Can attention be allocated to sensory modalities? *†

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Three experiments examined the effects of attention allocation to the modalities of vision, audition, and touch. The first two experiments utilized a simultaneous-successive comparison. The simultaneous procedure involved simultaneous monitoring of all three sensory modalities for the presence of a near-threshold stimulus. The successive condition allowed S to give his full attention to each sensory modality in turn. There was no advantage for the successive condition, whether the task consisted of detection of a single stimulus (Experiment I) or detection of the absence of one of many stimuli (Experiment II). Experiment III used a different paradigm to extend these results and bridge the gap between these results, those of Eijkman and Vendrik (1965), and those of Moray (1973a, b). We concluded that selective allocation of attention to sensory modalities does not affect the early stages of perceptual processing.

This paper seeks to determine whether S can divert attention to a particular sensory modality and thereby improve the quality with which a signal in that modality is processed. Furthermore, if an improvement occurs, will it be associated with a corresponding decrement for signals presented on a nonattended sensory modality? On the other hand, if no change in processing results from changes in attention allocation, it should be possible to localize the site of attention within the memory system. All current views of information processing agree that a host of selective attention effects operate in short-term memory following perceptual processing. These were termed "control processes" by Atkinson and Shiffrin (1968), and include rehearsal and coding. We wish to determine if selective attention to sensory modalities operates during the initial processing of information prior to short-term store.

Three classes of models of attention during sensory processing are shown in Fig. 1. The top panel illustrates a single-channel model in which information enters the recognition system from only a single source at any one moment. It is assumed, in this model, that attention is switched rapidly among various possible sources of sensory information. A model that has been interpreted in this fashion was proposed by Broadbent (1958) in the context of split-span dichotic listening experiments. Franzen, Markowitz, and Swets (1970) proposed a model of this type for the processing of near-threshold vibrotactile information. Estes and Taylor (1964, 1966) proposed a model of this type for visual processing. Moray (1970a, b) proposed such a model for dichotic tone detection.

A less extreme attentional model is shown in the middle panel of the figure. In this attenuation model, total processing capacity is limited, but some input is

simultaneously processed from many channels. The O's attentional control determines the relative amount of information processed in particular channels and sent on to the recognition devices. Treisman (1969), Moray (1969), and Neisser (1967) have proposed models of this type with evidence primarily based on dichotic listening and speech shadowing experiments. Rumelhart (1970) and Norman and Rumelhart (1970) have proposed a model of this type based primarily on experimentation in visual processing. It should be noted that both types of limited-capacity attentional models require a "preattentive" mechanism to direct attention to important channels (see Neisser, 1967, for a discussion of the need for preattention in these models).

The final class of models is seen in the lower panel of Fig. 1. These models assume minor limitations of

Fig. 1. General models of attention during sensory information processing. A, single-channel model; B, attenuation model; C, nonattention "independent" channels model.

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capacity (such as masking), and no attention during perceptual processing. All attentional effects are due to characteristics of short-term store following perceptual processing. Deutsch and Deutsch (1963) and Deutsch, Deutsch, and Lindsay (1967) have proposed such a model for auditory processing. Norman (1968) and Hochberg (1970) have proposed a generalized model with similar properties. Shiffrin and Gardner (1972) and Shiffrin and Geisler (1973) have proposed this model for visual processing and general sensory processing. Shiffrin, Craig, and Cohen (1973) proposed such a model for tactile processing. Shiffrin, Pisoni, and Castaneda-Mendez (1973) presented such a model for auditory processing.

In order to reduce the ambiguity of the succeeding discussion, we would like to introduce the terms "systemic processing" and "cognitive processing." Systemic processing is meant to refer to those stages of processing which occur automatically, with or without the S's attempted control. In this paper, we use the term "perceptual processing" not to refer to the S's memory of what he was presented, but interchangeably with "systemic processing." It is assumed that systemic processing results in a flood of information, at various stages or levels, being dumped into short-term store (active memory). Cognitive processing refers to control processes like scanning, rehearsal, coding, and decisions carried out on the information in short-term store, before it is forgotten. In general, we propose that the accuracy or quality of systemic processing cannot be controlled by the S. The speed of systemic processing can be affected by the S only in special circumstances, such as advance priming of a particular feature. Usually systemic processing will correspond to the concept of perceptual contact with features in long-term store. Attentional effects are assumed to occur during cognitive processing. Because much of the information in short-term store will be lost from that store very quickly, the order and nature of the consideration given to particular items will greatly affect the accuracy of decisions and report, especially when the amount of information needing consideration is large.

Although theories have been proposed in abundance, data sufficient to distinguish the models of Fig. 1 have been obtained only recently. The study most directly relevant to the present paper was carried out by Eijkman and Vendrik (1965). They presented signals (increments in intensity of a light and a tone, respectively) independently and randomly to the eye and to the ear. On each trial, Ss were instructed to judge independently if a signal had been presented on either modality. In control conditions, Ss responded only to visual signals or only to auditory signals (in the nonattended modality a stimulus was present, but without an increment). They found that the eye and ear acted as independent detectors of increments in stimulus intensity. Furthermore, no difference in detectability occurred when responses had to be made to both modalities, as compared with the control conditions in which only a

single modality required responses.

The Eijkman and Vendrik study stands out because it is one of a very few showing no effect of a strong attentional manipulation. Of course, other studies demonstrate attentional effects, but in rather different situations. Massaro and Kahn (1973) found, in a focused- vs divided-attention paradigm, that performance on a tone-recognition task when Ss had to monitor simultaneously a visual signal for duration (long or short) was significantly reduced from what it was in control trials when no visual duration judgment was required. However, this finding may have been due to the difficulty of the duration judgment task. This view is supported by results from a second part of the Eijkman and Vendrik (1965) study. When Ss judged durations of visual and auditory stimuli, bimodality presentation did not result in performance superior to either modality alone. It was concluded that strong interaction effects exist between modalities for duration judgments. Apparently, duration judgments require short-term memory and decision capacity which cannot be divided without loss. Thus, the results of Massaro and Kahn (1973) might be explained by the difficulty of the visual duration task; that is, deciding on the duration of the visual stimulus may take enough processing time so that relevant information concerning the tone would be lost before an appropriate decision could be made.¹

Taylor, Lindsay, and Forbes (1967) and Lindsay (1970) report on a paradigm in which four aspects of a stimulus complex might be varied: the lateral position of a dot (in visual noise) on a screen, its vertical position, the pitch of a tone (in auditory noise), and its intensity. Before each trial, S was instructed which aspects to attend to (one, two, or all four), and after the trial, S was told to which aspects (of those he attended) he was to respond. A consistent advantage was found for conditions in which Ss monitored a single channel over conditions in which Ss monitored more than one channel. There was no modality effect; that is, performance was the same whether S was monitoring two visual channels, two auditory channels, or one of each.

