Spatially-limited attention to vibrotactile stimulation[1]

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Weak vibrotactile signals were presented to human Os, in some instances to the index finger alone, in other instances to the middle finger alone, and in still other instances to the two fingers simultaneously. When the O knew in advance of a trial which finger(s) would be presented a signal, no spatial summation resulted, that is, the sensitivity of two fingers to two signals was no greater than the sensitivity of one finger to one signal. When the O was left uncertain about which finger(s) would be presented a signal on any given trial, a result having the appearance of spatial summation was obtained. The appearance is misleading; the difference between two-finger and one-finger sensitivity in this case reflects, instead, a decrement in the performance of the single fingers. Both results are consistent with a single-channel model of attention.

Picture an O resting the tip of an index finger on a small disk, and resting the tip of the middle finger on an adjacent disk. The O is called upon to detect weak vibrations of either disk or of both, the vibrations being fixed in frequency, amplitude, and duration.

Will detectability be greater when both disks are set into motion than when a single disk is in motion? The answer is, "Yes and no." The answer is "No" if the O knows in advance of a trial which disk(s) will vibrate. We conclude that there is no summation over the two fingers. The answer is "Yes" if the O is uncertain about which disk(s) will vibrate on a given trial. We suggest that the difference between one-finger and two-finger detectability in this case, just as the lack of a difference in the first case, represents a limitation on attention.

Two experiments were conducted. In the first, the cases of certain and uncertain signals were examined in succession: A series of daily sessions, spanning about 2 weeks, was devoted entirely to certain signals, and then another period of about 2 weeks was devoted entirely to uncertain signals. Given the results just summarized, it was desirable to conduct a second experiment that would permit a more valid comparison of the two cases. In the second experiment, with a different group of Os, both certain and uncertain signals were presented in each daily session.

EXPERIMENT 1

Procedure

Basic features of the experimental procedure were similar in the two experiments. We describe the general procedure now and mention a few minor differences in some parameter values when we come to consider Experiment 2.

The fingers were placed on the disks so that the area of contact was on the palmar surface about ¼ in. from the end of the fingers. The disks, ½ in. in diam, were vibrated sinusoidally at a frequency of 222 Hz for 500 msec. The sinusoids were always gated at a positive zero crossing, so the phase relation between the two disks was fixed. Other aspects of the apparatus and observing conditions have been described elsewhere (Swets, Markowitz, & Franzén, 1969).

The Os were three female high-school seniors. They worked 2 h a day and 5 days a week for a fixed rate of pay. Prior to collection of the data reported here, they each had approximately 15 days of practice.

The two-interval forced-choice method was used throughout. A vibration, of one disk or both as the case might be, occurred in one or the other of two temporal observation intervals with equal probability. The O pressed one of two buttons, with the other hand, to indicate the interval she believed to contain the vibration. The only dependent variable considered was the proportion of correct responses, P(C).

The observation intervals and the various other intervals of a trial cycle were marked by a row of lights. A warning light of 200 msec preceded the first observation interval. The duration of the two observation intervals, like the duration of the signal, was 500 msec, and the time between the two was 500 msec. The answer period of 1,500 msec was followed by a feedback period, during which the appropriate one of the lights that had marked the observation intervals was lit for 500 msec to indicate the correct response. After the feedback, 600 msec elapsed before the warning light for the next trial appeared.

Signal amplitudes were set to yield roughly equal detectability for the two fingers and for the three Os. The reference amplitudes, denoted 0 dB, were −23, −19, and −17 dB re 1.0 g rms for the index fingers of the three Os, respectively; the reference amplitude for the three middle fingers was −24 dB re 1.0 g rms. Three signal amplitudes were used: 0, 3, and 6 dB.[4]

Condition 1: Signal Specified Exactly

In the first experimental condition, the signal parameters were entirely constant throughout a group of 100 trials. Specifically, in a given group of 100 trials, only Finger 1 (index) was stimulated, or only Finger 2 (middle) was stimulated, or both Fingers 1 and 2 were stimulated on all trials. We call this procedure "signal specified exactly" (SSE)—the O knew exactly which finger(s) would be stimulated on each trial.

