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The Functional Approach to Memory [and Discussion]

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The functional approach to memory

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One approach to human memory is simply to test its efficiency by using different kinds of material that can be presented, retained and tested in different ways. From the pattern of results, we can draw conclusions about the kinds of mechanism involved. This approach has in recent years made a number of important advances.

A decade ago the dominant view was of a single short-term or temporary memory, with a secondary or long-term memory receiving information from it. It is now clear that there are several forms of temporary memory, with different properties. Equally, longer-term memory is no longer seen as a homogeneous system. A particularly fruitful issue is the manner in which the various methods of storage interact.

Setting the scene

Many of us nowadays share a common problem. A computer package that is supposed to carry out a certain kind of analysis may not in fact do so. The programmer has arranged for it to work correctly for most kinds of data. Yet when we put in our particular results, there turns out to be something about them that makes the computer divide by zero or try to find the square root of a negative number. The wise user of an unfamiliar package therefore tries it out first with some artificial numbers for which the answer is known, or compares the results given by the package with one kind of input, and the results it gives with another. In general, the cautious approach is to check systematically the behaviour of the computer and make sure that it is really doing what it claims.

In the same way, when we try to understand the mysteries of human memory, it is unwise to assume that we know what the process of remembering is, without checking. We can expose people to various kinds of experience, giving them visual or acoustic inputs, asking them to do something else at the same time as memorizing, or asking them to react to the experience in one way or another. We can later test their memory by many different methods, by asking for free recall, by asking if they recognize items, by seeing how far they benefit from hints, by concentrating on accuracy, by measuring the speed of their reactions, and so on. By comparing different conditions in this way we cannot of course say whether the machinery of memory operates through increased synaptic conductivity, changes in concentrations of transmitter, of location in the brain, and so on. But we can draw reasonably definite conclusions as to what the machinery is *doing*, what its functions are. To quote an old slogan from Adrian (1954), 'We must find out what human behaviour is like before we try to explain how it is produced'.

The functional approach, in other words, is to take intact human beings and work out what is happening inside their heads from carefully chosen tests of what they do. The papers that follow all adopt this approach. It is of course only one of the routes by which memory can be tackled. In the end this approach will need to be linked to knowledge of physiological and biochemical machinery; indeed, some links are already being made through studies of patients with brain injury. Similarly, a fully adequate theory of memory will need more rigour and more complexity than can be managed in natural language. Such theory will need to be formulated as computer programs, and the methods of artificial intelligence will therefore be required. The reason for confining this discussion purely to the functional approach is not in any way to deny the need for these other approaches; it is simply that there is a limit to the range of issues one can examine in fourteen papers. Some of the neuropsychological aspects have been touched upon in the Discussion Meeting on that subject held in 1981 (Broadbent & Weiskrantz (eds) 1982); it is to be hoped that the approach through artificial intelligence will also be covered in some later meeting. Meanwhile, the functional approach happens to have reached a particularly interesting stage, largely due to the efforts of many of the contributors to this meeting.

In this first paper, the reasons for the current interest need to be explained, even at the cost of boring those who know them already. Most of it will be fairly elementary and, as far as possible, uncontroversial. When personal views intrude, I shall try and make this clear.