These results are in contrast to those in a recent experiment by Moore and Massaro (1973). In their experiment, Ss identified the loudness and quality of an auditory stimulus as well in the divided-attention condition as in the focused-attention condition. One possible reason for the discrepancy is that in Lindsay's procedure the dimensions not attended by S were not varied; thus, the stimulus complex was not identical in the focused-attention and divided-attention conditions. Another possible reason that Lindsay and his associates obtained an attentional effect is that their divided-attention condition used a poststimulus cue to inform S to which dimension he should respond; conceivably, necessary information might be lost in the time after stimulus presentation before the response cue had been processed by S.

Treisman and Davies (1973) report two experiments

examining attention division to eye and to ear. In their first task, using a split-span technique, they showed that the greatest interference occurred when the same type of stimuli were presented in the same modality. We should note, however, that this decrement could have arisen in virtually any phase of the processing sequence, and there is no evidence indicating that the decrements arose during perceptual processing. The second task used a search technique for rapidly presented visual and/or auditory words and examined the reaction time given to verbal targets (members of a class) or physical targets (particular letters or sounds). Both experimental conditions and single-modality focused-attention control conditions were run. Although reaction time and probability correct measures both showed an advantage for focused- over divided-attention conditions, the locus of the advantage is not specified. Treisman and Davies (1973) themselves surmise that Ss, in fact, verbally encoded the "physical" targets as well as the verbal targets before they responded. Thus, due to the rapid presentation of pairs of items in a verbal search task, the divided-attention condition may not have allowed sufficient time to make the necessary decisions. This conclusion is in agreement with Moray's (1973a, b) results when Ss had to monitor rapid sequences of noise intervals for auditory signals on two channels. When a signal was perceived on one ear, performance was hurt on the other ear. Evidently, the rapid presentation of a series of items puts a great degree of load on the decision-making apparatus, hence producing an attention effect. The more difficult the task (as, for example, when verbal analysis is required), the more pronounced the attention effect should be—i.e., the greater advantage we should expect in a focused-attention condition.

Thus, although several studies have demonstrated that selective attention operates in cross-modality information processing situations, these results may have been due to memory and decision factors operating after systemic processing. The present studies were designed to specify further the site of attention in multimodality processing.

Attention studies within modalities have been more extensively examined. Recently, an experimental paradigm has been developed which appears to localize the site of selective attention. The basic method compares two conditions within a sensory processing task. In the simultaneous condition, a single short time interval is defined. During this interval, S must simultaneously monitor n channels for the presence of some specified information which appears randomly on one or more of these channels. In the sequential (or successive) condition, S pays attention to the n channels one at a time, in a known order, during n successive well-defined temporal intervals. In both cases, the n channels contain identical information. The simultaneous condition requires simultaneous sharing of attention among the n channels. The sequential

condition allows all the attention to be given to each channel in turn.

To insure that masking and other interactions between channels will be identical in the two conditions, the channels in the successive condition that do not require attention at a given moment are filled with information similar to that presented in the simultaneous condition on those channels. This information is extraneous, and S is told to ignore it. Finally, care is taken so that short-term memory will not be overloaded. This insures that S will be able to scan the incoming information and complete his decision before short-term forgetting occurs. Thus, the simultaneous condition will not be inferior due to short-term memory limitations. Under these circumstances, a comparison of the simultaneous and sequential conditions should provide a direct test of the degree to which selective attention occurs during perceptual processing.

In Shiffrin and Gardner (1972), three experiments were carried out in which the "channels" consisted of visual spatial locations and the task consisted of letter recognition. Shiffrin, Gardner, and Allmeyer (1973) presented two similar experiments except that the tasks consisted of dot detection. Shiffrin, Craig, and Cohen (1973) presented two experiments in which the channels consisted of spatial location on the skin and the tasks involved detection of a vibrotactile stimulus. Shiffrin, Pisoni, and Castaneda-Mendez (1973) reported two experiments in which the channels consisted of the two ears and the task consisted of recognition of speech-like syllables. In all of these experiments, performance in the simultaneous and sequential conditions was identical (if anything, the results indicated a slight advantage for simultaneous presentation). We concluded from these results that selective attention to particular channels within modalities does not affect perceptual processing, that the sensory processing system acts automatically, without S control, to encode stimulation and dump the results into short-term store.

These results from the sequential-simultaneous procedure are, in fact, supported by those from a number of important experiments in the literature. Grindley and Townsend (1968) showed independent visual processing from spatial locations, and argued for attention effects operating in memory. Sorkin, Pastore, and Pohlmann (1972), Sorkin, Pohlmann, and Gilliom (1973), Pastore and Sorkin (1972), and Sorkin and Pohlmann (1973) have studied tonal detection where the two ears, frequency, or both are the attended channels. Moray (1973a, b) has also studied attention to the two ears. The general finding from these studies is that independent detection on these channels takes place, at least when only one signal is presented. Moore and Massaro (1973) have found that frequency and intensity of simple tones may be processed independently. Posner and Boies (1971) have used reaction time measures in a

Fig. 2. Experiments I and II. Simultaneous and successive conditions are depicted for a single trial. At most, one signal was presented on a trial. The dashed lines indicate the possible positions in which the signal might appear. In Experiment I, the signal consisted of the presence of a near-threshold stimulus. In Experiment II, the signal consisted of the absence of a near-threshold stimulus (thus, either eight or nine near-threshold stimuli were presented on a trial in the successive condition).

stages-of-processing analysis to arrive at similar conclusions regarding the locus of attention. Gardner (1973) has come to independent processing conclusions from studies in visual spatial recognition.

This brief review supports the assertion that attention operates postperceptually in short-term memory, that S cannot use attention to affect the quality of processing given to information entering selected channels. Most of the research we have described, however, deals with channels within a single sensory modality. Even the Eijkman and Vendrik (1965) study utilized only two sensory modalities. The present study utilizes the simultaneous-sequential procedure described above to ascertain the S's ability to attend to three sensory modalities: vision, hearing, and touch. Can S perform as well when he must attend simultaneously to all three modalities as when he may attend completely to each modality in turn?

