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A COMPARATIVE EVALUATION OF VIBROTACTILE WARNING SIGNAL POTENTIAL

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TECHNICAL DOCUMENTARY REPORT NO. ESD-TDR-61-24
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ABSTRACT

The discriminative reaction times to auditory, visual and vibrotactile stimuli are compared. Reaction times to vibrotactile signals are at least as short as the reaction times for the other modalities, although more incorrect responses were made using that sense. Of greatest interest, however, the probability of a response being made to a vibratory signal appears to be the highest of the three. The implications of these findings are discussed.

Reviewed and approved for publication:

HERBERT RUBENSTEIN, CHIEF
Information Presentation Division
Operational Applications Laboratory

WILLIAM V. HAGIN, COLONEL, USAF
Director
Operational Applications Laboratory

A Comparative Evaluation of Vibrotactile Warning Signal Potential

William H. Sumby

A requirement for additional or supplementary information channels is becoming more and more apparent in modern weapon-systems. Situations arise in such systems where it is imperative that the reception of low probability messages be immediately accomplished even against a background of competitive messages. On the basis of work performed by Geldard[1] and his associates at the University of Virginia, it has been demonstrated that vibrotactile signals might satisfy the need. Such a signal can, indeed, be implemented as a communications device.[2] The research reported here is an attempt to investigate further such communicatory potential by comparing response characteristics to vibrotactile signals with those to auditory and visual signals.

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1. Geldard, F. A., Adventures in tactile literacy. Amer. Psychologist 1957, 12, 115-124

2. Howell, W. C., Training on a vibratory communication. Unpublished Master's thesis, University of Virginia, 1956.

At the present time, both visual and auditory warning signals are employed in weapon systems. For purposes of information transmission these modalities can, and do, accept a greater informational load than the other senses with present means of encoding.

With the increase in systems complexity, the possible hazard of channel saturation of the auditory and visual senses is known. In addition to the possible danger of saturation, there are other disadvantages encountered with both senses. For example, orientation of the head is important in order for visual signals to be detected. The generator of such signals must typically be placed in an area generally immediately adjacent to other visual displays. An auditory signal must be of such a wave form or composition so as not to be masked by the volume of ambient noise generated by an aircraft or other system.

At first appraisal a vibrotactile signal should not be subject to such short-comings, and might effectively be substituted for certain urgent low-information messages. The aim of this research, then, was exploratory, simply to determine the speed, accuracy, and certainty of responding to vibrotactile stimuli compared with audition and vision in comparable discriminatory situations. It was the intention that this work be preliminary to an evaluation of a vibrotactile signal in a more complex situation.

Method

Only a single variable of an auditory, visual or vibrotactile stimulus was manipulated: the intensity of the signal. Intensity was varied by controlling the voltage across the auditory, visual or vibrotactile transducers. Three stimulus values were chosen for each. A convenient middle stimulus value was selected. The low and high intensities were chosen by the following procedure. The intensity was successively increased or decreased to the value where 50 consecutive, errorless discriminations were obtained with each of four Ss in a paired comparison test against the middle value with unlimited response time. The stimulus values, in terms of dbs, selected and used are presented in Table 1. The differences in the ranges subtended by the three modalities are considerable.

Table 1

Intensity Values of Stimuli

	Modalities		
	Vision	Audition	Vibration
Low	13 db*	66 db	0 db
Middle	19 db	84 db	7 db
High	32 db	96 db	11 db

Vision- re 1 ft. c.

Audition- re 0.002 $dynes/cm^2$

Vibration- re 100 microns

The auditory signal was a 1,000 cps tone generated by an audio oscillator and delivered through a Permaflux PDR-8 headset. The lag time of the tone was about 20 msecs. The visual stimulus was formed by lamps positioned behind a milk-glass screen placed in an aperture one inch in diameter and subtending a visual angle of approximately three degrees. The rise time of the light output was 20 msecs. The vibrator was constructed by using the frame and six volt coil of a water aerator. The vibratory transducer was mounted at the end of a four inch strip of hacksaw blade which was fastened to the frame of the aerator and ran directly above the core of the coil. The transducer was made from a small cylinder of plastic. The inertial lag of the vibrator ranged between 16 and 24 msecs.

The S placed his left hand and arm on a platform and rested his index finger on the perimeter of a round opening three eighths of an inch in diameter, through which the transducer extended to the upper surface of the platform. The aerator frame was embedded in foam rubber and mounted on alternating layers of lead and Fiberglas. The arrangement minimized the transmission of vibration to parts of the apparatus other than the transducer.

The stimulus sequences were programmed on teletype tape. Four sequences were generated for each modality. Each sequence was made up of 63 stimulus presentations, 21 of each of the three values distributed randomly throughout each series.

In order to reduce anticipatory responses and the effect of temporal cues, the interval times were varied in units of three secs between 3 and 21 secs. That is there were seven possible temporal intervals between successive stimuli: 3, 6, 9, 12, 15, 18, and 21 secs. The temporal interval was distributed randomly throughout each sequence.