Nine groups of 100 trials were presented in each daily session. Three groups of trials were devoted to Finger 1, three to Finger 2, and three to Fingers 1 and 2. Whether a given group of trials would present a signal throughout to Finger 1, or to Finger 2, or to both fingers, was

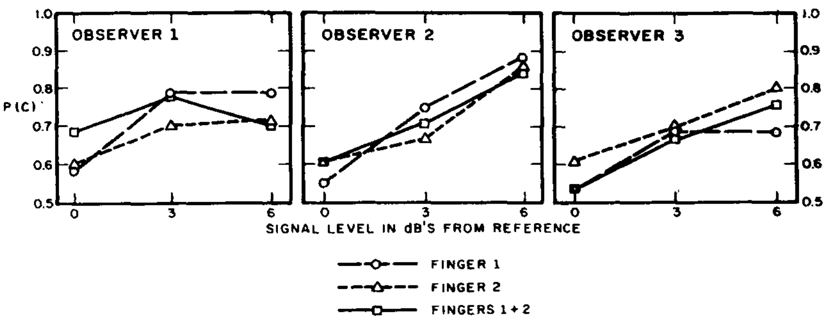

Fig. 1. P(C) vs signal level for three Os; for Finger 1, Finger 2, and Fingers 1 and 2, with the signal specified exactly.

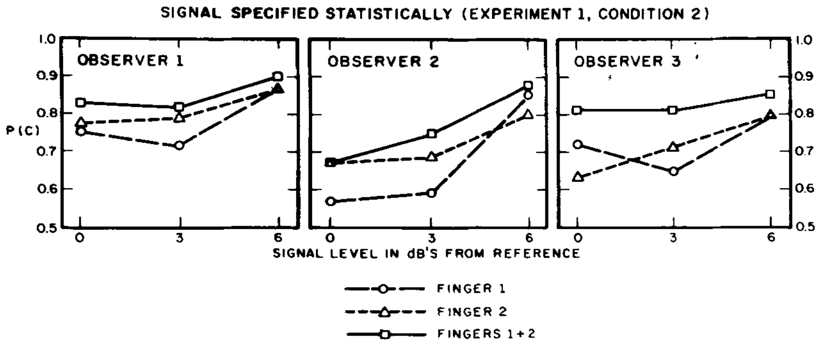

Fig. 2. P(C) vs signal level for three Os; for Finger 1, Finger 2, and Fingers 1 and 2, with the signal specified statistically.

determined randomly. Three successive daily sessions were devoted to each of the three signal amplitudes (in the order, 3, 0, and 6 dB). Thus, each value of P(C) was based on 900 trials.

The results are shown in Fig. 1. It is apparent that the detection performance of two fingers was no greater than the detection performance of the better single finger: P(C) for two fingers exceeds P(C) for the better single finger in only one of nine instances. No spatial summation is evident.[5]

These data are consistent with the results we obtained in an unpublished pilot experiment, and with the results of Experiment 2 presented below. These data are inconsistent with results reported recently by Craig (1968), unless the fact that Craig used the first and third, and the first and fourth, rather than the first and second fingers, is significant.

We might ask what increment in P(C) from one to two fingers would be expected under a summation hypothesis. Green and Swets (1966, pp. 238-242) have discussed two alternative models for summation, one based on detection theory and the other based on threshold theory. From equations they presented, it can be determined that—for values of P(C) for each single finger of 0.60, 0.70, 0.80, and 0.90—the two models predict increments ranging from 0.04 to 0.12. Data they presented show these two models to represent reasonably well the results obtained with visual and auditory stimuli.

A simple model that is consistent with the lack of summation we observed in the experiment at hand is the single-channel model of attention. This model asserts that the O can attend at any instant only to inputs to a single channel—in the present case, to a single finger.

