Short-term retention during a simultaneous detection task

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Subjects were required to perform a short-term memory task and a signal detection task, both individually and simultaneously. Memory performance was impaired only when the signals in the detection task were difficult to detect. The impairment in memory was restricted to items which appeared in the early positions of the list to be remembered. Detection performance was unaffected by the simultaneous task requirement and there was no correlation between performance on the two tasks when both were performed together. The results suggest that the difficulties Ss have when they attempt to perform several tasks at the same time may be due to limitations in the processes responsible for storing and retrieving information rather than those involved in the perceptual analysis of the incoming material.

When human Ss are asked to perform several tasks at the same time, performance on one or all of the tasks usually deteriorates from that observed when the same tasks are performed separately. Recent theories of attention have been concerned with the causes of this performance decrement and, in particular, with identifying the stage of signal analysis where the interference arises. In one type of experiment used to investigate this question, a S is required to monitor a "relevant" message channel when a number of different messages are presented to him simultaneously. The S's job is to select a particular channel and ignore all the others.

The results of the early experiments suggested that Ss used physical cues only to separate the messages (Cherry, 1953; Egan, Carterette, & Thwing, 1954; Speith, Curtis, & Webster, 1954). That is, only such cues as differences in voices, spatial location or auditory frequencies were used to distinguish the relevant messages from the background material. In general, the Ss appeared to perform only a crude perceptual analysis on the messages of secondary interest. Subsequent experiments have demonstrated that in addition to using gross physical cues, Ss sometimes were able to extract the meaning of an irrelevant message before they discontinued processing it (Grey & Wedderburn, 1960; Moray, 1959; Treisman, 1960, 1964a, b). To account for these results, several theorists have proposed that all incoming messages can be analyzed for their meaningful content (Deutsch & Deutsch, 1963; Norman, 1968). Thus, selection of a relevant message can be based both on its physical cues and on its meaning. But if it is true that we can in fact perceive and understand several simultaneous messages, then why should performance on a given task suffer when others must be performed at the same time? Why do two tasks interfere with one another when Ss attempt to do them together?

One logical source of the impairment in processing ability is in the mechanisms responsible for storing and retrieving information. Although an analysis for the physical properties and meaning of the inputs might be performed smoothly and efficiently on all incoming messages, a bottleneck in processing could still arise because of limitations in short-term memory and long-term retrieval capability. Recently, several experiments have investigated Ss' performance on memory tasks while they were asked to do a competing task simultaneously (Moray, 1959; Mowbray, 1964; Norman, in press). Unfortunately, these experiments share a number of difficulties. One difficulty comes from the type of competing

task most often used: shadowing. In this task, the S must repeat verbally the text of an auditory message as it is presented. The point under study is how well Ss can perform a second task while they are shadowing. The problem is to decide how to measure and interpret the shadowing performance. It has been difficult to determine the extent to which shadowing requires the continuous attention of the S and how much the shadowing response itself interferes with the perception and retention of other incoming messages. Another problem arises because of the verbal nature of shadowing. If we wish to study limitations on the retention of information, it seems unwise to use a competing task which is also heavily dependent on memory.

In the present study, we investigate changes in the short-term retention of information when Ss are also required to perform a psychophysical detection task. This approach has a number of virtues. First, both the detection and memory tasks are rather well understood; both can be analyzed using the same quantitative technique, namely, the theory of signal detection. Second, memory performance can be measured under conditions where Ss do not have to perform any overt response during the presentation of the material. This eliminates the possibility that the act of responding to incoming messages might be a source of interference with their perception and retention. It is generally assumed that the performance on simple detection tasks depends primarily on sensory and perceptual mechanisms, with memory processes playing only a minor role. By asking Ss to do both a detection and a memory task we can study the effects of increasing the perceptual load on a S under conditions where the load on memory remains relatively constant. Finally, the difficulty of performing either task can be systematically controlled. We can control the difficulty of the detection task by varying the signal-to-noise ratio. We can control the difficulty of the short-term memory task by varying the number of items occurring between the initial presentation of an item and its subsequent test for retention. Thus, we can investigate the way two tasks interact with one another as the difficulty of performing each task varies from perfect performance to levels not far from chance.

