pointed to the massive involvement of the frontal cortex in the episodic retrieval mode, it is easy to begin thinking of all kinds of other neurocognitive sets that play a central role in memory processes, even if their importance may have been less obvious in the past. In this manner, functional neuroimaging plays a critical role in shaping theoretical thought about memory.

Conclusions

Let me now sum up. I suggested that, contrary to traditional thinking, an overwhelmingly large majority of forms of learning are future-oriented. Any kind of conscious awareness of specific past happenings, the sort of mental activity that we usually associate with the term 'remembering', is largely irrelevant in these forms of memory.

The singular, and in many ways a most remarkable, exception to the future-oriented learning mechanisms and systems is episodic memory. There are grounds for believing that it has evolved rather recently and, in its fully developed form, is found only in the human species. Episodic memory makes possible remembering of events experienced in the past. Therefore, we can say that it is oriented to the past.

PET studies point to specific neuroanatomical regions involved in episodic encoding and retrieval. An especially interesting finding, because completely unheralded by previous research, is the so-called HERA pattern of neural activation in the frontal lobes: The left frontal lobe is more active in semantic-memory retrieval and episodic-memory encoding, and the right frontal lobe is more active in episodic-memory retrieval. Other findings, somewhat less consistently, point to the possibility that the HERA pattern extends posteriorly.

To date, several studies suggest that the frontally supported 'retrieval mode', and possibly the as yet unexplored 'encoding mode', represent particular instance of the concept of 'neurocognitive set'. Neurocognitive sets are patterns of coherent neuronal activity that determine the kind of processing performed on incoming and online information, that inhibit the many other kinds of processing that the brain is capable of performing on the same stimuli, and also enable the brain to do a great deal of task-relevant processing of a stimulus *before* the stimulus occurs.

Finally, it is easy to agree with those brain scientists who believe that the recently introduced and developed functional neuroimaging techniques will revolutionize the study of human memory. The importance of the technique not only lies in its ability to produce maps of functional neuroanatomy, but also in the way it forces us to see aspects of memory not seen before, and makes us think about memory in a way we have not thought before.

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