EXPERIMENT I

Method

Subjects. Ss were seven undergraduates, who were paid \$2/h for participation in the experiment.

Apparatus and Stimuli. Visual "noise" and signal were presented on a VR-14 screen. "Noise" was a clearly visible dot presented for 500 msec in the center of the screen.² The signal (always embedded in the noise interval) was a faint dot presented for 100 msec, about 1 cm to the right of the noise dot. The screen utilized a P-24 fast-decay phosphor.

Auditory noise was 500 msec of band-limited white noise presented through a pair of Grason-Stadler earphones. The auditory signal was a 1,000-Hz tone presented over the earphones, embedded in the noise interval—also 100 msec in duration.

The vibrotactile signal (there was no external tactile noise) was a 160-Hz pulse of 100 msec duration delivered through a

Goodmans V-47 vibrator. The vibrator was fitted with a cylindrical contactor, 6 mm in diam, which protruded through a fixed surround. The vibrator sat on a balance pan, which applied 20 g of constant pressure when S placed his finger on the contactor and held it as far down as the surround allowed.

Ss responded on a six-button response box. A Digital Equipment Corporation PDP-8/e computer controlled the presentation of stimuli and collection of responses.

Procedure. Ss were run individually. Before any data were collected, each S was trained for 5-10 sessions; training involved finding thresholds for each type of signal—visual, auditory, and tactile—in noise (noise always being the visual "noise" dot plus the auditory white noise). Intensities of the three signals were adjusted for each S so that probability of detection of each one alone was in the approximate range of .70-.85. Training included at least two sessions of practice with the experimental procedure. Sessions in both the training and the experimental phases lasted about 45 min.

For the experimental sessions, S was seated at the end of a table in a dimly lit room. Before him was a six-button response box. The VR-14 screen was at the opposite end of the table, about 4 ft in front of him. S wore a set of headphones and rested his right arm comfortably on a table to his right, with the right index finger on the contactor.

Each S ran under two conditions, as diagrammed in Fig. 2. In the simultaneous condition, a trial consisted of a single noise interval (500 msec), in which there could be centered a 100-msec signal. S initialized each trial by pressing the start button, at which time the intertrial fixation dot, centered on the screen between trials, disappeared. After 500 msec, the 500-msec noise interval began (a noise dot on the center of the screen plus white noise in the earphones), during which a single near-threshold stimulus might be presented. Five hundred milliseconds after termination of the noise interval, the intertrial fixation dot reappeared on the screen, signaling the response interval.

S made two responses on each trial—he first gave a forced choice among visual, auditory, and tactile, assuming a signal had been present; then he gave a yes-no response, stating whether he felt any signal at all had been presented. There was no time limit for responding.

Each block of 27 trials contained six visual-signal trials, six auditory-signal trials, six tactile-signal trials, and nine blank

Fig. 3. Experiment I. Probability of correct choice of modality as a function of condition for each modality and each S. Positive slope indicates an attentional effect.

trials, in a random order. At no time was more than one signal presented per trial.

In the successive condition, a trial consisted of three 500-msec noise intervals, separated by 500-msec silent periods (see Fig. 2). The first interval began 500 msec after S pressed the start button and the intertrial fixation dot disappeared. During the first interval, a visual signal might appear, during the second interval, an auditory signal might appear, and during the third interval, a tactile signal might appear. S knew this pattern to be in use. On any given trial, only one signal (or none) would be presented. Again, each block of 27 trials contained (in a random order) six visual, six auditory, and six tactile signal trials, and nine blank trials (no signal). Five hundred milliseconds after the third interval had terminated, the intertrial fixation point reappeared on the center of the screen, and S made two independent responses, just as in the simultaneous condition.

Thus, in both simultaneous and successive conditions, a single signal (at most) would be presented per trial. However, in the successive condition, S would know when to attend to each modality (if a visual signal was present, it would always occur in the first of the three noise intervals, etc.), whereas in the simultaneous condition, he would have to attend to all modalities at once.

A double block of trials consisted of a block of 27 simultaneous trials followed by a block of 27 successive trials (Type 1), or vice versa (Type 2). The order of trials within each new block was shuffled according to a random number generator routine. Ss were told that within each block of 27 trials (simultaneous or successive) there were an equal number of each type of signal; they were instructed to try to distribute their forced-choice guesses equally among the three modalities if they detected nothing.

Between the two blocks of a double block was a 10-sec pause, during which time the intertrial fixation dot disappeared from the screen. A session consisted of four to seven double blocks, all of a single type (1 or 2); for a given S, type of double block was alternated from session to session.

The first double block of a session was practice; the data from this practice were not saved, but were inspected by E to determine if the signal intensities should be adjusted (i.e., if S was too near 100% correct or too near chance responding on any modality). Adjustments were seldom necessary throughout the

experiment. The remaining three to six double blocks in the session (depending on each S's speed of responding) followed without interruption. Between each double block there was about a 2-min delay—time required for data to be transcribed to tape. Each S was run 2-3 sessions per week until he had completed 10 experimental sessions.

Results

Within each condition—simultaneous and successive—there is a 24-category breakdown of the data: on any given trial, there are 6 possible responses (2 yes-no by 3 forced choice), and the frequency of each possible response can be tabulated for each of the 4 types of trials (visual, auditory, tactile, and no signal). Thus, for example, in a given session, number of times S responded “tactile” and “yes,” given a visual signal trial—abbreviated (T,y | V)—would represent one of the 24 frequency counts. The data may be collapsed in several ways.³ First, the modality responses were examined. Figure 3 plots separately for each modality each S's probability of correctly identifying the stimulus on signal trials in simultaneous and successive conditions. The data are averaged over sessions for each S and collapsed over yes-no responses. The mean advantages across Ss for simultaneous over successive conditions, for visual, auditory, and tactile modalities, respectively, are 1.86%, 4.86%, and 3.14%. The standard errors of the mean differences are .80%, 1.80%, and 1.50%, respectively. Thus, if anything, there is a slight advantage for the simultaneous condition in all modalities.