The multiplicity of memories

The first and most notable findings of the functional approach is that there seem to be many different kinds of memory. Probably most of us start out with the simple assumption that there is one mechanism of storage, and that therefore when we remember different things the same general laws will apply in every case. After all, Newton's laws apply to falling bricks or to falling apples. But this turns out not to be true; experiments on the effect on memory of some factor A have often shown that the results are different when the task is to remember one kind of thing and when it is to remember another. A little over 10 years ago, when I gave a Review Lecture to this Society (Broadbent 1970), the 'modal model' was that there were two kinds of memory, short-term and long-term. This was because certain conditions alter the efficiency of one without changing the other; for instance, slowing the presentation rate of a series of words may improve memory for the tenth word back from the last, but have essentially no effect on the last two or three. Even 10 years ago, however, there were certain difficulties in this approach. These difficulties have become worse during the interval. One can no longer think of a single concept of short-term memory, because there are differences between material presented to the eye and to the ear (Crowder 1978), and differences between the case when the person is allowed to talk silently to themselves after the material has been presented and the case when this is made more difficult. For instance, one can use 'articulatory suppression', requiring the memorizer to say 'bla, bla, bla' or 'one, two three, four' while they are doing their task (Murray 1968; Baddeley *et al.* 1975). There are also differences (Baddeley & Lieberman 1980) between material that can form a spatial image and material that is purely verbal, or between allowing or preventing the person to make gestures with their hands while memorizing (Hulme 1981). One cannot have a single concept of short-term memory that will cope with all these variations. There seem to be many different kinds: the next six papers will make that abundantly clear.

In the same way, the concept of long-term memory has broken up into several different kinds of problem. On the one hand, the efficiency of memory depends very much on the way the person reacted to the original event at the time it happened. It is harder to remember a word if one has only looked at it to see how many letters it contained than it is if one tried to judge whether its meaning is pleasant or unpleasant. This effect of 'levels of processing', associated

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predominantly with the names of Craik & Lockhart (1972), is true whether memory is tested by recall or by recognition. Yet it is not true if one tests memory by asking the person to read a word exposed so briefly that it can hardly be glimpsed; the word is easier to see if it has been seen a little earlier, but the kind of reaction made to it is less important (Jacoby & Dallas 1981; Tulving *et al.* 1982). Once again, the principles of memory seem to be different depending on the kind of memory one is discussing, even within long-term memory.

One of the more important distinctions to be made is between the record of the past event itself and the record of the links between the event and its context or background. Because the latter are so important, the same memory may be unavailable at one time and yet become available later when the context is appropriate. It is perfectly possible to fail a memory test today, and yet to succeed tomorrow (Tulving & Thomson 1973). In analysing the way in which context plays its part in retrieval, the effects of mood on memory become important theoretically (Bower 1981); so also does a careful analysis of the way certain kinds of questioning or suggestion distort the accuracy of witnesses in legal cases (Loftus 1975).

There is of course a great deal of practical importance in the results of experiments on evidence and on mood. In current clinical practice a popular view is that a major factor in depression is the distorted tendency of patients to recall only the negative aspects of their lives (Beck 1976). Similarly, the reliability of eye-witnesses testimony is a matter of public concern (Devlin 1976). But from our present point of view, both kinds of phenomenon are interesting because they raise the question whether there is a single record of each experienced event, whether that record can be changed, and how the whole large set of records is searched to find the one that is wanted. These questions, of the nature of the longer-lasting trace and its retrieval, will come up in the second half of the meeting.

If we look at our knowledge of memory with the eyes of a biochemist, hoping ultimately to uncover the physical mechanisms that store effects of past experience, then this state of affairs must be rather alarming. Must one look for many different mechanisms rather than just one? To some extent, I think the answer *must* be 'Yes'. The problems of creating a lasting representation of experience, of maintaining it, and of finding it again when it is needed, are logically different and require different kinds of answer. But even beyond that distinction, the current state of empirical knowledge points to variety rather than parsimony. We are used to living with a variety of transmitter substances to convey information across synapses; why should there not similarly be a number of mechanisms for the storage of information? Admittedly it would be useful to keep the number down as far as possible. I personally prefer therefore to group the phenomena of memory into five classes. Others may well differ on the classification; but they do discuss the same phenomena, so my classification may be useful to orient those unfamiliar with these problems. They can then reject it later!

A rough classification of phenomena

The distinctions between my five classes are given in table 1. All of them consider the case in which a person is given something to remember; the differences lie in the ways one can produce forgetting.

First, there is forgetting as a function of fresh *stimuli*, without any action being required. For instance, after one has heard a series of spoken words, hearing a fresh spoken word may cause them to be forgotten, even though one does not have to do anything about it.

