Some features of a recently-proposed model of the human nervous system are subjected to experimental test. The findings support a limited-channel-capacity concept but suggest that the perceptual mechanism is more flexible than the model implies.

SOME HUMAN PERCEPTUAL LIMITS

G. H. Mowbray

To the designer of complex weapon systems, one of man's prime assets is his flexibility, an asset that can be attributed to two extremely versatile sensory systems, namely vision and audition, which feed the most complicated computer known to exist. Because of the extreme cost of devising machinery to duplicate such highly complex processes, it is obvious that such vital parts of weapon systems as their information processing centers are, and will probably continue to be, operated by man.

In order to make efficient use of the data processing capabilities of humans, increasing knowledge of them is essential. The extent and the limits of these capabilities depend on the basic characteristics of the human perceptual system. An analysis of much research concerned with human perception has recently led one investigator, D. E. Broadbent, to propose a model of the human nervous system whose essential features include a short-term information storage capability, a selective filter, and a limited-capacity perceptual channel.[1] The short-term store is assumed to occupy a position ahead of the limited-capacity channel and to be capable of storing incoming information for about one second. Increased storage time may be provided by returning information to the store after passage through the limited-capacity channel. This process may be repeated indefinitely at the expense of restricting the flow of new information or even reducing it to zero.

In describing the selective filter, Broadbent suggests that there is at the input to the nervous system a filter which will allow some classes of stimuli to pass but not others. This filter may be switched from one class of stimulus events to another. It perhaps can be seen that this is a necessary adjunct if one is to explain the rapid shifting of attention that occurs, or may occur, when the nervous system is bombarded by two simultaneous and conflicting streams of stimulation. The filter can be biased by instruction or by some internal requirement, establishing the basis for "set," or the predilection for selecting certain classes of stimuli from among the many that may be present in the environment at a given time. Similarly, it is proposed that the filter has a bias toward novel or unexpected stimuli. Thus, an intense noise amid otherwise quiet surroundings is likely to cause a shift of the filter, to the momentary detriment of whatever task was previously occupying the limited-channel capacity of the organism. Those are the major descriptive aspects of the filter, as Broadbent envisages it; he states quantitatively that a complete cycle of two perceptions and two shifts of the filter occupies from one to two seconds.

Those parts of Broadbent's model that are of particular interest here are the short-term store with a decay time of about one second and the selective filter that can be switched between sensory inputs at such a rate that two perceptions and two shifts require from one to two seconds. The experiment described herein was designed to test these aspects of the model. Note, however, that the conditions under which this experiment was conducted were quite different from those that led to the formulation of the Broadbent model.

[1] D. E. Broadbent, "Perception and Communication," Pergamon Press, London, 1958.

The Experiment

Five male and five female college students were required to listen through earphones to a 50-word list of English words that had been recorded at a controlled rate of about two words per second. The words, drawn from the Thorndike-Lorge lists of the most commonly used words in the English language, were mostly two, three, or four syllables long. As they were read, the students were required to "shadow" them, i.e., repeat them aloud as they were presented. At the same time they were told to view a small area of a projection screen on which other printed English words would appear from time to time. Following the presentation of the 50-word auditory list the subjects were asked to recall all of the visual words that had appeared and in their proper order.

The subjects were all well-practiced in auditory shadowing, with and without accompanying visual words, before any experimental trials were begun. The time required to attain proficiency in this task varied from 2 to 4 hours, depending on the subject. The experimenter decided on the basis of a subject's performance whether or not he was ready to begin the experimental trials.

During the experimental trials the shadowing responses of the subjects were recorded on tape. Only one, two, or three visual words were presented with any 50-word auditory list, and on certain control lists no visual words appeared at all; the subjects were never informed of what condition to expect. All visual words were randomly chosen and were different from any words appearing on the auditory lists. Exposure time of all visual words was 1/25 sec, and they were timed to coincide with a word on the auditory lists.

All subjects were tested on 30 control and 30 experimental lists. Of the latter, 10 were accompanied by one visual word, 10 by two visual words, and 10 by three visual words, with words occurring equally often within the first, middle, and final thirds of the auditory presentation. There was only one visual word within any one-third of a list, and its position within that one-third was essentially random, with the restriction that at least five auditory words intervene between successive visual words. The subjects were not informed of this circumstance.

