ON THE DIVISION OF ATTENTION:
A DISPROOF OF THE
SINGLE CHANNEL HYPOTHESIS

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In dichotic listening, subjects are apparently unable to attend simultaneously to two concurrent, auditory speech messages. However, in two experiments reported here, it is shown that people can attend to and repeat back continuous speech at the same time as taking in complex, unrelated visual scenes, or even while sight-reading piano music. In both cases performance with divided attention was very good, and in the case of sight-reading was as good as with undivided attention. There was little or no effect of the dual task on the accuracy of speech shadowing. These results are incompatible with the hypothesis that human attention is limited by the capacity of a general-purpose central processor in the nervous system. An alternative, "multi-channel", hypothesis is outlined.

Introduction

Over the past decade, one hypothesis on the limits of human attention and performance has achieved something of the status of a central dogma. This is the hypothesis that the brain, in its moment-to-moment decision-taking regarding both immediate and potential future response, acts as a single communication channel of limited capacity (Broadbent, 1958; Craik, 1948; Welford, 1952). According to this view, performance of two or more concurrent tasks can only be maintained by the rapid alternation of attention (i.e. by time-sharing on the access to a general-purpose central channel) between the requirements of the different tasks. Where one of the tasks is such as to demand continuous occupation of the single channel, information relating to other tasks is necessarily excluded. Their performance fails. Alternatively, if information relating to a second task is admitted, performance of the first will be disrupted.

There have been numerous recent reaffirmations of this so-called single channel hypothesis (Broadbent, 1971; Deutsch and Deutsch, 1963; Kahneman, 1970; Kristofferson, 1967; Lindsay, 1970; Moray, 1967, 1969; Morton and Broadbent, 1967; Neisser, 1967; Norman, 1968; Smith, 1969; Swets and Kristofferson, 1970; Welford, 1968), although coupled with widely differing speculations regarding the origin of the supposed central bottleneck. Controversy in this area has been confined largely to two issues: (1) the level at which selection between competing messages or tasks becomes necessary (i.e. on the amount of pre-processing prior to access to the single channel) and (2) the adequacy with which competing or irrelevant messages are "rejected". Relating to (1), it has been widely accepted that, on the input side, different "analysers" can operate in parallel on different aspects
of the sensory data. (Thus, in the Conclusions to her lucid and oft-quoted review, Treisman (1969) writes: “These findings suggest that division of attention between two or more inputs and between two or more targets is difficult or impossible when no time is allowed for alternating attention or serial analysis . . . while division of attention between analysers is relatively efficient . . .”, p. 296.) It has also been suggested (e.g. Shaffer, 1971) that, in a continuous task, simultaneous or overlapping processing of input and output can occur. On the other hand the basic postulate of a general-purpose central processor of limited capacity at some stage (“categorization”, “translation”?) between input and output as the basis of human attention limitations does not appear to have been seriously challenged, at least in recent years.

(The single channel hypothesis has a weak and a strong version. The strong version asserts that no two independent sensory messages can be handled concurrently. The weak version asserts simply that there is a limited processing capacity to a single—i.e. general-purpose—“central channel”; so long as this is not exceeded, more than one signal may be dealt with at the same time. The experiments described here are directed at the weaker version, any refutation of which is a fortiori a rejection of the strong version also.)

The most striking evidence put forward in support of the single channel hypothesis concerns the inability of human subjects to take in more than one verbal message at a time: the “cocktail party problem” (Cherry, 1953). Commonly, experiments on this problem have included the requirement that the subject also continuously repeat back, or “shadow”, one of the messages as it is presented, to ensure that he is objectively attending to at least one of them. In this situation the subject is unable to report or recognize afterwards any of the contents of the message he had not been shadowing, nor even what language it was spoken in, at least for any part of the non-shadowed message presented more than a few seconds prior to an interruption of shadowing, (Glucksberg and Cowen, 1970; Moray, 1959; Norman, 1969; Mowbray, 1964). Analogous results have been obtained when parallel lines of printed text are presented for reading (Neisser, 1969), and when different prose passages are presented simultaneously to eye and ear (Mowbray, 1953). In the context of the single channel hypothesis, the interpretation of these results which presented itself was therefore that shadowing one continuous language input satisfied the theoretical condition of full, continuous occupation of the limited capacity single channel.