METHOD

Subjects were required to perform a memory task alone (M), a detection task alone (D), and both a memory and a detection task together (MD). The memory and the detection signals were always presented to the Ss. The differences among the conditions resulted from differences in the instructions about which tasks required attention and responses.

The Memory Task

Memory was tested by the recognition method. On each trial, a list of six three-digit numbers was presented (to the right ear) at a rate of one number every second. Then the end of the list was indicated by a high-pitched tone and a three-digit test number was presented. The S's task was to indicate whether or not the test number had appeared in the preceding list and to express his confidence in the accuracy of his response. On two-thirds of the trials the test number was old—it was the same as a number which had been presented in the previous list. On one-third of the trials the test item was

Fig. 1. The sequence of events on a single trial. The time relationships shown are approximate and are not drawn to scale. Each cycle shown for "digits" represents the occurrence of a three-digit number.

new; it had not appeared in the previous list. Each of the six positions was tested equally often. The difficulty of the recognition task varied with the serial position tested: the last item of the list was expected always to be remembered; the first few items would seldom be remembered. The details of the procedure and, in fact, the magnetic tapes used to test memory were the same as those used by Wickelgren and Norman (1966).

The Detection Task

The S was required to detect a 600-Hz tone imbedded in band-limited white noise (300 to 1200 Hz). A four-alternative temporal forced-choice procedure was used. On every trial, four noise bursts were presented in succession. A signal was added to three of the four noise bursts; the S's job was to determine which of the bursts did *not* contain a signal. Each noise burst lasted for 1 sec followed by a ½-sec silent interval. Thus, the four bursts and silent intervals lasted 6 sec, coinciding exactly with the duration of the memory presentation. The signal itself was presented for 100 msec and occurred randomly at any one of four equally spaced positions within the 1-sec noise burst. The sequence of signal events on each trial is summarized in Fig. 1.

The parameters of the signal detection task were chosen to force the Ss to listen for the signal during the entire 6-sec interval of each trial. Ss never knew in which part of the noise burst the signal might be presented nor from which of the noise bursts the signal would be deleted. A signal duration of 100 msec was selected, since, for durations of less than about 150 msec, detectability is strongly dependent on signal duration. If the S did not listen to the entire signal, there would be a measurable decrease in his detection performance. With a longer signal, one could argue that a S need not attend to the signal throughout its full duration in order to maintain the maximum level of detectability.

Preparation of the Stimulus Materials

All the signals were prerecorded on magnetic tape. For the memory task there were three tapes, each with 83 lists. On each tape, 25 lists had new test items, and 50 lists had old items. The remaining eight lists were practice lists which were used at the start of each session and after rest intervals during a session. For the detection task, the pure tone signals were recorded on one track of a magnetic tape and the noise bursts on a second track. Three tapes containing the signals for the detection task were constructed with each tape synchronized exactly to one of the memory tapes.

During the course of the experiment, the memory and

detection signals were presented by means of two synchronized tape recorders. The output of the tape recorder containing the digit list was connected to the right earphone of each of three headsets. The two channels of the tape recorder containing the detection signals were passed through separate attenuators and then mixed. The output of the mixer was connected to the left earphone of each headset.

During the experiment the noise level was always held constant and the signal amplitude was controlled by means of the attenuators. Four values of signal amplitude were chosen to provide a range of difficulty for the detection task. In order of decreasing signal-to-noise ratio (and, therefore, increasing difficulty of the task) levels of +5, 0, -5, and -10 dB were used. The numbers indicate the differences in the signal-to-noise ratio at each level; they are accurate measures of these differences, but are arbitrary with respect to a standard reference level. The loudnesses of the digit lists and the noise bursts were approximately equal and both were at a comfortable listening level.

Data Collection

Each experimental condition was tested in a sequence of 75 trials during which the attention requirement and signal-to-noise ratios were held constant. The three main conditions (M, D, and MD) were tested in random order in every experimental session. Across sessions, all possible combinations of the three attention conditions, the four different signal-to-noise ratios, and the three different sets of lists were tested in a counterbalanced order.

Due to an error in the control settings, the results obtained for one of the sets of digit lists had to be discarded. A total of 3600 responses was obtained from each S on the remaining lists, 900 responses from conditions M and D and from each task in Condition MD. Of the 900 responses for each attention condition, 150 responses were obtained at the +5 and -10 dB signal-to-noise ratios and 300 responses were obtained at the 0 and -5 dB signal-to-noise ratios.