Next, the yes-no data were analyzed. Table 1 presents the percentage of trials each S responded “yes” for each of the four types of trial, for each condition (collapsed over modality response). From these data, a d' -related

Table 1
Experiment I: Percent Trials S Responded "Yes"
Collapsed Over Modality Responses

Ss	Condition							
	Simultaneous				Successive			
	Vis	Aud	Tact	Blank	Vis	Aud	Tact	Blank
1	92	80	72	6	89	83	69	1
2	76	57	73	8	67	49	61	3
3	77	80	70	28	75	73	62	27
4	55	73	59	5	44	67	52	4
5	53	87	76	15	41	83	71	8
6	69	67	67	10	70	57	60	4
7	75	75	75	11	77	68	52	5
Mean	71	75	70	12	66	70	62	8

measure may be calculated for each modality by taking as a "hit rate" the proportion of trials when that signal was present that S responded "yes" (regardless of which modality he chose) and taking as a "false-alarm rate" the proportion of blank trials that S responded "yes." Such measures were calculated for each S in each condition and each modality and are presented in Fig. 4. We refer to the measure as a "biased D' ," since the influence of intermodality interactions is unknown—i.e., the effect on visual D' of counting (T,y | V) as a "visual hit" is unknown. Table 1 indicates that all Ss had higher "hit rates" in almost all cases in the simultaneous condition than in the successive condition, but that each S also had a higher "false alarm rate" in the simultaneous condition. The biased D' measures in Fig. 4 show, however, that with the exception of S 1, detectability measured in this way is not different between the two conditions. The mean advantages in D' across Ss for simultaneous over successive conditions are $-.25$, $-.21$, and $-.13$ for visual, auditory, and tactile, respectively. The standard errors of the mean differences are, respectively, $.11$, $.13$, and $.12$. S 1 had higher D' for all modalities in the successive condition—but it should be noted that this S's false alarm rate in the successive condition is very low— $.01$ —and that the D' score with such a low false-alarm rate is highly uncertain.

One could argue that "biased D' " is an ambiguous measure of detectability. Unfortunately, there is no unarguable nonparametric index of detectability for the yes-no data. (The probability of correct modality judgment is a measure less susceptible to alternative interpretations.) In order to treat the yes-no data effectively, we shall attempt to find a model which closely describes the data. It should be possible to compare the yes-no data for the sequential and simultaneous conditions within the framework of a satisfactory model.

A Model for Tri-Modality Detection. We propose perhaps the simplest possible model for this situation. This model is a threshold-type model which is similar to those discussed by Shipley (1965) and Lindner (1968). We assume attention has no effect. We suppose that there is a noise and signal-plus-noise distribution for each

modality. Each modality has its own criterion for saying "yes" somewhere along its respective observation axis. Now, on a particular trial—either simultaneous or successive—S samples from three distributions (on a visual signal trial, he samples from the visual signal-plus-noise distribution, from the tactile noise distribution, and from the auditory noise distribution). On any trial, S records for each modality whether the observation exceeded the criterion. If only one observation is above its criterion, the decision is simple: S responds with that modality and says "yes." If no observations are above criterion, S chooses the modality according to a personal guessing bias and says "no." If two or more observations are above criterion, S chooses among the modalities that surpassed criterion (according to the same guessing bias, renormalizing if necessary) and says "yes." Thus, for example, if a given S's bias is

Fig. 4. Experiment I. Empirical "biased" measure, D' , based on yes-no data for each condition, each modality, and each S. Positive slope indicates an attentional effect.

Table 2
Estimated Parameters and χ^2 Values

Ss	Condition	Vis		Aud		Tact		χ^2	df	p
		d'	β	d'	β	d'	β			
1	SIM	3.72	2.32	2.66	1.83	2.81	2.25	16.4	22	.8
	SUC	4.05	2.80	3.53	2.59	3.30	2.80	8.2	22	.99
	JOINT SIM SUC	3.78	2.35 2.54	2.87	1.97 2.02	2.93	2.34 2.46	61.57	47	.10
2	SIM	3.20	2.53	1.78	1.61	3.04	2.45	27.8	22	.2
	SUC	2.96	2.52	1.98	2.03	3.04	2.80	19.2	22	.6
	JOINT SIM SUC	3.12	2.45 2.68	1.86	1.66 1.94	3.02	2.44 2.78	49.47	47	.35
3	SIM	1.99	1.37	1.94	1.18	1.84	1.48	32.8	22	> .05
	SUC	1.72	1.16	1.69	1.23	1.65	1.60	22.3	22	.5
	JOINT SIM SUC	1.84	1.30 1.22	1.81	1.13 1.28	1.74	1.43 1.65	73.96	47	< .025
4	SIM	2.06	1.95	2.84	2.26	2.61	2.43	22.6	22	.5
	SUC	1.96	2.14	2.67	2.26	2.38	2.38	17.3	22	.75
	JOINT SIM SUC	2.02	1.93 2.18	2.75	2.18 2.32	2.48	2.32 2.46	43.65	47	.6
5	SIM	2.47	2.53	2.74	1.62	2.07	1.40	27.1	22	.2
	SUC	2.57	2.90	2.97	2.05	2.21	1.65	30.1	22	.1
	JOINT SIM SUC	2.47	2.52 2.81	2.83	1.66 1.94	2.14	1.43 1.61	63.14	47	> .05
6	SIM	2.91	2.44	2.10	1.70	2.56	2.16	25.7	22	.3
	SUC	2.70	2.20	2.22	2.07	2.13	1.89	28.6	22	.2
	JOINT SIM SUC	2.79	2.34 2.28	2.09	1.69 1.93	2.38	2.01 2.11	61.60	47	> .10
7	SIM	3.13	2.57	2.34	1.72	2.19	1.59	51.9	22	< .001
	SUC	3.60	2.90	2.70	2.28	1.79	1.76	33.5	22	.05
	JOINT SIM SUC	3.63	3.07 2.93	2.45	1.79 2.02	2.00	1.46 1.91	95.14	47	< .001

Note—JOINT refers to a simultaneous fit to both conditions assuming d' equal for both conditions within each modality. The p value gives the probability that χ^2 would be greater than the observed value by chance.

.50-.30-.20 for visual, auditory, and tactile signals, and if on a given trial visual and auditory observations surpass criterion, the prediction is that S will say "yes"—that he will respond "visual" with probability $.5/(.5 + .3) = .625$, and "auditory" with probability $.3/(.5 + .3) = .375$.

For each modality, we assume that the noise and signal-plus-noise distributions are normal and have equal variance. The model is described more fully and the mathematical predictions are given in the Appendix.