One thing that stands out about these and other experimental paradigms (e.g. Moray, 1969) which have been employed in support of the single channel hypothesis is that they call for simultaneous attention to two closely similar, or even identical, tasks. That is, either the sensory inputs concerned, or more importantly the functions to be computed on them, appear similar in kind. It is possible, therefore, that the difficulty in such cases derives not from exceeding the limited capacity of a single, general-purpose central processor, but more simply from the difficulty of keeping separate (i.e. of not confusing or confounding) two closely similar but unrelated messages. In either case the subject’s only workable strategy may be to filter or reject one of them. On the other hand where the messages, or the tasks to be performed, are highly dissimilar, we suggest (Allport, 1971b) this difficulty
should not arise, and both tasks should be able to be performed simultaneously. We therefore looked for situations involving highly dissimilar tasks, but of comparable information content, which could provide a critical test of the single channel hypothesis, and which at the same time might throw some light on the conditions in which division of attention is or is not possible.

Two experiments are described. In both, auditory speech shadowing was one of the concurrent tasks, since it is generally represented, on the evidence just reviewed, as the paradigm of tasks requiring complete and uninterrupted occupation of the hypothetical single channel. It also has the advantage that details of performance at this task are relatively well documented.

**Experiment I**

In the first experiment a monaural, auditory shadowing task was combined with simultaneous presentation of either verbal or non-verbal stimuli to be memorized (words or pictures). The words were presented, in different conditions, either auditorily or visually.

**Method**

**Materials**

The texts for auditory shadowing were passages from George Orwell's "Selected Essays" recorded in a female voice on a Ferrograph twin-track tape-recorder, and delivered to the subject's right ear by headphones. Each passage was about 180 words long and lasted 1 min. Another tape recorder monitored the subject's shadowing performance. The competing memory stimuli were of three kinds: (1) A list of 15 words, recorded by a male voice at the rate of one every 3 sec, delivered to the subject's left ear by well-padded headphones. This condition was modelled on experiments previously described by Moray (1959), and others.

(2) Words presented visually, in upper case type, also at the rate of one every 3 sec. (3) A series of 15 coloured photographs, displayed at the same rate. The words for auditory and visual presentation were concrete nouns of 2–3 syllables, having a frequency of one per million in the Thordike–Lorge word list (Thordike and Lorge, 1944). The pictures were complex scenes selected from coloured magazines, to have as varied as possible subject matter; they had not previously been seen by any of the subjects. (We selected each set of memory items from a pilot experiment, using other subjects and without the concurrent shadowing task, to obtain equal levels of difficulty—i.e. equal probability of subsequent correct recognition—both between different sets of the same type and, in particular, between the different types of memory item. The same set of 15 memory items was of course presented once only to each experimental subject.) A Kodak Carousel slide projector exposed the visual items for 1.7 sec each, with 1.3 sec between exposures, on a white screen 45 cm by 60 cm. The words occupied about one third of the screen in horizontal extent, or approximately 7 degrees of visual angle (at a viewing distance of 160 cm).

**Procedure**

We tested how much our subjects had taken in of the memory items by a forced-choice recognition procedure. After each 1-min trial, there was an interval of 1 min and then the 15 test items just presented were again shown with 15 new items drawn from the same population; the 30 items were presented singly in random order. The subjects responded to each item either "Yes", if they believed it to be one of the original test items, or "No", if not. They were given no indication of their accuracy. Recognition memory was tested in this way for both divided and undivided attention, i.e. both with, and without, concurrent
auditory shadowing during presentation of the memory items. In the dual task condition it was stressed that the shadowing task was to be treated as primary.

On the first day the subjects practised auditory shadowing, without competing inputs, to a criterion of one 1-min passage repeated without errors (words omitted or confused). Experimental testing was carried out on the following day in two 45-min sessions for each subject. The order in which the different conditions were encountered was counterbalanced across subjects, and between the first and second experimental session. In the first experimental session a trial under undivided attention was immediately followed by one trial of the corresponding dual task condition, and so on, through the three different types of memory item. In the second session the order of alternation was reversed. In the dual tasks, presentation of the memory items began 7.5 sec after the start of the shadowing text and terminated 7.5 sec before the text came to an end.

