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IDENTIFICATION OF SIMULTANEOUSLY PRESENTED SIMPLE VISUAL AND AUDITORY STIMULI [1]

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ABSTRACT

Two experiments are reported. Both involved absolute judgments of simple visual and auditory stimuli of very short (20 msec and 50 msec) and longer (2 sec) duration, under the conditions of simultaneous presentation of stimuli from both modalities. The experiments were designed to explore certain implications of the hypothesis that simultaneously presented stimuli are attended sequentially. Although simultaneously presented stimuli were not identified as efficiently as the same stimuli presented singly, no evidence for the sequential processing hypothesis was found.

1. Introduction

Ample evidence exists that an observer (*O*) cannot respond to simultaneously presented stimuli as efficiently as he can respond to the same stimuli when they are presented alone (e.g. Broadbent, 1958; Mowbray, 1954; Peterson and Kroener, 1964; Poulton, 1956). This evidence has been interpreted to mean that a person cannot pay attention to two things at the same time. To explain the partial success that *O*s in various experiments have shown in responding to more than one environmental source of information, the sequential processing hypothesis has usually been invoked.

The best-known version of the sequential hypothesis has been proposed by Broadbent (1958). According to his model, the central information processing mechanism, i.e. attention, is capable of handling information from only one 'channel' at a time. To deal with simultaneous multiple inputs, attention is switched from channel to channel, sampling information for a brief, finite interval from each channel sequentially. A certain amount of 'dead' time is 'wasted' while attention is switched from one channel to another. To counteract the deleterious effects of limited central processing

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mechanism and the 'dead' switching time, a temporary pre-perceptual store is postulated as part of the perceptual system. Incoming information from a given channel can be held in this store for a brief period of time prior to processing while attention deals with another channel.

A critical variable in an experimental test of the sequential hypothesis should be the duration of the signal in multiple input tasks. If two inputs of long duration occur simultaneously, *O* can switch attention from one to the other and process both inputs in a leisurely fashion without any loss of available information. If, on the other hand, two simultaneous inputs are of very short duration, there may not be sufficient time available to handle information from both channels in succession. Thus, greater impairment of *Os*' performance in simultaneous input tasks should occur if inputs are of short duration than if they are of long duration.

This implication of the sequential processing hypothesis was tested in two experiments reported in the present paper. The *Os* in both experiments had to identify simple auditory and visual stimuli, presented either alone or simultaneously from both modalities, in an absolute judgment task (GARNER and HAKE, 1951; POLLACK, 1952). Stimulus duration was either short (20 or 50 msec) or long (2 sec). Since a number of experimenters have estimated the amount of time necessary for switching attention from one channel to another to be of the order of 0.2 to 0.5 sec (e.g. BROADBENT, 1958; CHERRY and TAYLOR, 1954; MAGER, 1925; PAULI, 1937), durations of 20 or 50 msec can be considered short enough to render switching of attention from one sensory modality to another impossible during the physical presence of both signals, thus forcing the observer to rely on the rapidly decaying information in the pre-perceptual store. Stimuli of 2 sec duration, however, are sufficiently long so that attention can be switched from one modality to the second while the stimulus from the second modality is still physically present.

The main purpose of the experiments, therefore, was to investigate the tenability of the sequential processing hypothesis in an absolute judgment task with inputs from two sensory modalities. The hypothesis would gain support if simultaneously presented stimuli of short duration were identified relatively less accurately than simultaneously presented stimuli of long duration. The second purpose of the experiments was to gain further empirical evidence about *Os*' ability to identify simple stimuli under the conditions of simultaneous inputs.

2. EXPERIMENT I

2.1. *Method*

Stimuli. The visual stimuli were circular patches of white light, 1.5 in. in diameter, on a dark background, while auditory stimuli were pure tones of

1000 cps. Both visual and auditory stimuli varied along the dimension of intensity in 0.3 log unit steps. The maximum luminance of visual stimuli was 2.45 foot-candles, while the maximum sound-pressure level of auditory stimuli was 80 db re 0.0002 dynes/cm^2. Three levels of stimulus duration were used: 20 msec, 50 msec, and 2 sec. These durations were controlled by electronic timers.

Tasks. Observers identified visual and auditory stimuli by assigning numbers 1 to 8 to them depending on the perceived intensity of each stimulus. In task S, single stimuli from one modality were presented and judged one at a time. In task 2 S, two stimuli from both modalities were presented simultaneously, but only one of the modalities had to be attended and judged. In tasks R_1 and R_2, two stimuli from both modalities were presented simultaneously and *O*s had to make judgments about both modalities. One of the modalities was designated the *primary modality,* the other the *secondary modality. O*s had to concentrate on the primary modality, attempt to identify its stimulus as well as possible, and then do as well as possible on the secondary modality, without jeopardizing the identification of the stimulus in the primary modality. After thus identifying both stimuli, *O*s reported the judgment of the stimulus in the primary modality first, and that in the secondary modality second. Thus, under the conditions of simultaneous presentation, task R_1 was conserned with the identification of stimuli in the primary modality, and task R_2 with the identification of stimuli in the secondary modality.