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Second, there is forgetting as a function of *actions*, without any new stimuli and without thought being required. For instance, the technique of articulatory suppression in which the person looks at memory material while saying something irrelevant, predictable and repetitive.

These two kinds of forgetting depend on the relation between the memory material and the stimulus or action. That is, an irrelevant spoken word interferes with memory for speech but not for written words. Irrelevant articulation interferes with verbal memory, but to interfere with memory for the tracing by hand of nonsense shapes, one needs interfering hand gestures. (Hulme 1981).

TABLE 1

Changes in memory occur through:

(1) *stimuli*, with no action
(2) *actions*, with no stimulus
(3) *processing*, with 1 and 2 excluded
(4) *context* changes
(5) *same event*, presented previously

There is a third kind of forgetting, as a function of *processing* rather than stimulus or action. In this case, the memory material is followed by a task that uses stimuli and actions that would by themselves not be expected to give forgetting. Phillips & Christie (1977) have shown effects when sounds that require action do interfere with visual memory. To take an old study of my own (Broadbent & Gregory 1965), reaction time with the hand to a touch on the finger will interfere with spoken recall of verbal stimuli. In this kind of forgetting it is not so much similarity of input or output that matters, but how much one has to do.

The fourth kind of forgetting depends on *context*, the original event occurring in association with new events different from those originally surrounding it. As Tulving showed some time ago, words that cannot be recalled in the absence of any hints are nevertheless available somewhere in memory, because when a person is given a hint of the general category to which the words belong they nevertheless pop up into full recall (Tulving & Pearlstone 1966). More recently he has shown that in a suitable context people will even fail to recognize things they have themselves recalled earlier (Tulving 1968; Watkins & Tulving 1975). In contrast to the other three classes of effect, what we seem to have here is a problem of finding the particular record of past experience, not a problem of preserving the record itself. Most studies in this fourth area are dealing with relatively long-term retention, whereas the other three are naturally dealing with temporary and volatile effects. It is impossible to avoid other stimulation, thought, or action for very long after one memorizes. Most forgetting of the first three kinds will therefore happen quite soon after presentation. This fourth kind is more likely to be studied with longer retention intervals.

There is a final fifth group of phenomena, which is harder to define. Perhaps one could call it the class of effects independent of *other* activity. There are some effects that have to do with earlier experience of the event itself. For example, if one is given a list of words and then asked if a particular word was in the list, the speed of decision will be faster if that same word was used in an earlier trial of the same experiment (Monsell 1978). This applies even though lots of things have happened in the interval, so this is not an effect in our first three classes. On the other hand, it is not the same as my fourth class either, as a fresh association of item with a different set of other items might be expected to impair memory rather than improve it. This fifth class is the one in which I would put effects such as those of Jacoby & Dallas (1981) or Tulving *et al.* (1982).

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A simple scheme to locate these phenomena

Some people prefer to use a map of spatial arrangement of different functions as an aid to thought. For such people, I would suggest that they think of memory as a kind of Maltese cross, with four wide arms all opening out from a central point. Each arm is a different class of 'representation', that is, of persisting state that corresponds to past external events. The information can go from any arm to any other arm, through the centre, which contains processing rather than representation. That is, it contains the events that change one representation into another, and thus occur at particular times. In the earlier classification of phenomena, each arm of the cross corresponds to one of the first four classes; the fifth is in the centre. (The cross analogy is expanded with far more detail by Broadbent (1983).)

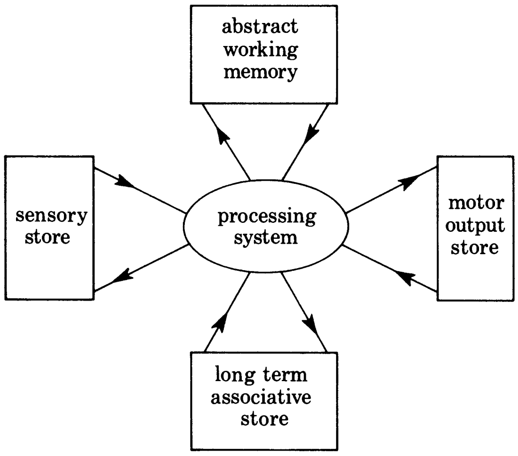

Figure 1. A simple model to conceptualize the current classifications of memory. (Reproduced from Broadbent (1983), with permission.)