Subjects

Three females served as paid Ss in the experiment. Prior to the beginning of the experiment, each S was given 8 h of practice on the detection task during which the signal-to-noise ratios to be used in the experiment were established. In addition, the Ss were given 3 h of practice on the memory task. During the experiment, all Ss were tested at the same time in individual experimental booths. They reported their responses on mark-sense cards which were interpreted and analyzed by computer. The order of report in the MD conditions was fixed; Ss reported their responses for the memory task first and for the detection task second. Twenty experimental sessions in all were conducted.

RESULTS

Memory Performance

The serial position curves obtained from the tests of memory for Conditions M and MD (averaged across signal-to-noise ratios) are shown in Fig. 2. As illustrated by the averaged results, the conditions are difficult to compare with one another because of different levels of false recognition—responses of "Yes" to an item not appearing in the preceding list. In situations like this it is convenient to specify performance on the memory task by means of the d' statistic of signal detection theory, since both correct and false recognition scores are incorporated into one measure. (A discussion of the rationale and procedure used for estimating memory strength with the d' statistic can be found in Wickelgren and Norman, 1966.) Performance was very similar for both sets of lists; therefore, the data for the two sets were averaged before the d' measures were computed. An analysis of variance showed no

Fig. 2. Serial position curves for memory test alone (solid line) and with detection (dotted line), averaged across signal-to-noise ratios.

significant interaction of Ss with conditions and so only the mean values across Ss will be reported.

Average performance on the memory task as a function of the signal-to-noise ratio used in the accompanying detection task (Condition MD) is shown in Fig. 3A. Figure 4 shows the variation in memory strength with serial position for the different list positions. In Condition MD at the two higher signal-to-noise ratios (+5, 0), the overall performance on the memory task does not seem to have been affected by the addition of the detection task (Fig. 3A). Memory performance begins to deteriorate only as the detection task becomes more difficult. From Fig. 4, it is evident that even under difficult detection conditions (-5, -10), the memory performance for the last item on the list (Position 6) is essentially perfect. The main effect on memory caused by performing the two tasks simultaneously shows up only in the early positions of the memory list (Positions 1, 2, 3). Performance on later serial positions is independent of whether or not simultaneous detection is required. Thus, the retention loss caused by the introduction of a simultaneous detection task seems to be restricted to conditions where the detection task is difficult and where the information has been in short-term memory for some period of time before it is tested for retention.

Detection Performance

Performance on the detection task is illustrated in Fig. 3B, both as per cent correct and as the equivalent d' scores. The detection results are easy to summarize: Performance of detection alone (Condition D) and detection with a memory task (Condition MD) appears to be identical. The precision of detection is not affected by requiring a S to perform a memory task at the same time. In view of the perfect performance at the higher signal-to-noise ratios, several points should be noted about the relative difficulty of the detection task under the conditions of this experiment. Although detection performance is essentially perfect except for the -10-dB signal-to-noise ratio, the signals used are not readily detectable by a naive O. Even at the highest signal-to-noise ratio (+5 dB) a good deal of training is required to obtain perfect performance. The fact that memory performance did start to deteriorate at the -5-dB level even though detection performance was perfect suggests that considerable effort was needed to maintain this high level of performance.

Correlation of Performance on the Two Tasks

Some theories of attention propose that humans are capable of dealing with but one channel of information at a time

(Broadbent, 1958; Treisman, 1964a, b; Treisman & Riley, in press). According to this view, performance can be maintained or improved on one task only at the expense of performance on competing tasks. For example, the fact that retention in Condition MD is impaired for initial items in the list but not for the later items might be attributed to a tendency to attend more to the detection task during the first part of a trial. We would then expect the probability of detection to be highest when the signal was deleted from the first or second noise burst. Table 1 shows the probability of correct detection in each of the four detection intervals for both M and MD conditions. Detection probability is very similar for the four presentation intervals. If anything, detection seems to be slightly lower in the MD task relative to the D task in the first interval.