Observers. Four undergraduate Honour Psychology students, two men and two women, served as *O*s. Three of them had previously participated in a similar experiment (LINDSAY et al., 1965). All *O*s were aware of the general design of the experiment, but did not know the results of the previous experiment.

Design. With two modalities (audition and vision), four tasks (S, 2S, R_1, and R_2), and three stimulus durations (20 msec, 50 msec, and 2 sec) combined factorially, there were 24 different experimental conditions. All four *O*s served under all 24 conditions. Data relevant to each of these conditions were collected in a separate experimental session, except that data for task R_1 in one modality and R_2 in the other modality at a given level of stimulus duration were collected at the same time in one session. The order of experimental conditions administered to *O*s was determined separately for each *O* on a semi-random basis.

In an experimental session, each of the eight stimuli in a given modality was presented 32 times. Thus each *O* made a total of 256 single or double judgments in each experimental session. The order of stimuli in a session was randomized, with the restriction that the same stimulus did not occur more than twice in succession. For the conditions involving simultaneous presentations, the eight visual and auditory stimuli were paired in such a manner that each of the 64 possible combinations of stimuli from the two modalities occurred exactly four times in a block of 256 trials.

Procedure. At the beginning of each session *O*s were informed of the conditions of presentation in the session and, in case the task involved simultaneous presentation, primary and secondary modalities were specified. Single stimuli or simultaneous pairs of stimuli were then presented at the rate of one every

12 sec. A warning signal preceded each presentation. On each trial *O* recorded his response or responses in writing and was then informed by *E* what the stimulus or stimuli had been. Brief rest periods were given *O*s after blocks of 64 trials.

2.2. Results

The primary response variable used in this experiment was the amount of transmitted information (*T*) *per modality*. A separate *T* value was calculated for each *O* for a given task condition. *T*, as it is used here, corresponds to Garner's (1962) measure of partial contingent uncertainty, $U_w(x:y)$, where *w* represents *O*s, *x* stimuli, and *y* responses. Under the conditions of simultaneous presentation, a separate *T* value was calculated separately and independently for each modality. Additional analyses failed to reveal any cross-modality effects.

Mean *T* values, averaged over four *O*s, for all experimental conditions, are shown in table 1. All three treatment variables were highly significant.

Table 1

Experiment I. Mean amount of information transmitted (in bits) under different experimental conditions.

Modality	Duration	Task				
		S	2S	R_1	R_2	Mean
Auditory	20 msec	1.54	1.51	1.36	1.28	1.42
	50 msec	1.51	1.54	1.46	1.38	1.47
	2 sec	1.74	1.80	1.71	1.63	1.72
	Mean	1.59	1.62	1.51	1.43	1.54
Visual	20 msec	1.86	1.91	1.81	1.51	1.77
	50 msec	1.84	1.99	1.88	1.57	1.82
	2 sec	2.16	2.06	2.05	1.78	2.01
	Mean	1.95	1.99	1.91	1.62	1.87
Overall Mean		1.77	1.80	1.71	1.53	1.70

The *F* ratio for Modality was 141.9 (1 & 18 *df*), for Tasks 20.5 (3 & 18 *df*), and for Duration 35.7 (2 & 18 *df*). These three variables together accounted for 69 % of the total variance in the data. None of the interactions was significant, although the interaction between Modality and Tasks barely missed being significant at the .05 level, $F = 3.11$ (3 & 18 *df*). The difference between task R_2 and the other tasks was greater for visual stimuli than for auditory stimuli.

The outcome of the experiment confirms the results of the over-lapping parts of the earlier experiment (LINDSAY et al., 1965) in all important respects Information transmission varied directly with stimulus duration, it was less under conditions of simultaneous presentation than under conditions of single-modality presentation, and less in the secondary modality than the primary modality. A new finding was that there were no obvious or systematic differences in the accuracy of judgments of single stimuli between tasks S and 2S, suggesting that the mere presence of a stimulus from another modality has no effect on identification of stimuli from the modality to which *O* attends. The observed decrement in *O*s' performance in tasks R_1 and R_2, therefore, must be attributable to the requirement that *O* attend or respond to stimuli from both modalities.