One arm of the cross corresponds to sensory memory. It receives signals not only from the centre but also from the outside world. It is also divided into parts corresponding to different kinds of stimulus. If therefore some event is detected by the senses, and belongs to the same class as another event that is being held in this arm of the cross, memory for the latter will be impaired. Events in other classes will not have this effect. If somebody says to us 'Pass me the salt, please', the word 'please' produces forgetting and makes it more likely that we shall give them soup or salad.

A second arm of the cross corresponds to motor output storage. It contains a string of commands for a sequence of actions; it will thus hold information such as a telephone number in the form of instructions to the articulatory system to say those words. The instructions need not be translated into external action, but merely provide a temporary form of storage until the person has to carry out some other action using the same system. You can remember a phone number by saying it to yourself as long as you do not have to talk to somebody else; but you can walk, or point, or raise your eyebrows, and still remember the phone number.

The third arm of the cross contains a small amount of information in a form which is neither sensory nor motor. It can only get there by active processing from one of the other arms, and when more is inserted the items that are there already are lost. Remember the touch and verbal memory interference, or the Phillips & Christie (1977) study.

Fourthly, the remaining arm of the cross contains information on the associations between events rather than on the occurrence of events. A very common way of thinking of this fourth system is in terms of a network of nodes and links, each node representing an event. Thus if one has learnt a list rather shallowly, the network might look rather like figure 2. After more elaborate processing, the network would look like figure 3. In trying to recall the list, the minimum entry point would be the node 'What I learned 10 minutes ago', but other points of entry might also be used. A more complex net such as figure 3 would allow more points of entry and therefore a better chance of retrieving the words. This is particularly true if, at the time of recall an appropriate hint or cue is given, which calls up one of the alternative entry points.

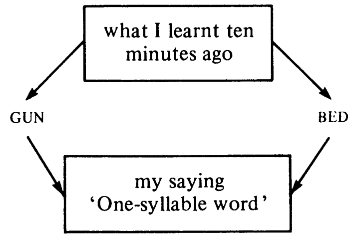

FIGURE 2. A network to represent the state of associative memory after learning the words 'gun' and 'bed' with a shallow task of naming the number of syllables per word.

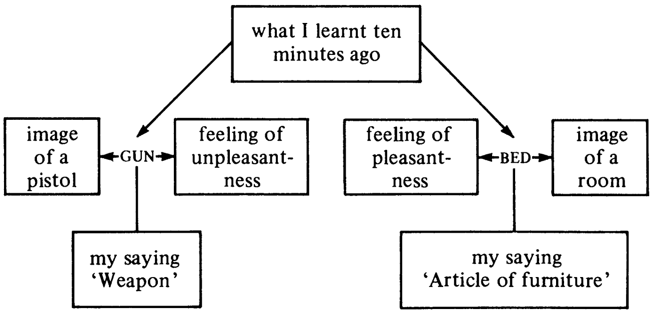

FIGURE 3. A network for the state of memory after the more elaborate task of categorizing words.