A counterbalanced design shown in Table 2 was used. Four Ss began the experiment by responding to the auditory sequences (A) for the first six days of the experiment. Of these four, two

Table 2

Experimental Design

	Subjects					
Days	1&2	3&4	5&6	7&8	9&10	11&12
1-6	A	A	V	V	T	T
7-12	V	T	A	T	A	V
13-18	T	V	T	A	V	A

continued with six days of visual sequences, and two Ss with vibratory sequences. At the end of this period they again changed modality. That is, the two Ss who finished the visual changed to vibratory, and those who finished vibratory changed to visual. Similarly four Ss began the experiment with vision (V) and four with vibration (T).

Instructions were read to the Ss immediately prior to the first experimental session. They were told to respond as quickly and as accurately as possible. Before the first test tape was presented, a practice tape was given to acquaint the Ss with the stimulus values. On each succeeding day the same practice tape was presented just before the experimental session. Instructions to the Ss to work quickly and accurately were repeated before each session.

The Ss responded to the stimuli by depressing one of three telegraph keys, each key corresponding to a particular stimulus intensity. The keys were mounted on the arm platform arranged in an arc corresponding approximately to the arc described by the finger tips. In all cases, the left key corresponded to the least intense stimulus and the right key to the most intense.

The stimulus duration was one-half sec. The response latency and the response were automatically recorded on teletype tape. At the termination of each sequence, the Ss were informed immediately as to the distribution of latencies and the approximate number of errors committed. Three or four sequences were presented during each session. The latencies were recorded in 50 msec units up to a limit of 1550 msec.

The Ss were university undergraduates, six men and six women. All had visual and auditory acuities within the "normal" ranges. None had had previous experience with similar tasks. They were paid for their services.

Results

Large, relatively constant individual differences in response latencies were noted. Because of the particular design used, resulting in but four Ss per cell, such differences could easily distort the analysis if the raw scores were simply combined. In order to eliminate the variance attributable to individual subject differences the following procedure was employed. 1) For each S, under all conditions, his median reaction time was calculated; 2) for all Ss, under all conditions,

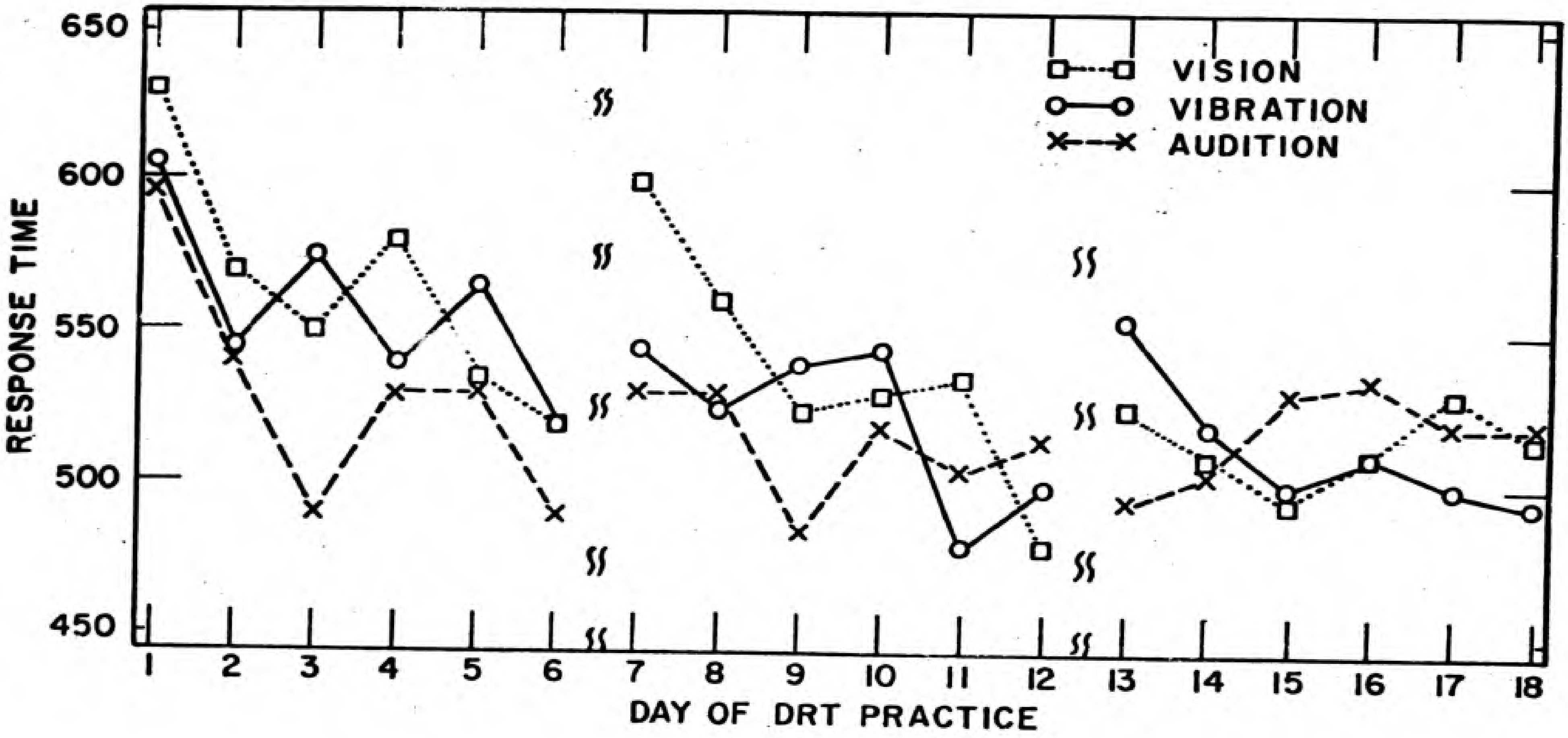

Fig. 1. Response latencies as a function of day of practice.