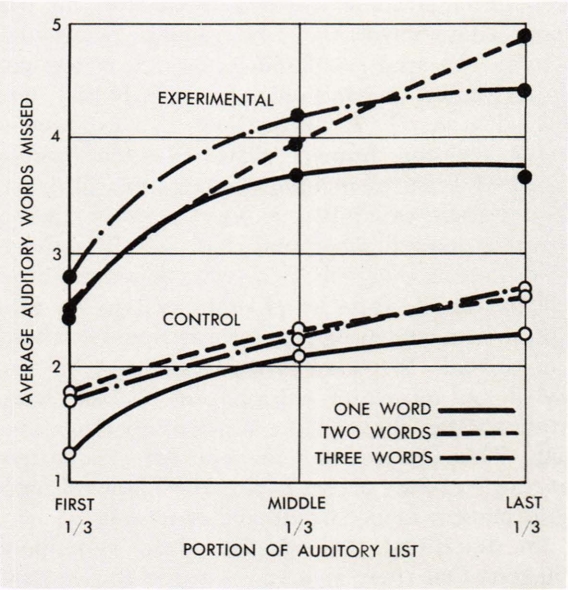
The experimental and control auditory lists were recorded separately on magnetic tape by three different speakers and in three completely different orders, although the same words were used. Therefore, each third of the subjects heard a different voice and a different word order. Each subject's control lists were identical in composition to his experimental lists, the only difference being that with the latter he was also presented one, two, or three visual words.

The Results

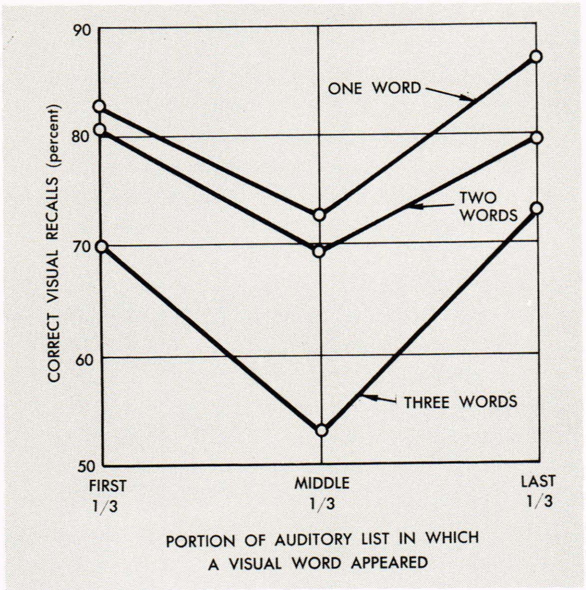
The average number of auditory words missed for the control and the experimental conditions is shown in the first illustration as a function of the portion of a list in which the visual word occurred. This points out, first of all, that with the control lists there is a progressive increase in the number of auditory words missed as the list proceeds. It is not a great increase—from approximately a word and a half to two words and a half—but it suggests that the subjects were stressed to keep up with the auditory shadowing. This is an essential factor in the context of this experiment.

The second point that is clear from this figure is that presentation of a visual word during auditory shadowing causes an increase in auditory errors. With the exception of the final point on the two-word curve, this increase seems to be fairly constant for all conditions.

We must next consider how well the subjects



Average number of shadowing responses missed for successive portions of the auditory list for the control and experimental lists.

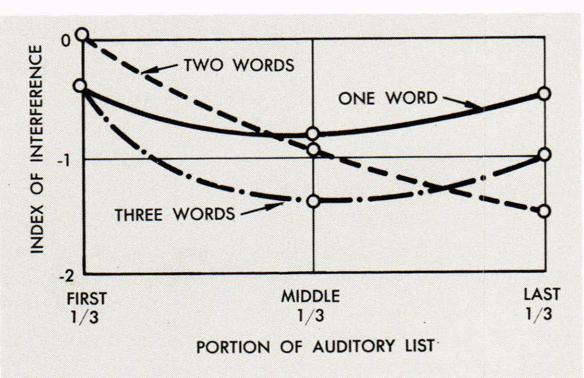


Percentage of correct visual recalls for words presented in successive portions of the list to be shadowed.

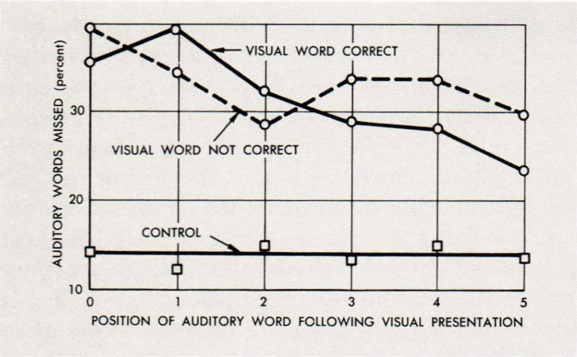
remembered the visual words that were shown to them during the auditory shadowing. The second figure shows these results. Here the percentage of visual words correctly reported is plotted as a function of the portion of the auditory list with which it was associated. Looking first at the occasions on which only one visual word accompanied an auditory list, it is important to note that the word presented during the first one-third of the list was as successfully recalled as the one presented during the final one-third. Therefore, being in the memory store for about 15 to 18 sec apparently caused no more deterioration in memory than being there for only 4 or 5 sec. This, of course, runs counter to any short-term decaying-trace theory of immediate memory unless it can be argued that the subject had time to rehearse the visually-presented words during the process of auditory shadowing. According to Broadbent, to succeed at this the visual word from the short-term store would have to traverse the limited-capacity channel and return to storage at least once every second. While this was being accomplished, the channel capacity would be severely restricted. Such is the nature of a limited-channel-capacity concept. Yet the continuing, auditory shadowing task, to be carried out successfully, required undiminished channel capacity.