This model was fit to the data from each S, separately for successive and simultaneous conditions. The model has six parameters: these may be considered to be hit rate and false-alarm rates for each of the three modalities (where hit and false-alarm rates now refer to theoretical values depending on each S's signal and noise distributions and on the criterion chosen for each modality), or equivalently, may be d' and β for each of the three modalities. Guessing bias was estimated from each set of data from the distribution of modality responses on blank trials on which S had responded "no." Data consisted of 28 measures—the 24 response categories mentioned above, plus the collapsed yes data (probability of saying "yes," given each type of trial). The latter 4 dependent measures were added to give

extra weighting to the yes-no data. A computer STEPIT program used a minimum chi-square criterion to estimate the parameters for each S for simultaneous and successive conditions. These resultant parameters are given in Table 2, together with the minimum chi-square value (based on expected and observed frequencies in the 28 cells) and p value for that chi square.⁴ As can be seen from the table, fits were reasonable for all but S 7.

We do not argue from our model's fit to the data that the model is correct in all respects. In fact, we shall see below that data, or certain fine aspects of the data, would lead us to reject the model in its present form for several of the Ss. Nevertheless, the model comes quite close to the data and hence should give us a reasonable basis for comparing detectability in the successive and simultaneous conditions. We should note in this regard that the parameter space in the d' values is quite sharp near the best fit values—even a small deviation in the d' values from those listed causes a significant worsening of the fit to the data. This fact could be inferred from the closeness of the d' values in the simultaneous and successive conditions; were the parameter space shallow, pure chance would have resulted in much larger deviations. More to the point, the STEPIT program produces standard error estimates for the parameters,

Fig. 5. Experiment I. Theoretical measure d' based on a simple all-or-none model. Separate measures were calculated for each S and each modality in simultaneous and successive conditions. Positive slope indicates an attentional effect.

which in all cases were under 6% of the best fit d' values.

The theoretical d' measures as listed in Table 2 are shown in Fig. 5; they agree very closely with the biased D' measures calculated from the yes responses, except for an overall upward displacement, which is probably explained by the contaminations in the "yes" hit rates due to intermodality interactions. In any event, there does not appear to be any difference between d' s for the successive and simultaneous conditions. The mean advantages in theoretical d' across Ss for simultaneous over successive conditions are: -.01, -.19, .09 for visual, auditory, and tactile, respectively. The standard errors of the mean differences, calculated across Ss, are .11, .14, .12, respectively.

As a more stringent test of the model, we assumed

that d' was identical for the simultaneous and successive conditions and simultaneously fit all 56 points with nine parameters: a d' , a beta value for simultaneous condition, and a beta value for successive, for each of the three modalities. The minimum chi-square parameters, together with the chi-square values and p values, are presented in Table 2. Once again, the parameter space was quite sharp near the best fit d' values. The fits in general appear to be nearly as good as those for the original model, supporting the hypothesis that d' was identical for the successive and simultaneous conditions.

It is important to note that the models we have applied are criterion models—they assume that S does not utilize the perceived magnitudes of the information from each modality. S is assumed to make an all-or-none judgment for each modality concerning the possible presence of a signal and then to respond accordingly. This lack of attention to "magnitude" is not unreasonable if one considers the difficulties of comparing information in different modalities with each other. For example, the S may not know how to compare the magnitude of a visual observation with the magnitude of a tactile observation. From the point of view of normative signal detection theory, such comparisons should certainly be possible: S could convert the magnitudes to a common likelihood ratio scale, and compare the ratios. We have not attempted to fit such a model, and cannot, therefore, rule it out.

Shipley (1965) has considered a threshold model for a detection-recognition situation like ours, but with two auditory sources rather than three modalities. She found reasonable support for a threshold-type model. Lindner (1968) examined a situation similar to Shipley's, but found that a threshold-type model did not fit his data. In particular, he found that the probability of a correct modality judgment, conditional upon a "no" detection response, was above the guessing level, contrary to the predictions of a simple threshold model. This result was not found by Shipley, leading Lindner to suggest that instructional differences could have been an important factor. Lindner emphasized to the Ss that they could expect to be above chance on a modality judgment, even if they did not think a signal was present. We examined our data for an effect of this kind. The proportions of modality responses when the S responded "no" and no signal was, in fact, presented was compared with the corresponding proportions when the S responded "no" and a signal was presented. In fact, several Ss showed an above-chance tendency to predict modality correctly, even though they said they did not think *any* signal was present. S 7 showed a considerable tendency of this sort, and this deviation from predictions was solely responsible for the model's failure to predict his data. Other Ss to show tendencies of this type were 2 and 4, who showed a tendency significant at near the .05 level. The other Ss did not show this tendency. Thus, our data lie between those found by Shipley and Lindner—some

Ss follow the threshold predictions and some do not. Note that a magnitude model predicts above-chance modality performance conditional upon a "no" detection response. However, a modified threshold model in which the S sometimes says "no" even when a signal is above criterion can also predict such effects. Our present data do not seem sufficient to distinguish these models, but simultaneous-successive comparisons should be robust whichever model is correct.

The data and the results of the model explorations clearly demonstrate that there is no advantage—either when detecting threshold signals (yes-no) or naming them (which modality?)—for a successive condition over a simultaneous condition. A model postulating attentional effects during perceptual processing would predict that the successive procedure should be advantageous. For example, a single-channel model would predict an advantage for the successive condition of about .24 (for the probability of correct modality judgment). Note that the signals are brief enough, and of low enough signal-to-noise ratio, that performance is far from perfect even in the successive condition, where S has $\frac{1}{2}$ sec to switch attention to each modality in turn. Certainly, then, attention must be shared among the modalities in the simultaneous condition. We conclude, therefore, that the data support the notion that no "cross-modality" attention exists at early stages of processing: the number of modalities monitored for a possible signal does not affect the processing of a signal on any of them.

Data for six of the seven Ss—for both simultaneous and successive conditions—were seen to fit fairly well a simple criterion model which assumes that Ss take three independent measures of signal strength from three independent pairs of signal and signal-plus-noise distributions—one pair for each modality—and responds accordingly to a straightforward decision rule. Fits remained good when the additional assumption was made that detectability (d') for each type of stimulus be equal for simultaneous and successive conditions. Thus, the data support the hypothesis that the three modality channels are monitored independently and automatically, without operation of attention.