Condition 2: Signal Specified Statistically

The limited-attention model suggests that the detection performance of the pair of fingers would be greater than that of either single finger if the O were uncertain about which signal(s) were to occur on any trial. When signals are delivered to both channels, the O will always be attending to a channel with a signal present; when a signal is delivered to only one channel, the O will be oblivious to it on the portion of trials during which he is attending to the other channel. This predicted result has the appearance of spatial summation. According to the model, however, the difference between one-finger and two-finger detectability stems from a decrement in the performance of the single fingers, rather than an enhancement of performance provided by summation.

The experimental procedure just characterized, termed "signal specified statistically" (SSS), was used in a second condition of Experiment 1. Whether one or the other or both disks would vibrate was determined randomly from trial to trial, with the three kinds of stimulation equiprobable. Again, 900 trials per day, with three (successive) days at each of the three signal amplitudes (in the order, 3, 0, and 6 dB), yielded values of P(C) based on 900 trials.

The results are shown in Fig. 2. The pair of signals is seen to be consistently more detectable than either signal alone: P(C) for the pair of fingers exceeds P(C) for the better single finger in eight of nine instances.

A Comparison of the Two Conditions

Interpretation of both conditions of this first experiment as consistent with the single-channel model—that is, interpretation of Condition 2 (SSS) as indicating not summation of two fingers but rather a decrement due to uncertainty when only one of the fingers is stimulated—requires that there be no increase in P(C) for Fingers 1 and 2 from Condition 1 to Condition 2, and that there be a decrease in P(C) for the single fingers from Condition 1 to Condition 2.

A brief glance at Figs. 1 and 2 is enough to show what a detailed analysis shows, namely, that these predictions of the single-channel model were not met. We considered the possibility that there was a general improvement in detectability from Condition 1 to Condition 2 as an effect of learning. So we designed a second experiment to provide adequate counterbalancing of the SSE and SSS conditions.

EXPERIMENT 2

Procedure

Three new Os were employed for this experiment. They were given 7 days of practice before the experiment proper began. The reference signal amplitudes for these three Os, denoted 0 dB, were −24, −27, and −28 dB for the index fingers, and −25, −24, and −29 dB for the middle fingers, re 1.0 g rms. Three signal levels were used: 0, 2, and 4 dB.[6]

Each daily session contained one group of 150 trials devoted to Finger 1, one group of 150 trials devoted to Finger 2, and one group of 150 trials devoted to Fingers 1 and 2, all SSE. Each daily session also contained three groups of 150 trials devoted to SSS. The six groups of trials each day were presented in a random order.

The signal level was changed from day to day, with all three levels used before one was repeated. The 18 days of the experiment permitted the three signal levels to be presented in each of their six possible different orders. The experiment yielded values of P(C) based on 900 trials.

Table 1

Data from Experiment 2. The Percentage of Correct Responses for Three Os at Three Signal Amplitudes, for Three Patterns of Stimulation, under the Conditions of Certain and Uncertain Signals

Condition	Signal Specified Exactly									Signal Specified Statistically								
Observer	1			2			3			1			2			3		
Finger(s)	1	2	1+2	1	2	1+2	1	2	1+2	1	2	1+2	1	2	1+2	1	2	1+2
0 dB	66	62	63	73	70	74	49	54	56	62	66	68	67	65	68	48	57	56
2 dB	82	81	84	88	81	86	56	69	72	65	77	79	76	69	80	49	64	60
4 dB	90	84	89	89	91	95	55	88	85	74	85	87	85	87	92	52	74	74