Now, since we have seen that shadowing responses were worse when visual words were presented, and that a great many visual words were correctly recalled, the question arises of whether the loss of auditory words was offset by the gain of correctly remembered visual words. To determine this, an index of interference was developed which, simply stated, is the following: the average number of auditory words missed on the control lists for a given one-third of the list was subtracted from the average number of auditory words missed on the experimental lists for a corresponding one-third of the list. This gives a figure that represents the amount of interference (or average words missed) due to a visual word having been presented at that particular time. The average number of visual words correctly recalled for the same one-third of the list was figured and compared with the interference figure. If these two figures turn out to be identical, then the average loss of auditory words is exactly compensated for by the average gain of visual words and the index of interference is zero. Any excess of auditory loss over visual gain would yield a negative figure and, conversely, any excess of visual gain over auditory loss would yield a positive figure. The third illustration shows this index of interference plotted for all conditions and for the various portions of the list.

The main result shown by this type of analysis is that in gaining one visual word, more than one auditory word, on the average, was sacrificed. An even exchange—one visual for one auditory—would have resulted in an index of interference of zero. The results of these tests, however, are nearly all negative and, in fact, most are near minus one and below, which means that generally two auditory words were



Index of interference for the experimental conditions as a function of the portion of the auditory list in which a visual word was presented.



Percentage of auditory words missed as a function of their position following presentation of a visual word.

lost for every visual word gained. Was this extra loss caused by the attempt to remember the visual word through rehearsal or was it due to something else? It might be possible to find out if it was through rehearsal by comparing one-word lists with each other. Thus, the over-all auditory shadowing responses of a list that had a word presented in the first third of a list should be worse than one that had a word presented in the final third if rehearsal were a major factor in determining interference. An analysis of this sort was performed, and it was found that an average of 7.84 mistakes per list in auditory shadowing occurred when the visual word appeared in the first one-third of the list, and an average of 7.54 mistakes per list occurred when the visual word appeared in the final one-third of the list. It seems fair to conclude that if rehearsal were taking place, this type of analysis does not make it dramatically evident.

The final result concerns the way in which the presentation of a visual word affected the shadowing responses for the auditory word with which it coincided, as well as for those immediately following it. The final illustration shows the percentage of auditory words missed as a function of the position of the auditory word following presentation of the visual word. Zero on the abscissa corresponds to the auditory word that occurred coincident with the visual presentation, whereas "one" represents the auditory word immediately following, and so forth. All one-, two-, and three-word conditions have been combined, but the results are plotted separately according to whether the visual word was correctly remembered or not. The results of the control lists are provided for comparison.

First, and surprisingly, there appears to be no difference between remembering a word and not remembering it, so far as this analysis is concerned. This seems to argue further that no rehearsal of the visually-presented words was taking place for it seems inconceivable that the same amount of rehearsal, leading to the same order of interference with the shadowing responses, should in one case lead to successful retention and in the other case not.

The second thing to note in this illustration is the rather amazing fact that more than 60% of the shadowing responses that coincided, as near as was experimentally possible, with the presentation of the visual word were errorless.

In the light of these data, what can be concluded about the quantitative aspects of Broadbent's perceptual model? As far as the filter-switching time is concerned, it appears that it must be much more rapid than previously stated. In 65% of the experimental trials roughly five perceptions and two shifts of the filter were accomplished in about two seconds. The limited-channel-capacity concept is generally well supported since the index of interference revealed an over-all loss of information transmission when an already fully-occupied channel was further stimulated. Human channel capacity has been shown in the past to vary enormously with the transmission task employed and the manner of information encoding. However, a figure of 35 bits/sec is generally accepted for rapid oral reading and does not appear to be out of line with these findings.

The results on the temporal aspects of the short-term memory are equivocal. If filter-switching is much more rapid than has heretofore been considered possible, then it seems entirely likely that the visually-presented words in these tests became a part of long-term memory by making several rapid transits of the perceptual channel while auditory shadowing was in progress. Since the last illustration indicated that interference to the shadowing responses extended with diminished vigor over at least the five auditory words subsequent to the appearance of the visual word, this possibility is strengthened. Furthermore, it suggests that relatively few such cycling processes may be required to create a semi-permanent store. There is also a hint that succeeding cycles require less and less channel capacity. Whether this could be due to increasingly rapid filter-switching times or to some other presently unrecognized factors remains a matter for speculation.