The failure to find a significant interaction between duration and tasks, replicating a similar failure in the earlier experiment (LINDSAY et al., 1965), indicates that the relative accuracy of identification of simultaneously presented stimuli is not different for stimuli of short duration than stimuli of long duration. The results, therefore, appear to throw doubt on the tenability of the sequential processing hypothesis under the experimental conditions investigated here.

3. EXPERIMENT II

The expected interaction between stimulus duration and tasks may have failed to materialize in Experiment I because of the mitigating effects on stimulus duration produced by the existence and operation of a temporary pre-perceptual store of the kind described by BROADBENT (1958). This store might hold sensory information from the secondary modality long enough to permit the system to process information from two modalities sequentially even if the duration of the physical stimulus is very short.

The effective length of the interval during which unprocessed information stays available in the temporary store can be assumed to depend on the intensity of the original signal. If this is the case, and if the sequential processing hypothesis is true, then one might expect that simultaneously presented stimuli of short duration can be identified more accurately if the intensity of the stimulus is high than if it is low, particularly in task R_2 where the stimuli from the secondary modality are presumably processed after the stimuli from the primary modality.

Experiment II was therefore designed to examine the effect of stimulus intensity on the identification of simultaneously presented auditory and visual stimuli of short and long duration.

3.1. *Method*

Stimuli. Visual stimuli were outline circles drawn in black ink on white bristol board and presented by means of a Gerbrands two-field mirror tachistoscope. Ten different sizes varying in 0.25 in. steps from 0.50 in. to 3.25 in. in diameter were used. The intensity of these visual stimuli was manipulated in terms of the luminance of the pre-exposure and exposure fields of the tachistoscope. A high (H) level of intensity of 4.2 foot-candles and a low (L) level of intensity of 0.03 foot-candles were used. Auditory stimuli were ten pure tones varying in frequency from 1000 cps to 1900 cps in 100 cps steps. A high intensity of 85 db and a low intensity of 15 db above each *O*'s detection threshold for a 1500 cps tone were used. Both visual and auditory stimuli were presented for durations of either 50 msec or 2 sec.

Tasks. The tasks used in this experiment were those referred to as tasks S, R_1 and R_2 in Experiment I.

Observers. A young man and a young woman, both of whom had participated in Experiment I served as *O*s. Both *O*s were thoroughly familiar with the general procedure. They did not know the results of Experiment I.

Design. The treatment variables were: (1) Tasks: S, R_1, and R_2, (2) Modalities: audition and vision, (3) Duration: 50 msec and 2 sec, (4) Intensity of the stimulus from the primary modality: high (H) or low (L), and (5) Intensity of the stimulus from the secondary modality: H or L. Since there was no secondary modality in task S, the design was not completely balanced, but otherwise all treatment variables were combined factorially.

Both *O*s served under all experimental conditions. They were tested individually, one session providing data for each of the treatment combinations, with the exception of sessions involving double judgments as described in Experiment I. Consequently, each *O* served in 24 sessions, eight involving single and 16 involving double judgments. The order in which experimental conditions were administered was determined separately and randomly for each *O*.

In an experimental session, each of the ten stimuli in a given modality was presented 40 times. Thus in each session each *O* made a total of 400 single or double judgments. The randomization of stimulus sequences and of sequences of combinations of stimuli from the two modalities followed the same general procedure that was used in Experiment I.

Procedure. The procedure was identical with that used in Experiment I with the exception that *O*s recorded their responses on IBM mark-sense cards. These were converted to punched cards and processed on the IBM 7090 computer.

3.2. *Results*

A *T* value was computed on the basis of 400 responses given by an *O* per modality under each treatment combination. Because of the incompleteness of the design, it was not possible to do an overall analysis of variance involving all five treatment variables. Therefore, two different analyses were done. The first analysis involved the following treatment variables: tasks, modality, duration, and the intensity of stimuli in the modality being judged.

In task R_1 and R_2, each *O*'s data were pooled over two intensity levels of the other modality. The mean *T* values corresponding to this analysis are summarized in table 2. The analysis yielded highly significant ($p < .001$) effects

TABLE 2

Experiment II. Mean amount of information transmitted (in bits) under different experimental conditions.