Subjects

The subjects were six female undergraduates. They were told that they were participating in a study of dual task performance, but were otherwise not informed about the nature of the experiment. They were encouraged to perform as well as they could, and appeared to be highly motivated and to enjoy testing themselves in the experiment.

Results

Figure 1(a) shows the results. Recognition memory for auditory words presented during shadowing approached chance level (50% errors). This is the result obtained by other experimenters (Glucksberg and Cowen, 1970; Moray, 1959; Norman, 1969; Mowbray, 1964). Subsequent recognition of visually presented words was also greatly affected by shadowing during presentation; all subjects on every trial made more errors in recognizing the visual words under divided attention than under undivided attention. (Questioned about their performance after the experiment, the subjects claimed to have recognized the visual words, at least in part, on the basis of their visual characteristics: number of letters, presence of repeated letters, small marks on the slides. Had they been forced to respond on the basis of semantic or phonological rather than visual properties of the words,
auditory prose shadowing

**Discussion**

These results are not easily reconciled with the single channel hypothesis. According to most versions of this hypothesis (e.g. Broadbent, 1971; Neisser, 1967; Welford, 1968), inputs to long-term memory must pass through the general-purpose 'single channel'. If this is already fully occupied by the shadowing task, then merely altering the modality or other characteristics of a secondary input could not affect the latter's chances of gaining entry to long-term memory (provided, of course, for the weak version of the hypothesis, that the information content of the secondary input is not also drastically reduced; this latter does not appear a very promising way out for the hypothesis in the present case). It cannot be argued in defence of the single channel hypothesis that the shadowing task, even though at a very fast rate, might not have been such as to fully occupy the capacity of the hypothetical single channel, since in that case the hypothesis is unable to account for the almost complete failure to remember the auditory word list (and to a lesser extent the visual word list) under the same conditions of concurrent shadowing during presentation. Neither does it appear plausible to argue that very rapid switching or time-sharing on the single channel may be possible as between the processing of pictures and the shadowing task, but not between discrete auditory words and shadowing. If the processing of visual input is intrinsically very much faster than that of auditory inputs, then how is the relatively large deterioration in the case of visually presented words, under divided attention, to be explained?

**Experiment II**

The second experiment investigated the simultaneous performance of continuous auditory prose shadowing and playing piano music from a score.
Method

Materials

The shadowing task was similar to that in Experiment 1, except that recorded prose passages, of approximately 1 min duration, were presented at 150 words per min. Passages were of two levels of difficulty: “easy” texts were selected from an anthology of humorous narrative prose, containing predominantly high-frequency words; “difficult” texts were taken from a textbook of early Norse history, containing a high proportion of low-frequency words. The music for sight-reading consisted of examination pieces, Grades II and IV, of the Associated Board of the Royal Schools of Music (1970 and 1971), none of which had previously been seen by the subjects.

The prose for shadowing was delivered binaurally by headphones, and the subjects’ performance on the shadowing and piano playing tasks was recorded on separate tracks of a tape recorder. In the dual task conditions, the prose passage commenced 10 sec after the subject had started sight-reading. The instructions were to continue as evenly and accurately as possible on both tasks, and not to try to correct errors. Neither task was presented as primary. The subjects were also warned that, following some of the trials, they would be asked questions about the content of the prose passages they had just shadowed.

Procedure

Subjects received ten 1-min passages of practice at auditory shadowing with easy narrative prose. All subjects reached the criterion of two successive trials without omissions in this period. They then received two trials of practice at sight-reading, one each at Grades II and IV, and finally seven trials at the combined task of shadowing and piano sight-reading simultaneously. On the day following practice, the subjects served in two experimental sessions of sight-reading both with and without concurrent auditory shadowing. In session 1 the sight-reading alone was performed first (i.e. the subject ignored the simultaneously presented prose passage) and the dual task second; in session 2 this sequence was reversed. Each subject performed two trials of the dual task at each possible combination of “easy” or “difficult” prose and Grade II or IV of piano music. The subjects were five third-year undergraduate Music students.