It was seen that there was a consistent criterion shift between conditions, both for responding "yes" overtly and, according to the best fits to the model, for the three hypothetical pairs of distributions underlying the overt responses. That is, Ss were more willing to respond "yes" implicitly to each channel in the simultaneous than in the successive condition. Such criterion shifts may have been due to the decreased confidence Ss had in their judgments when decisions were spread out in time in the successive condition. Most important for purposes of this experiment is that detectability is equal between the conditions in spite of the criterion shift—both when detectability is indexed by the "biased D' " of the yes-no data and when it is indexed by theoretical d' measures generated by the initial version of the model.

Despite the foregoing evidence, it might be argued that single signals, as used in this experiment, do not put sufficient load on the system to provide an adequate test for attention; that is, the single signal might be processed by a filter simply because no signals arrive through the other channels to compete for the selector (Broadbent, 1958).⁵ Experiment II provided a surer test by increasing the information load on the entire system. In this experiment, all modalities and intervals (except possibly one) contained signals, and S attempted to detect the absence of a signal. It should be emphasized that both this experiment and Experiment I are one-way tests. A finding of no difference between simultaneous and successive conditions unambiguously supports the conclusion that no attention is operating during systemic processing, but the finding of a simultaneous advantage may be interpreted in either of two ways: either attention is operating during systemic processing or the information load is sufficient to affect decision and/or memory factors and thereby produce a decrement in the simultaneous condition.

EXPERIMENT II

Method

Subjects. An attempt was made to utilize the seven Ss who had participated in Experiment I; four were reached who were willing to be Ss in Experiment II. In addition, another undergraduate was used, making five Ss in all. Ss were paid \$2/h.

Apparatus and Stimuli. The apparatus and stimuli used in Experiment II were identical to those used in Experiment I.

Procedure. The procedure was identical to that of Experiment I, except that Ss were not to detect the possible *absence* of one of many threshold signals. Thus, on a given trial in the simultaneous condition, two or three signals would be presented in the noise interval (noise was identical to that of Experiment I), and S would make two independent responses, as before: (1) which modality was missing (visual, auditory, tactile), and (2) was any signal missing (yes-no). In the successive condition, either eight or nine signals were presented altogether during a single trial.

To facilitate exposition, the following terminology is adopted: "visual signal" trial refers to a trial when auditory and tactile threshold stimuli are presented and the visual threshold stimulus is absent; "auditory signal" trial refers to a trial when auditory threshold stimulus is absent and visual and tactile stimuli are present; etc. A "blank" trial refers to a trial when all three threshold stimuli are presented. As in Experiment I, each block of 27 trials contained 6 "visual," 6 "auditory," and 6 "tactile" signal trials plus 9 "blank" trials. In the case of successive trials, if a "visual" signal was present, it would always occur in the first of the three noise intervals, and the other two intervals would be "blank"; similarly for "auditory" (second interval) and "tactile" (third interval)—see Fig. 2.

In all other particulars, the procedure was identical to Experiment I. Each S ran eight to nine sessions after several training sessions (for threshold determination and practice with the procedure).

Results

Figure 6 shows the probability of correctly naming the missing stimulus, collapsed over yes-no data, by modality for each condition for each S. The mean

Fig. 6. Experiment II. Probability of correct choice of modality as a function of condition for each modality and each S. Positive slope indicates an attentional effect.

advantages across Ss for simultaneous over successive conditions are 6.6%, 0.2%, and -2.2% for visual, auditory, and tactile, respectively. The standard errors of the mean differences are, respectively, 2.8%, 5.2%, and 3.1%. Although the variability was much greater than for the comparable data from Experiment I (Fig. 3), it can be seen that there is no overall advantage for the successive condition.

Biased D' measures were calculated from the yes-no data, collapsed over modality responses, in the same manner as described above for Experiment I. These data are shown in Fig. 7 by condition and by modality for each S. The mean advantages in D' across Ss for simultaneous over successive conditions are: .15, .02, -.07 for visual, auditory, and tactile, respectively. The standard errors of the mean differences are, respectively, .09, .17, and .10. Again, no overall advantage is evidenced for the successive condition.

Discussion

The inter-S and intra-S variability in the data was much greater in Experiment II than in Experiment I. Furthermore, Ss' threshold intensities for the three types of stimuli were extremely variable through the course of the experiment, requiring E to continually readjust these intensities from day to day. These difficulties probably reflect the more difficult nature of the task for S; however, despite the difficulties, the data support those of Experiment I: there is no advantage for the successive condition over the simultaneous condition, and hence we conclude again that there is no attention operating at early stages of processing when signals are presented in different modalities.

The day-to-day changes in threshold intensities make

Fig. 7. Experiment II. Analysis of yes-no data. Empirical "biased" measure D' for each condition, modality, and S. Positive slope indicates an attentional effect.

Fig. 8. Experiment III. Timing is shown for one block of trials. In divided-attention conditions, S responds independently to possible visual and auditory signals during each interval. In focused-attention conditions, S responded to signals in one modality only, though the bimodal stimulus sequence was unchanged.

it difficult to apply a model like that applied to Experiment I. We fit the model to the data from each S, but only one of the five Ss was accurately fit. We feel that a much better result could be obtained if the data from each day were fit separately, but we have not attempted to carry out this rather prodigious project.

The results of these experiments strongly support those of Eijkman and Vendrik (1965). It is important to note a series of experiments by Moray (1973a, b) which differ from the Eijkman and Vendrik paradigm in two central features. First, Moray used the two ears as channels; second, he used a repeated trials procedure in which a long sequence of trials would occur less than 1 sec apart. The results partially confirmed those of Eijkman and Vendrik (1965): when only one signal was presented, the focused and divided conditions showed equal performance. But when two signals were presented in the divided-attention condition, performance was reduced for each channel.

The differences between the Moray results and the Eijkman and Vendrik results could have been due either to the channel differences between the studies or to the repeated trials procedure. To discover which, we carried out an experiment in the auditory and visual modalities, using a repeated trials procedure like that of Moray (1973a, b).

EXPERIMENT III

Method

Subjects. Six new undergraduates served as Ss. They were paid \$2/h.

Apparatus and Stimuli. The apparatus and stimuli were identical to those used in the first two experiments; however, there was no tactile signal used in the present experiment. Visual noise—a clearly seen dot in the middle of the screen—and auditory noise—band-limited Gaussian noise delivered through the headphones—were identical to those described above for the first two experiments.