There are therefore four kinds of representation. When one speaks of information as being in memory, it can be in any of these kinds of representation, and it can move around from one to another. Whether it does so, and the sequence in which it does so, depends on the task, the circumstances and the history of the person involved. It is not an invariant progression from one form of memory to another, as was thought in, say, 1970. For those unfamiliar with the area, it may be useful at this point to give some of the reasons for regarding the arms of the cross as separate forms, manifestations or kinds of memory. When sensory memory is disrupted by a later stimulus, the effect is usually greatest on the last input to have arrived (see, for example, Crowder & Morton 1969; Broadbent *et al.* 1978*b*; Martin & Jones 1979). If on the other hand one uses articulatory suppression to produce forgetting, by getting the person to repeat something irrelevant while memorizing, then the effect is often greatest at the beginning of the list that is to be recalled (Baddeley *et al.* 1975; Broadbent & Broadbent 1981). This makes sense if you look at the cross, because information at the end of a list cannot get through to the motor store while that at the beginning is still in sensory store. It is much more likely that the early information will go through to be articulated, and so will be disturbed by articulatory suppression. The later information, on the other hand, will still be in the sensory store, and so vulnerable to a later sensory event.

This pattern of results depends on the processing system's being in action and ready to handle information as it arrives. It has been shown by Routh (1976) that things are rather different if one occupies the person with some other task while the memory information is arriving. In terms of the Maltese cross, the second task occupies the processing system and makes it harder to transfer information from the sensory to the motor memory. Correspondingly, in Routh's results there is evidence for sensory memory early in the list of items, not confined to the last few.

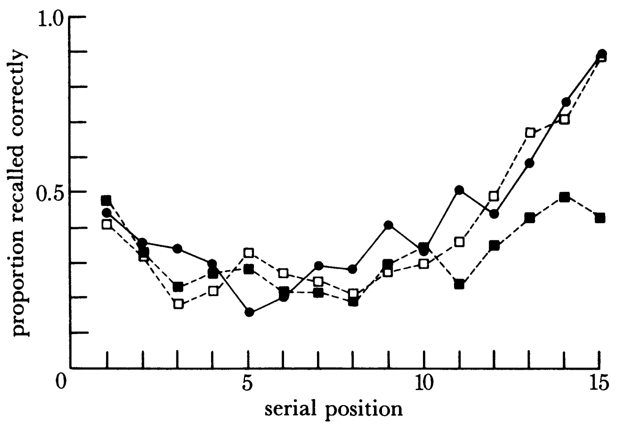

FIGURE 4. Effect on memory for acoustic and for visual stimuli, when a later task is performed by using stimuli from the sense not used for memory. Note the effect of sensory storage, primarily on the last items presented. ●, Visual control; ■, visual–auditory; □, auditory–visual. (Reproduced from Broadbent *et al.* (1978*b*), with permission.)

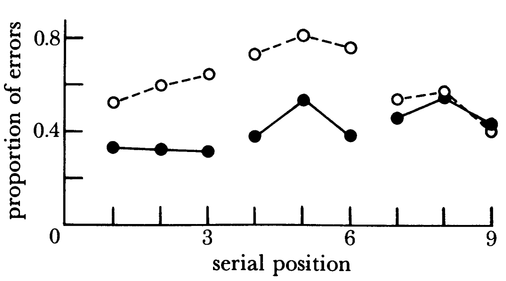

FIGURE 5. Effect of articulatory suppression on memory for visual letters. Note that the effect is largely at the beginning of the list. ●, No suppression; ○, suppression present. (Reproduced from Broadbent & Broadbent (1981), with permission.)

This is the general form of argument that is used in making distinctions within memory; it is logically the same as the argument originally used to distinguish short-term from long-term memory, but now it distinguishes between different kinds of temporary memory. The third arm of the cross, the abstract working memory, stems from the seminal work of Baddeley & Hitch (1974); let me give as an example of the supporting evidence a study by Broadbent & Broadbent (1981). We gave people lists of letters to recall, with sensory memory largely eliminated. Some of the lists were made up of meaningful triplets of letters, such as BBC, FBI, UNO, and so on. These lists were much easier; presumably the individual letters (which arrived sequentially) were

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stored very briefly and then recombined into some fresh code when the meaningful triplet had arrived. At first sight one might guess that each letter was held briefly in internal speech until that point; but articulatory suppression did not reduce the size of the effect. It merely reduced the total level of performance. Apparently therefore the storage of individual letters long enough to reach the meaningful unit was not articulatory. The nature of this central non-sensory, non-motor temporary store is, however, one of the major current problems.