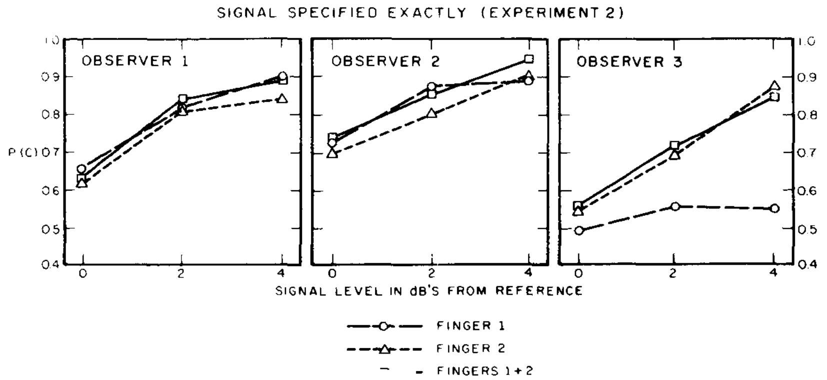

Fig. 3. P(C) vs signal level for three Os; for Finger 1, Finger 2, and Fingers 1 and 2, with the signal specified exactly.

Results

The data of Experiment 2 are given in Table 1. Comparisons of principal interest are presented graphically in subsequent figures.

Figure 3 shows the data for the fingers singly and together under SSE. We can see, as in Experiment 1, that one would be hard pressed to make a case for spatial summation. Values of P(C) for two fingers are not consistently greater than values of P(C) for the better single finger, and in no instance is the difference in this direction larger than 0.04. If we look at the 18 sessions of the experiment individually (data not presented here), we find that P(C) for two fingers exceeds P(C) for the better single finger in four sessions for O 1 and in seven sessions for Os 2 and 3—about what we would expect under the hypothesis of no difference.

Figure 4 shows the data for the case of SSS. At this point, for reasons that will be apparent, we must distinguish between the behaviors of different Os. The results of Os 1 and 2 are like the results obtained in Experiment 1: P(C) for two fingers is consistently greater than P(C) for either single finger.

Observer 3 also shows, we contend, the decrement from uncertainty, but she shows it in a different way. Quite clearly, she adopted a pure strategy with respect to her distribution of attention, rather than what might be called a "probability-matching" strategy. In particular, she seems, in this case of SSS, to have been attending only to Finger 2. We can note that there is very little difference between Finger 2 and Fingers 1 and 2, and, importantly, that the performance of Finger 1 is at the level of chance. The basis for her adoption of this strategy is suggested by her SSE data shown in Fig. 3: In her case, the Es did not succeed in their attempt to choose signal levels that would yield approximately equal detectabilities for the two single fingers under SSE, and, as a consequence, probability matching under SSS would lead her to a lower P(C) overall than would the pure strategy.

The data shown in Fig. 4 are surely not conclusive evidence in support of the notion that the Os in our experiment could deliberately choose a particular strategy of performance. These data are sufficiently suggestive, however, to our minds, to make the notion one worth considering further. Thinking in terms of conscious strategies is compatible with our thinking in terms of an attentional process, and we had arrived at that point before we saw the data shown in Fig. 4. The evidence for a central, attentional process, and the evidence for individual differences in strategy, in experiments on frequency selectivity in audition has been reviewed by Swets (1963).

In general, then, the results of Experiment 2 corroborate the results of Experiment 1, and our interpretation of them. Let us consider now those comparisons between SSE and SSS data that Experiment 2 was designed to allow.

The single-channel model predicts that the performance of single fingers will be generally better under SSE than under SSS. Figure 5 confirms this prediction for Finger 1, for all Os. Figure 6 confirms the prediction for Finger 2, for O 2 only. We can see that O 1 does about as well with Finger 2 under SSS as under SSE; we might expect this result on the basis of a previous figure: Fig. 4 shows that although O 1 appears not to adopt a pure strategy (Finger 1 is above the chance level), she does to a degree favor Finger 2 over Finger 1 in the SSS case. On the basis of results presented earlier, O 3 should show little difference between SSE and SSS for Finger 2; her results diverge unaccountably at the highest signal level.

In any event, on the whole, single-finger performance is better under SSE than under SSS. This result is consistent with analogous studies in audition (Swets, 1963) and with another study of pressure stimuli (Meyer, Gross, & Teuber, 1963).