A single-channel attention mechanism might also be expected to produce a negative correlation in the trial-to-trial performance on the two tasks. If Ss can attend to only one channel at a time, then on the trials on which they are correct on the detection task, they should be less likely also to be correct on the memory task. To examine this possibility, we have computed the conditional probability of a correct response on the memory task separately for those trials where detection performance was correct and for those trials where detection performance was incorrect. These probabilities are shown in Table 2.

The data do not provide any evidence that a single-channel mechanism underlies performance in this experiment. The probability that Ss correctly remember the information presented on one channel is independent of whether or not they correctly detect a signal occurring simultaneously on a different channel.

DISCUSSION

An important finding in this experiment is that the introduction of one task is not in itself sufficient to affect performance on another. Memory is impaired only when both

Fig. 3. Average performance on memory and detection. Solid lines represent performance on single-task conditions (M and D); dotted lines represent performance when both tasks were performed together (Condition MD). In A, each point represents the average d' performance from Serial Positions 1 through 5.

Fig. 4. Memory strength as a function of serial position. The solid line represents average performance when the memory task was performed alone (Condition M). The dotted and dashed lines show memory performance in Condition MD, with signal-to-noise ratios of 0 and +5 (dotted line) and ratios of -5 and -10 (dashed line). Performance was perfect on Serial Position 6, and so is not shown on this graph.

the detection and the memory tasks are made difficult. This pattern of results allows us to dismiss several possible interpretations of the impairment in memory performance. First, they rule out the possibility that the sheer act of responding to one of these tasks interferes with the performance of the other. Second, they argue against any theory which suggests that the simultaneous transmission and processing of information in different channels simply raises the overall noise level which in turn makes perception more inaccurate. Third, they indicate that the memory and the detection tasks do not compete directly for a limited short-term storage facility. Whatever additional memory load is imposed by the performance of a simultaneous detection task, it is not in itself sufficient to alter the retention function. Since the rate of presentation and the number of signals to be handled was the same at all signal-to-noise ratios, it is unlikely that it was an increase in memory load that caused the retention loss in the more difficult detection conditions. Thus, the memory deficit under simultaneous conditions seems to be due to a change in the perceptual rather than the memory requirements imposed by the competing task. In general, the

findings are consistent with the notion of an upper limit on the available processing capacity. Evidently, an increasing proportion of that capacity must be allocated to the detection task as its perceptual difficulty increases.

In spite of the fact that the major factor in this experiment seems to be the perceptual demands imposed by the competing task, the performance of the detection task does not interfere with the *perception* of the digit list. We base this assertion on the fact that the last item in the list was always remembered perfectly in Condition MD (see Table 2). Perception of the item did not seem to be affected by the fact that the Ss were required to perform a detection task at the same time. Thus, the introduction of a difficult perceptual task on a second channel seems to interfere primarily when the mechanisms responsible for maintaining the strength of items in memory, rather than with those involved in the initial perception and registration of the incoming material.

We can examine this conclusion somewhat more systematically if we consider performance in a short-term memory task to be the result of three separate factors: a perceptual factor (α) representing the initial strength at which an item is registered in memory; a decay factor (ϕ) representing the rate at which information is lost from short-term memory; and a long-term memory component (λ) representing the amount of information that can be transferred into long-term storage and, therefore, be permanently available for recall. Using these three factors, Norman (1966) and Wickelgren and Norman (1966) have suggested that a short-term retention function can be described by an equation of the form:

$$t(i) = \alpha\phi^i + \lambda \quad (1)$$

where i represents the number of items intervening between the presentation of an item and its subsequent test and $t(i)$ represents the strength of an item at the time it is tested.

According to our arguments, the addition of a competing detection task should not affect the perceptual factor, α . The major difference in the memory functions between the single-channel (M) and two-channel (MD) conditions should be in the retention parameters, ϕ or λ . To test this notion, Eq. 1 was fitted to the retention curves obtained in this experiment by an iterative procedure which approximates the least-squares solution. The three parameters were computed separately for Condition M and for high (+5 and 0 dB) and low (-5 and -10 dB) signal-to-noise ratios in Condition MD. Although there are not sufficient data to draw a firm conclusion, the results of the analysis indicate that both the perceptual and decay factors (α and ϕ) are similar for all conditions. The major differences among the functions is in the estimate for λ ; when the signal was difficult to detect, the long-term component in the MD conditions is about 30% of the value obtained for Condition M.