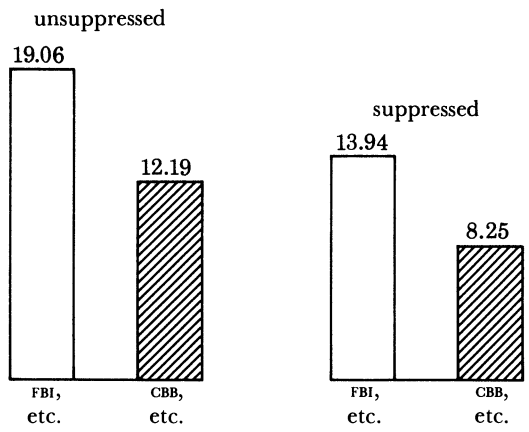

FIGURE 6. Effect of meaningfulness of letter triplets presented visually: numbers correct out of 24. Note that the effect is of approximately equal size whether or not articulation is suppressed. That is, the temporary store for isolated letters does not appear to be articulatory. (From the data of Broadbent & Broadbent (1981).)

SOME POINTS OF CONTROVERSY

Let us turn now to some differences between my own preferred way of looking at things and that of others. First, let me emphasize the exact definition I used for sensory memory. It is quite common to think of sensory memory as a kind of analogue of the physical stimulus, as if it were a persistence of activity in the original projection area or something of that sort. That will not do, because for example heard speech and lip-read speech may interfere with each other even though one is coming to the eye and one to the ear (Campbell & Dodd 1980). The point is that the memory is interfered with by an irrelevant stimulus, and that there are classes of mutually interfering stimuli; not that each class is necessarily confined to one sense-organ. The definition of a sensory memory is merely that it can be damaged by stimuli without action.

Second, let us look more closely at the nature of the network in the fourth arm of the cross. On the face of it, a mechanism of that kind would greatly favour the learning of materials that are arranged in branching trees of hierarchies. It would also suggest that memory in the network should be asymmetric, with some dominant nodes acting as the addresses of the files, so that it should be easier to recall B given A than to recall A given B. Neither of these predictions is borne out empirically. Organized networks that are non-hierarchic are just as easy to learn as hierarchic ones (Broadbent *et al.* 1978*a*), and although some words in a sentence may be particularly important for recall, it turns out on analysis that this is not because of asymmetry. Given three words in a sentence, A, B and C, the probability of recall of A given each of the others may well be equal to the probability of each of the others given A (Wilhite 1982). I would therefore argue that the network in long-term memory is merely a mathematical description of a store consisting of many fragments, each associating a few elements, and with elements

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repeated in several fragments (Broadbent 1981). This is of course the view of Jones (1976, 1978), as will appear in a later paper.

Third, I wish to emphasize the difference between lasting representations and the events, the processes, that transform one representation into another. The effects of past experience appear in both; many approaches to memory confine themselves to one, and I believe this to be a mistake. In the Maltese cross, the processes are in the middle and the representation in the arms.

The experience of the person not only changes representations, it also changes processes. As an adult, I know that a particular visual input is appropriate for saying the word 'cat'; when I have that pattern in my sensory store, I can transfer it into a pattern of articulatory commands in motor store. A young child, however, cannot. The nature of the processing, the centre of the cross, has changed in me from the form it had when I was young. Although one can call this 'memory' if one chooses to do so, it is logically different from the existence of a representation of an event. It also seems to be different functionally. The results of Jacoby & Dallas (1981) and of Tulving *et al.* (1982) have already been mentioned. One can give as another example the work of Warrington & Weiskrantz (1974) on amnesia. Certain kinds of brain injury cause a person to forget words more completely than normal people do, when one tests by simply asking for recall. If, however, one presents to the eye fragments of a word, those fragments will trigger the person to say the word if they have seen it recently; but this kind of memory is not affected by the brain injuries that produce amnesia. One must not confuse processes and their products; representations are different from processes.