Results

The accuracy of prose shadowing with concurrent sight-reading is shown in Figure 2(a). In session 1 the overall frequency of errors is affected both by the difficulty of the prose to be shadowed and by the Grade of concurrent sight-reading required. By session 2, however, the latter effect has entirely disappeared. Notice that only shadowing of the “easy” prose is to be directly compared with the criterion performance (zero omissions) in undivided attention, since this was obtained for “easy” texts only. The majority of errors were syllable or word repetitions (stammering), and mispronunciations. The few omission errors with “easy” text under divided attention were due to two subjects. The remainder shadowed without any omissions. None of the error rates with “easy” prose were significantly different from the criterion performance under undivided attention, except in session 1 when combined with Grade IV sight-reading ($t = 4.48, P < 0.05$). As a further check on the possibility of rapid alternation of attention between the shadowing and sight-reading tasks, and since timing is a critical feature of the latter, we also examined the fidelity of shadowing in the timing of inter-word intervals relative to the recording they shadowed. One trial was taken from each subject’s records under divided attention, and the time intervals between successive
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FIGURE 2. (a) Accuracy of auditory shadowing (Experiment II) is shown in terms of the mean number of errors per one-minute trial, for both “easy” and “difficult” prose, and with two grades of difficulty of concurrent sight-reading. Grade II of concurrent sight-reading Grade IV of concurrent sight-reading. (b) Accuracy of sight-reading piano music of two grades of difficulty is shown in terms of the mean number of errors per trial (max > 300) both with and without concurrent auditory shadowing. Errors marked “R” above the horizontal bar on each column refer to rhythm or timing errors in performance; those below the bar are wrong notes. □ Undivided attention; ■ With concurrent auditory shadowing.

word onsets both for the original tape on that particular trial and for the subject's shadowing output were obtained. This was approximated by replaying the recordings at the slowest tape speed and keying word onset times manually on a pen recorder. The results, summarized in Figure 3, showed that the time relations

FIGURE 3. Inter-word intervals (onset—onset) in both the original tape-recorded text for shadowing (the “model”) and in the subjects’ repetition of it while simultaneously sight-reading on the piano. □ Model. ■ Subject.
in shadowing were a faithful replica of the shadowed message. There was no indication of an increase in very long or very short inter-word intervals, which would be expected if there were any tendency to shadow in intermittent bursts of rapid speech and silence.

Accuracy of sight-reading performance is shown in Figure 2(b). (Each subject's tape-recorded performances were scored independently by a member of Reading University Music department. He did not know, when scoring, which condition was being run.) The main feature of these results is that there is no increase in errors either in the form of wrong notes or of timing errors under divided attention, except in the first session at Grade IV where there is a small increase in the frequency of timing errors ($t = 8.18, P < 0.01$). Indeed in all other conditions there was a slight but non-significant improvement in accuracy under the divided attention condition. As in the complementary case of shadowing, the frequency of errors in sight-reading reflected the difficulty of the concurrent task during session 1, but this effect had disappeared by session 2.

During the combined task, the subjects were able to take in the meaning of the prose messages, and to answer questions about them afterwards. Immediately after shadowing Difficult prose our subjects answered on average 61% of questions correctly when the simultaneous sight-reading had been at Grade II, and 56% at Grade IV. The difference was not significant. The same questions presented to control subjects, who had not heard the prose passages concerned and were asked to guess the answers, were answered 12% correctly. Subjects shadowing the same passages with undivided attention gave 57% correct answers. The difference between memory for the shadowed text in divided and undivided attention was not statistically significant. The most remarkable feature of these results, however, was the wide variation between the different experimental subjects. One, the most competent pianist in the group, scored 81% correct. The least proficient sight-reader among our subjects only answered 14% of the same questions correctly.