Figure 7 shows two-finger performance under SSE and under SSS. Unlike the results of Experiment 1, the SSS performance is clearly not superior, so we are not inclined to interpret the superiority of two fingers over one finger in the SSS case (Figs. 2 and 4) as an increment due to spatial summation.

If anything, Fig. 7 shows the performance for SSE to be better than that for SSS. Such a result is consistent with uniformly attending to the better finger under SSE, and attending sometimes to the poorer finger, in order to achieve somewhat uniform performance on the two single fingers, under SSS. In keeping with our previous discussion of O 3's strategy, however, there should be little difference in Fig. 7 for her; we have no explanation to offer as to why the difference for her is as large as it is.

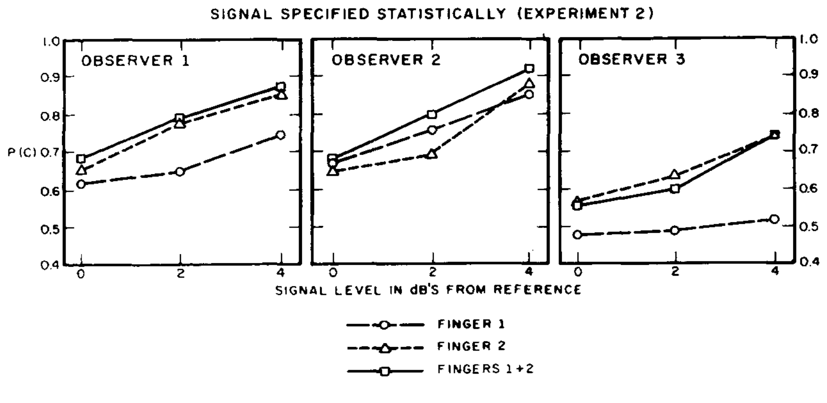

Fig. 4. P(C) vs signal level for three Os; for Finger 1, Finger 2, and Fingers 1 and 2, with the signal specified statistically.

DISCUSSION

The data of these experiments, showing no summation of vibrotactile stimuli to two fingers, support a single-channel model of attention. Only weak signals were examined and the single-channel model is here proposed to apply only to weak signals.

Vibrotactile spatial summation has been observed in a study that explored relatively strong stimuli with direct scaling methods

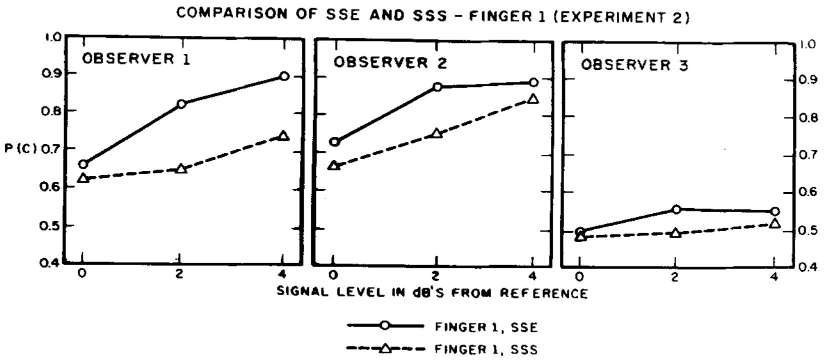

Fig. 5. P(C) vs signal level for three Os; comparison of Finger 1 in SSE with Finger 1 in SSS.

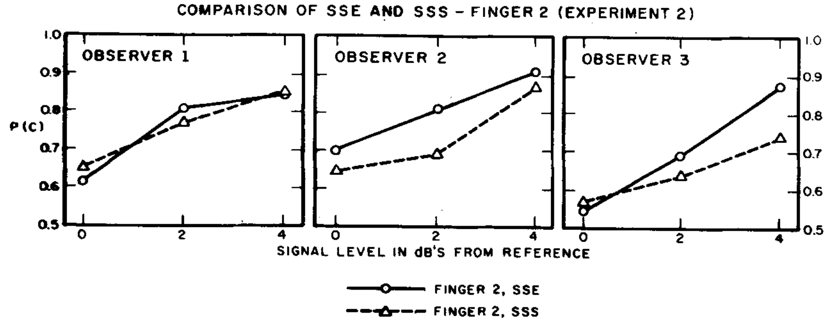

Fig. 6. P(C) vs signal level for three Os; comparison of Finger 2 in SSE with Finger 2 in SSS.