Lastly, let me take the same distinction between representation and process, and emphasize certain difficulties that appear in network interpretations of context changes in memory. As appears in later papers, in a certain mood people are better at recalling events that happened when they were previously in that same mood (Bower 1981). That fits the same kind of theory as can be used for the 'levels of processing' effects. But it is also true that in a happy mood you are better at recalling nice words even though you were not particularly happy when you met those words (Teasdale & Russell 1983). Now this is very different from the 'levels of processing' effect. If one gives at recall a hint that takes the form of naming the category to which a word belongs, this is chiefly helpful only when the category was named when the word was memorized; if it was not, the hint may do no good at all (Fisher & Craik 1977; see Tulving (1979) for a discussion). One should not be surprised at this. The advantages of a retrieval cue are known to decrease if there are more things associated with it; in a single experiment there will be few words in a certain category, but in life in general there are many. A cue that did not occur at presentation will therefore suffer from overload and have a diluted effect. But there are very many nice words, and happy moods must have been associated with enormous numbers in life in general. How then can a mood that was not present during original learning have an effect in selecting which words are recalled?

I therefore believe that there is a discrepancy between the results of mood experiments and those of experiments on change of context between original learning and later recall. I would suggest that, instead of regarding the mood effect as located in the associative net, we should see it as a change in the processing system. That change causes certain parts of the network to be emphasized in selection, or certain temporary codes to be easier to create, so that the effect is different from that found in levels of processing. However, different and more authoritative views will appear in later papers.

This paper has struck an uneasy balance between introduction and originality; the reader

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should beware of confusing the more provocative later sections with the overview given previously.

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Discussion

D. R. J. Laming (*Department of Experimental Psychology, University of Cambridge, U.K.*). How can Dr Broadbent be sure that the different classes of phenomena that he distinguishes are due to different mnemonic mechanisms or processes and not to different psychological properties of the material to be remembered or of the experimental demands placed on the subjects, the mnenomic machinery being common?

D. E. Broadbent. By using the same material and experimental demands in each of the experiments: for example, if we are comparing acoustic and visual sensory memory we use the same words in both cases, with the same instructions; any intervening task should be the same except for the sense organ of delivery, and so on.

Elizabeth Loftus (*Psychology Department, University of Washington, Seattle, U.S.A.*). Dr Broadbent has claimed that sensory memory is 'storage disrupted by something you do not have to do anything about'. This definition seems too broad. For example, consider retrograde amnesia, or loss of memory for events that occur before some critical incident, such as a head injury, electroconvulsive stimulation, or the administration of a variety of drugs. Such loss can occur even in the absence of a physical insult to the brain, for example when a person simply views a violent or traumatic event. In these cases, one finds that storage of information is 'disrupted by something you do not have to do anything about'. And yet it appears that the disruption in these cases is of storage that is well past the stage of sensory memory. Does this suggest that Dr Broadbent's definition of sensory memory will encompass too much?

D. E. Broadbent. Could I draw attention to another part of my definition of sensory memory? The disruptive event has to belong to the same class as the original input to memory: that is, speech sounds damage memory for speech sounds but not for printed words. Retrograde amnesia is not restricted in this way, and therefore is not involving sensory memory.

Maryanne Martin (*Department of Experimental Psychology, University of Oxford, U.K.*). In the Maltese cross, which parts of the system are limited?

D. E. Broadbent. There are several kinds of limit in the system; the sensory memory is limited only by the number of different classes of sensation, which must be very large. The motor store is limited by the temporal duration of the string of motor commands it can hold; for example, according to Dr Baddeley's group one can hold only about $1\frac{1}{2}$ s worth of internal speech. The abstract working memory seems rather to hold a fixed number of separate items or units, and loses an old one if one wants to hold a fresh one. My own estimate is that the limited number is about three items. The long-term associative store is essentially unlimited. Lastly, the processing system (and that alone) is limited in 'capacity' in the informational sense; it can handle within a given time many probable transformations, or few improbable ones.

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