**Discussion**

In many respects the finding that auditory speech shadowing and playing piano music from a score can be combined simultaneously, with little or no loss of efficiency in either task, is even more striking than the similar demonstration regarding the memorization of pictures. In the authors' opinion, the results of the sight-reading experiment are wholly incompatible with the single channel hypothesis. The only option open to supporters of this hypothesis is presumably to argue *ex post facto* that the auditory shadowing task cannot occupy all, or even most, of the single channel capacity. But if this is so, then the single channel hypothesis fails to account for the frequently replicated inability of subjects while shadowing to take in the contents of even very simple concurrent language inputs, which was after all one of the principal phenomena that the hypothesis was designed to explain. It is this contrast with the results of dichotic listening experiments which is of primary importance; the question of whether the time sharing is complete or not is secondary to the main theoretical argument. The word rate and relative unpredictability of the prose used for shadowing in the present experiment are at least as great as that in other experiments in which the, now classical, failure to
divide attention between competing speech inputs was found, and the accuracy of shadowing by our subjects was at least as good as in these experiments. If there is, in the functional organization of the brain, anything analogous to the general-purpose central processor of the von Neumann computer, we are forced to conclude that it is not involved in the performance of these tasks.

A more appropriate model would be that of a number of independent, special-purpose computers (processors and stores) operating in parallel and, at least in some cases, capable of accepting only one message or "chunk" of information at a time. In general, we suggest, any complex task will depend on the operation of a number of independent, specialized processors, many of which may be common to other tasks. To the extent to which the same processors are involved in any two particular tasks, truly simultaneous performance of these two tasks will be impossible. On the other hand, the same tasks paired respectively with another task requiring none of the same basic processors can in principle be performed in parallel with the latter without mutual interference. We will refer to this general class of model, for convenience, as the "multi-channel" hypothesis.

Clearly, if we are correct, the mistake made in postulating the generalized single channel hypothesis was to assume that the information-processing bottlenecks, for which evidence could be found in a number of different experimental situations, were manifestations in each case of the same, "central" bottleneck. Seen in this light, there is nothing particularly surprising, or even novel, about the multi-channel hypothesis. It agrees well with what is known of the gross functional anatomy of the brain (Luria, 1970), and, so far as it goes, with single unit physiology. It is also in general agreement with the evidence of simultaneous processing of stimuli varying along different attributes or "dimensions" within the same sense mode (Allport, 1971a; Hawkins, 1969; Marcell, 1970; and others), and with the elegant demonstrations by Brooks of interference between reading and visualizing the referent of a verbal description (Brooks, 1967, 1970). An alternative and simpler explanation of the results of Experiment I might be given in terms of functional independence between the two cerebral hemispheres, with language processing in the left or "dominant" hemisphere, picture processing in the right. This interpretation could only with difficulty be extended to the second experiment, at least in regard to the control of right-hand fingering in piano playing. It is altogether implausible if applied to the results, just cited, showing full parity of performance in the simultaneous processing of, for example, colour and form information from tachistoscopic exposures.

We do not wish to deny that the brain may, in certain circumstances, exhibit "single channel" operation as a whole. This may occur when someone concentrates on a particular task: most, or all, of the specialized processors are being held "on call" to the same message source whether they are in fact being used or not. We deny merely that this organization is obligatory. In a pilot study for Experiment I we observed in ourselves, as subjects, a strong initial disposition to look away or close our eyes while shadowing, in order not to be distracted by the intruding picture series. It came as a surprise to discover, on the first attempt, that division of attention between these two inputs was in fact quite easy. The more unpredictable (to the subject) the demands of a particular task, or the greater the
penalties for errors in its performance, the less the probability that multi-channel or distributed processing of other tasks, even though possible, will be permitted. For this reason, failure to obtain efficient performance of two concurrent tasks is not in itself unambiguous evidence that the functional "capacity" for both is lacking; a change of payoff may produce a quite different result (e.g. Kahneman, 1970). If, as seems plausible, one component in the acquisition of a skill is an improvement in predicting, or discriminating, the demands which are likely to be made by the task, then, with increasing skill, functions not in fact necessary to the performance should no longer be held on call, and so pre-empted from other tasks: with increasing skill, less "concentration" is needed. Similar predictions concerning the effects of practice on the division of attention have sometimes been claimed for the single channel hypothesis, and any hypothesis on the nature of attention must of course be able to deal with these, often very striking, effects. We include the foregoing speculative remarks merely to show that the single channel hypothesis has no special claim in this respect.

References


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