Procedure. Ss were run individually in sessions lasting approximately an hour. The first few sessions for each S were training: visual and auditory thresholds were determined in noise and S was allowed to become familiar with the apparatus and experimental procedure.

For an experimental session, S was seated at the end of a table in a dimly lit room, facing the VR-14 screen, which was on the other end of the table, approximately 4 ft distant. S adjusted the headphones, which were worn throughout the session.

A trial consisted of 24 500-msec noise intervals (visual and auditory noise) separated by 1-sec response intervals, as illustrated in Fig. 8. In a trial, there were 6 visual-signal-only, 6 auditory-signal-only, 6 both-signal, and 6 neither-signal (blank) intervals, randomly shuffled for each new trial. Signals, when present, were 100 msec in duration, centered in the noise interval. S initialized each trial by pressing the start button, at which time the intertrial fixation dot, centered on the screen, disappeared; the first noise interval began 500 msec later.

There were three conditions in the experiment: in the visual instruction condition, S was to respond by pressing the leftmost button on the response box (with his left hand) each time he detected a visual signal (ignoring auditory signals); in the auditory instruction condition, S was to press the rightmost button (with his right hand) each time he detected an auditory signal (ignoring visual signals); in the both instructions condition, S was to respond to visual signals with the leftmost button and auditory signals with the rightmost button, pressing both simultaneously, for example, if he thought he detected both signals in a given interval. The first two conditions are thus "focused-attention" conditions, and the last is a "divided-attention" condition.

S received all three conditions each session (in a changing order from session to session). A typical session began with 6 practice trials—2 in each condition. Then S received 15 trials in each condition (each condition being completed before the next one began). A visual cue on the screen before the first trial of each new condition indicated to S which condition was beginning. Ss were run two to three sessions per week until eight experimental sessions had been completed.

Results and Discussion

For each modality under each type of condition—focused vs divided—separate d' measures were calculated for those intervals when the other signal was present and when it was absent. These d' measures are plotted by S in Figs. 9 and 10 (for auditory and visual signals, respectively). In the auditory modality, the mean advantages in d' across Ss for focused over divided attention conditions are .18 and .56 for trials with visual signals absent or present, respectively. The standard errors of the mean differences are, respectively, .12 and .15. In the visual modality, the mean advantages in d'

Fig. 9. Experiment III. d' for auditory stimuli for focused and divided attention conditions, for each S, as a function of the presence or absence of a signal on the visual channel. Negative slope indicates an attentional effect.

across Ss for focused over divided attention conditions are .11 and .27 for trials with auditory signals absent or present, respectively. The standard errors of the mean differences are, respectively, .08 and .09.

The central point to note is that the single-modality-listening and two-modality-listening conditions are about equal when there is no signal on the other modality. However, a marked decrement occurs when there is a signal present on the other channel. This result is similar to that found by Moray (1973a, b) in two-ear situations and to that found by Sorkin, Pohlmann, and Gilliom (1973) in a related two-ear paradigm. Sorkin and Pohlmann (1973) discuss two possible hypotheses to account for a two-channel decrement when signals are present on both channels. A "response" hypothesis, first proposed by M. Treisman (1972), suggests that the criterion for response on a given channel varies with the magnitude of the observation on the other channel: up to a point, the larger the magnitude, the greater the criterion variability. Thus, an average decrement in d' is predicted on trials which produce large observations on both channels (both signals presented). As Sorkin and Pohlmann (1973) point out, however, such a strategy—making the criterion on one channel contingent upon the observation in the other channel—is nonoptimal for S unless there exist interchannel signal contingencies and he is aware of them. In the present experiment, of course, presentation of the two signals was completely independent.

A second hypothesis discussed by Sorkin and Pohlmann (1973), attributed to J. D. Gilliom (see Sorkin, Pohlmann, & Gilliom, 1973), is the interrupt model. According to this hypothesis, S simultaneously monitors the two channels and independently integrates

magnitude information on each. When the magnitude of either channel reaches some criterion level, an interrupt occurs and integration on both channels ceases; then further processing (identifying, naming, responding) is carried out in series, beginning with the activated channel. Information decays in the other channel, and a decrement with two signals presented is again predicted.

In view of Moray's (1973a, b) results, which found a "two-channel decrement" with massed observation intervals, and Eijkman and Vendrik's (1965) results, which did not find the effect with a single-interval procedure, we suggest that such an interrupt hypothesis is quite tenable. Specifically, we would suppose that what is interrupted are very late stages of processing. The interruption is initiated by a large observation on the other channel and may be caused either by the response itself (as in Sorkin, Pohlmann, & Gilliom, 1973) or by the arrival of the next observation interval. Thus, in our experiment, S may find it difficult to make multiple "simultaneous" decisions on a continuing basis. By the time a decision has been made that a signal is present on one modality and the response begun, the next trial may already be occurring and S might halt further consideration of the information processed during the previous trial. Only a small proportion of misses of this sort could account for the observed decrement in the two-channel situation. Furthermore, the same mechanism could account for a much smaller decrement when there is no signal on the other channel, if one considers the effect of false alarms.

SUMMARY AND CONCLUSIONS

The first two experiments demonstrated that the necessity for simultaneous monitoring of three different sensory modalities for the presence of a near-threshold

Fig. 10. Experiment III. d' for visual stimuli for focused and divided attention conditions, for each S, as a function of the presence or absence of a signal on the auditory channel. Negative slope indicates an attentional effect.

signal does not reduce performance in comparison with a condition in which each sensory modality can be given full attention in turn. This result was obtained whether one or many signals were presented together in the various modalities. It thus appears that the necessity for simultaneous monitoring does not reduce performance. A simple threshold-type model fit the data reasonably well and supported these conclusions. We suggest that all the relevant information in the signals and noise is abstracted automatically by the processing system and dumped into short-term store. Experiments I and II are designed so that all relevant decisions can be made and completed before any of this information is lost from short-term store. Hence, no difference results between simultaneous and successive conditions. Experiment III, however, utilizes a procedure in which all the relevant information cannot be effectively scanned between successive presentations. Thus, a performance decrement occurs when two signals are presented simultaneously.

In common with a series of previous experiments, our results suggest that selective attention plays no role during perceptual processing. We suggest that selective attention results from a variety of control processes that S utilizes in short-term store subsequent to perceptual processing. While previous studies have led us to these conclusions based on channel manipulation within single sensory modalities, the present studies suggest the same conclusion regarding attention allocation to the separate modalities of vision, audition, and touch.