and neurophysiological techniques, though the scaling data suggested the possibility of no summation at signal levels close to the levels used in the present study (Franzén & Offenloch, 1969). In contrast to our results, a previous study using weak signals showed spatial summation to occur when immediately adjacent areas of the skin were stimulated by means of a piston and a concentric ring (Eijkman, 1959).

Studies of weak auditory signals in noise have led to mixed results. Some have shown summation for tones with small frequency separation, and no summation for tones with large frequency separation; others have shown summation to occur even at large separations. An experiment on weak visual signals has shown the amount of summation to decrease as the distance between two points of light is increased; the range explored in this experiment was approximately 3 min to 60 min of visual arc. The literature on spatial summation in these two senses was recently reviewed in more detail elsewhere (Green & Swets, 1966).

Let us note in closing an implication of the present study for the design of future experiments of this kind. This study points up, again, the need to consider the knowledge that the O has about the signal or signals to be presented on any trial. If we had given this variable inadequate treatment—by considering only the casc in which the different patterns of stimulation were finely counterbalanced and varied randomly from trial to trial—we might well have been led to interpret our results as support for the concept of spatial summation.

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NOTES

1. This work was supported by the Human Performance Branch of the NASA-Ames Research Center and the Swedish Council for Social Science Research. Paul F. Coughlin constructed and maintained the experimental apparatus; Barbara Noel collected the data.

2. Dr. Franzén was on leave from the Royal Institute of Technology, Stockholm. His present address is Department of Neurology, Karolinska sjukhuset, Stockholm 60, Sweden.

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4. Expressed in terms of displacement amplitudes, specifically, in microns peak to peak, the signal levels for the index fingers were: O 1–1.0, 1.4, and 2.0; O 2–1.6, 2.3, and 3.2; O 3–2.0, 2.8, and 4.0. For all middle fingers, the three levels were 0.9, 1.3, and 1.8.

5. That not all of the curves are monotonically increasing can probably be attributed to a constraint placed on the range of the three signal amplitudes; it was desirable to select all amplitudes for the single-finger signals from the lower part of the psychometric range, in order to permit measurement of any summation over the pair of fingers that might have occurred.

6. In microns, peak to peak, the signal levels for the index fingers were: O 1–0.9, 1.1, and 1.4; O 2–0.6, 0.8, and 1.0; O 3–0.6, 0.7, and 0.9. And for the middle fingers: O 1–0.8, 1.0, and 1.3; O 2–0.9, 1.1, and 1.4; O 3–0.5, 0.6, and 0.8.

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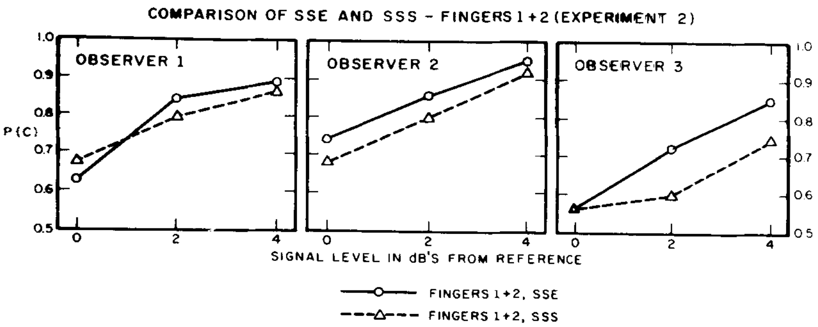

Fig. 7. P(C) vs signal level for three Os; comparison of Fingers 1 and 2 in SSE with Fingers 1 and 2 in SSS.