A number of difficulties are raised by the constancy of performance on the detection task even when the signals are difficult to detect and the items are hard to remember. There are several possible explanations. One possibility is that the Ss did not divide their attention equally between the two tasks but gave first priority to detection. It is not clear why Ss would give most of their attention to the detection task,

Table 1
The Probability of a Correct Detection in Each of the Four Signal Intervals (Signal-to-Noise Ratios of -5 and -10 dB only)

Condition	Signal Interval				Mean
	1	2	3	4	
D	.81	.82	.82	.82	.82
MD	.77	.83	.84	.84	.82

Table 2
Probability of Correct Performance on Memory Task Conditional on Detection Performance (Signal-to-Noise Ratio of -10 dB only)

Detection	Serial Position						New Item	Mean
	1	2	3	4	5	6		
Correct	.34	.39	.53	.85	.97	1.00	.85	.74
Incorrect	.42	.36	.48	.88	.95	1.00	.93	.76

however, since no instructions were given regarding preferential treatment of either task. Moreover, the fact that memory performance in the latter positions of the list was not affected by the addition of the detection task argues against the possibility that Ss consistently neglected the memory task in order to attend more fully to detection. Alternatively, we might argue that the relatively small role played by memory in the performance of a detection task makes it immune to the factors which produce interference in the short-term memory task. However, if detection is a rather automatic process which is immune to interference, then Ss should be able to concentrate on the memory task and maintain the retention levels found under single-channel conditions. Moreover, Broadbent and Gregory (1963) have reported that when Ss are forced to give preferential treatment to a memory task, performance on a competing detection task is substantially impaired. In their experiment, detection responses were accepted only when Ss showed perfect recall of a digit list prior to reporting their detection responses. Broadbent and Gregory's Ss, however, were not trained Os and we have found detection performance to be quite unstable without training. A convincing explanation of detection performance in this type of situation will have to await a more exhaustive mapping of the factors involved.

In conclusion, let us try to piece together some of the evidence regarding the relative contribution of memory and perceptual factors in the performance of simultaneous tasks. If we consider simple psychophysical tasks, such as intensity or frequency discrimination, the interference of one task upon another seems to be primarily of perceptual origin (Lindsay, in press). The results of these experiments can be interpreted as changes in the level of perceptual noise. When Ss are performing at the limit of their discriminative ability, the added noise results in a measurable, and to some extent, predictable decrement in performance. Verbal messages, however, do not seem to suffer any major perceptual distortions when several inputs are processed at the same time. At first glance this might seem unreasonable. The recognition of verbal material clearly involves a more complex and sophisticated analysis than that required for the discrimination of psychophysical signals. Following this line of reasoning, some investigators have argued that the perceptual processing of verbal material should be more vulnerable to disruption from a competing task than the analysis of a simple psychophysical signal (Treisman & Geffen, 1967). The increase in complexity, however, seems to be compensated for by a large amount of redundancy associated with verbal signals. This redundancy would tend to make the processing of a verbal message relatively insensitive to any perceptual overloading that results when several messages are analyzed simultaneously. (For example, Licklider and Miller, 1951, demonstrated some of the drastic distortions that can be applied to speech with little or no impairment in intelligibility.) Note that we do not wish to claim that there is no information loss during the perception of verbal inputs, only that the loss is ordinarily not large enough to impair recognition.

There is a disruption in retention when Ss are unable to devote full attention to the verbal material. This source of interference seems to be of two types. First, when the competing task does not in itself involve any substantial amount of storage capacity, the processes responsible for longer-term storage are disrupted. This might come about because of interference with a S's ability to rehearse material which has been presented to him. Although requiring the S to

perform a detection simultaneously with a memory task may not impede the acquisition of material into short-term memory, it certainly impedes his ability to process it further. However, if the competing task also requires a S to deal with verbal messages, these extra verbal items may compete directly for a limited short-term memory facility. This would tend to lower the whole serial position curve rather than selectively alter the long-term component (for example, see Norman, 1969, in press). It is likely that both these factors were operating in previous investigations that have shown substantial decrements in performance when Ss attempt to perform several complex verbal tasks at the same time.

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NOTES

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