APPENDIX

A SIMPLE NONATTENTION CRITERION MODEL FOR TRIMODALITY DETECTION

On a given trial (either simultaneous or successive condition), there may be a visual, auditory, or tactile signal presented (V, A, or T), or there may be none presented (N). The model assumes six normal distributions—the noise and the signal-plus-noise distribution within each modality have equal variance. For each modality, S has a criterion along the horizontal axis, which we may think of as representing perceived signal strength.

On each trial, S makes three independent observations; for example, on a visual signal trial, he samples from the visual signal distribution, from the auditory noise distribution, and from the tactile noise distribution; on a blank trial, S would make his three observations from the three noise distributions, etc. We assume that S does not utilize the magnitudes of the samples taken; he records for each modality only whether or not the sample lies above the criterion.

To make his two independent responses (forced choice and yes-no), S uses the following decision rule: if any of the three observations surpasses its respective criterion, S responds "yes" (y); otherwise, he responds "no" (n). In the latter case, S chooses modality according to a guessing strategy. If a single observation surpasses criterion, of course, S chooses that modality; if two or more observations surpass criterion, S chooses

modality according to his guessing bias, renormalizing if necessary. For fitting, the guessing biases were estimated from each S's data from the distribution of modality responses on blank trials on which S responded "no."

The six parameters can be conceived of either as a d' and a β for each modality or, alternatively, as a hit rate and false alarm rate for each modality. The following predictions are in terms of hit rates (H) and false-alarm rates (F), where H is equal to the area under the signal distribution to the right of criterion, and F is equal to the area under the noise distribution to the right of criterion. Subscripts V, A, and T denote the modality, G denotes guessing bias for modality responses. (Note that $G_V + G_A + G_T = 1.00$.)

The following equations give the predictions for responding "visual" to all types of trials; exactly analogous expressions would apply to "auditory" and "tactile" responses. The notation is straightforward; for example, $P(V, y | T)$ is the predicted probability of responding "visual" and "yes," given a tactile signal.

The parameters of the model were evaluated by using a minimum chi-square criterion. Equations a through h for each modality plus the four yes-no equations were fit to the corresponding 28 data points. The parameters were chosen for each S to minimize the discrepancy between the data and the predictions by a chi-square criterion. (When a predicted frequency was smaller than 1.0, the term in the denominator of chi square was replaced by the observed frequency.)

A later version of the model assumed that d' was identical for the simultaneous and successive conditions, within each modality. In this case, nine parameters were chosen so as to best fit 56 data points.

Yes-No Responses

$$P(y | V) = 1 - (1 - H_V)(1 - F_A)(1 - F_T)$$

$$P(y | A) = 1 - (1 - F_V)(1 - H_A)(1 - F_T)$$

$$P(y | T) = 1 - (1 - F_V)(1 - F_A)(1 - H_T)$$

$$P(y | N) = 1 - (1 - F_V)(1 - F_A)(1 - F_T)$$

Broken-Down "Visual" Responses

Visual Signal Presented

$$\begin{aligned} P(V, y | V) = & H_V(1 - F_A)(1 - F_T) \\ & + \frac{G_V}{G_V + G_A} H_V F_A (1 - F_T) \\ & + \frac{G_V}{G_V + G_T} H_V (1 - F_A) F_T + G_V H_V F_A F_T \end{aligned} \quad (a)$$

$$P(V, n | V) = G_V(1 - H_V)(1 - F_A)(1 - F_T) \quad (b)$$

$$P(V | V) = P(V, y | V) + P(V, n | V)$$

Auditory Signal Presented

$$\begin{aligned}
 P(V, y | A) &= F_V(1 - H_A)(1 - F_T) \\
 &+ \frac{G_V}{G_V + G_A} F_V H_A(1 - F_T) \\
 &+ \frac{G_V}{G_V + G_T} F_V(1 - H_A)F_T + G_V F_V H_A F_T
 \end{aligned} \quad (c)$$

$$P(V, n | A) = G_V(1 - F_V)(1 - H_A)(1 - F_T) \quad (d)$$

$$P(V | A) = P(V, y | A) + P(V, n | A)$$

Tactile Signal Presented

$$\begin{aligned}
 P(V, y | T) &= F_V(1 - F_A)(1 - H_T) \\
 &+ \frac{G_V}{G_V + G_A} F_V F_A(1 - H_T) \\
 &+ \frac{G_V}{G_V + G_T} F_V(1 - F_A)H_T + G_V F_V F_A H_T
 \end{aligned} \quad (e)$$

$$P(V, n | T) = G_V(1 - F_V)(1 - F_A)(1 - H_T) \quad (f)$$

$$P(V | T) = P(V, y | T) + P(V, n | T)$$

No Signal Presented

$$\begin{aligned}
 P(V, y | N) &= F_V(1 - F_A)(1 - F_T) \\
 &+ \frac{G_V}{G_V + G_A} F_V F_A(1 - F_T) \\
 &+ \frac{G_V}{G_V + G_T} F_V(1 - F_A)F_T + G_V F_V F_A F_T
 \end{aligned} \quad (g)$$

$$P(V, n | N) = G_V(1 - F_V)(1 - F_A)(1 - F_T) \quad (h)$$

$$P(V | N) = P(V, y | N) + P(V, n | N)$$

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NOTES

1. Corroborating this view is Massaro's subsequent finding (personal communication) that in a similar visual-auditory attention experiment, where no duration judgments were

required, the focused-attention trials showed no better performance on either modality than the divided-attention trials.

2. "Noise" is used here, and throughout the paper, to refer to the interval-defining stimulus for a modality. No reference is intended to randomness in the stimulus, although in the case of auditory "noise," the "noise" is actually a sample of white gaussian noise.

3. A complete breakdown of the data by Ss is available from the authors upon request.

4. In a number of ways, the chi square we calculated does not fit the strict mathematical requirements for the distribution. For one thing, there are really only 20 independent data points per S, although we fit 28 points. Thus, our p values are to be considered illustrative rather than strict statistical statements.

5. The argument with respect to load is somewhat dubious when discussing near-threshold stimuli, since all intervals, even those containing no signal, are in fact noise intervals which S must evaluate to determine the possible presence of a signal. The argument would be stronger if the signal appeared in an intense noise burst during one interval and all other intervals and modalities were effectively "silent." In the present experiment, however, all intervals and modalities required evaluation by S.

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