Modality	Duration	Task and Intensity						Mean
		S		R_1		R_2		
		High	Low	High	Low	High	Low	
Auditory	50 msec	1.92	1.62	1.72	1.40	1.62	1.55	1.64
	2 sec	1.98	1.89	1.78	1.77	1.83	1.68	1.82
Visual	50 msec	2.56	2.51	2.31	2.29	1.58	1.62	2.14
	2 sec	2.60	2.77	2.55	2.61	2.20	2.08	2.47
Mean		2.27	2.20	2.09	2.01	1.81	1.73	2.02

associated with Tasks: $F = 105.9$ (2 & 9 *df*), Modality: $F = 484.9$ (1 & 9 *df*), Duration: $F = 94.2$ (1 & 9 *df*), and the interaction between Tasks and Modality: $F = 52.0$ (2 & 9 *df*). These four sources of variance accounted for 86.8 % of the total variance in the data. The general pattern of the results was very much the same as had been observed in Experiment I. Information transmission was higher for visual than auditory stimuli, higher for 2 sec than 50 msec stimuli, and higher for single than double judgments. In addition, the decrement in information transmission from task R_1 to task R_2 was greater for visual than auditory stimuli.

The interaction between Modality and Intensity yielded an *F* of 10.5 (1 & 9 *df*), $p < .05$. Auditory stimuli of high intensity were identified more accurately than auditory stimuli of low intensity, but intensity did not have any effect on the judgments of visual stimuli.

The interaction among Modality, Duration, and Tasks was also significant at the .05 level, $F = 5.02$ (2 & 9 *df*), as well as its other two component interactions, Modality × Duration, $F = 7.54$ (1 & 9 *df*), and Duration × Tasks, $F = 4.79$ (2 & 9 *df*). In the auditory modality, information transmission was practically identical for tasks R_1 and R_2 at each of the two levels of stimulus duration, while in the visual modality the difference between tasks R_1 and R_2 was greater for 50 msec stimuli than for 2 sec stimuli.

The second analysis of variance of the data involved only tasks R_1 and R_2. The treatment variables tested in this analysis were tasks (R_1 and R_2), modality, duration, intensity of the stimuli in the primary modality, and intensity of the stimuli in the secondary modality. This second analysis showed again modality, duration, tasks, and the interaction between modality and tasks all to be significant at the .001 level, the four sources of variance accounting for 77.4 % of the total variance. No other significant *F* ratios were obtained.

The most relevant feature of these results is the absence of interaction between stimulus intensity and tasks. Intensity of visual stimuli had no effect on identification of these stimuli. Loud tones were identified more accurately than soft tones, contrary to the findings of POLLACK (1953), but this difference was independent of both stimulus duration and tasks. The finding thus again fails to provide support for the sequential processing hypothesis.

On the other hand, the finding that identification of long visual stimuli in task R_2 was reliably more accurate, in relation to tasks S and R_1, than was identification of short visual stimuli appears to be consonant with the sequential hypothesis. But this evidence is considerably weakened by the fact that a sizable impairment in identification of long visual stimuli in task R_2 also occurred despite the reasonable assumption that sequential processing and switching of attention in handling such long stimuli should be relatively easy. This latter finding makes the implications of the interaction between stimulus duration and tasks in the visual modality somewhat ambiguous.

4. DISCUSSION

The evidence from both experiments is quite clear that *O*s cannot identify simple auditory and visual stimuli as efficiently when two stimuli from different modalities are presented simultaneously as they can when stimuli are presented one at a time. The reduction in *T* from tasks S and 2S on the one hand, to tasks R_1 and R_2 on the other is not large, but it is highly reliable. This evidence is compatible with the view that a person cannot pay attention or respond to two things at the same time.

But the evidence, on the whole, is rather negative with respect to the simple derivations from the sequential processing hypothesis which were tested in the two experiments. The impairment in *O*s' performance under the conditions of simultanous presentation of stimuli was to a large extent independent of duration of stimuli, a variable of critical importance for the sequential processing mechanism that includes an appreciable switching time.

The data reported here appear more compatible with two other possible views of the mechanism of limited attention. The first possibility is to retain the feature of sequential processing, but to assume, as KRISTOFFERSON (1965) has done, that switching from one channel to the other is practically instantaneous. The second possibility is to abandon the notion of strict all-or-none type sequential processing and to assume, as TREISMAN (1960), and BROADBENT and GREGORY (1963) have done, that under the conditions where *O* has to handle two sources of information at the same time the information from the nonattended source is only 'attenuated'. The present data also suggest, however, that whatever the nature of the postulated attenuation of information from the nonattended or secondarily attended source, it is probably not comparable to the reduction in stimulus intensity, since stimulus intensity does not seem to be a relevant determinant of the ease of identification of simultaneously presented stimuli.

Although the data of the two experiments reported here seem to be more compatible with either of these two views of the mechanism of attention than they are with the classical sequential hypothesis, it is also possible that the bottleneck in information flow in the absolute judgment task involving simultaneous stimuli from two modalities lies at the output side, and that the observed impairment in performance under these conditions is attributable to response conflict or memory factors rather than to perceptual processes.

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