an overall median reaction time was calculated; and 3) each treated score of a given S was then adjusted by the difference between his median reaction time and the overall median reaction time, i.e., step 2 minus step 1.

The median response latencies with the variance attributable to individual subjects eliminated are shown graphically in Fig. 1. The abscissa represents the day of the experiment. A break mark indicates that the Ss changed modalities at this point as described in the Method section. The ordinate represents the response in msecs. Each point represents the median response time of approximately 880 responses.

The functions indicate that discriminatory reaction time in a simple discriminative situation appears to be independent of the modality after sufficient practice. This is most clearly borne out in the right-hand section of Fig. 1. Different practice rates and transfer effects are indicated however. There is evidence showing that reaction times to the auditory stimuli reach an asymptote at about the third day of practice and that transfer from one of the other modalities to audition is already at a maximum.

The practice effects and transfer effects from one modality to another are most clearly evidenced in Fig. 2 in which the scores for all three modalities are combined for each period of six experimental days.

It is indicated that little improvement can be expected after the eighth

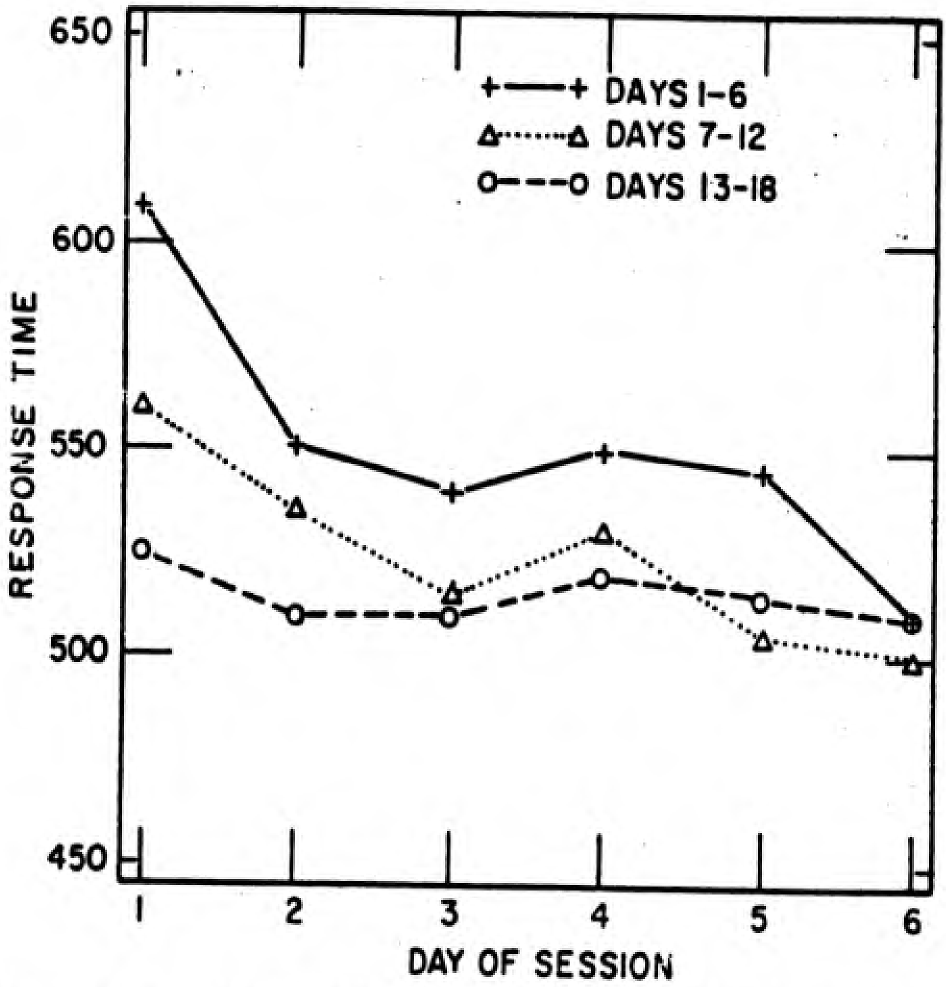

Fig. 2. Response latencies combined over modalities as a function of day of practice.

or ninth day of testing, i.e., after the second or third day of the second session. The transfer effects after the sixth day are greater than 50 percent of the range. Between the 12th and 13th days transfer is nearly complete.

Figure 3 represents the latency scores for each modality combined over sessions.

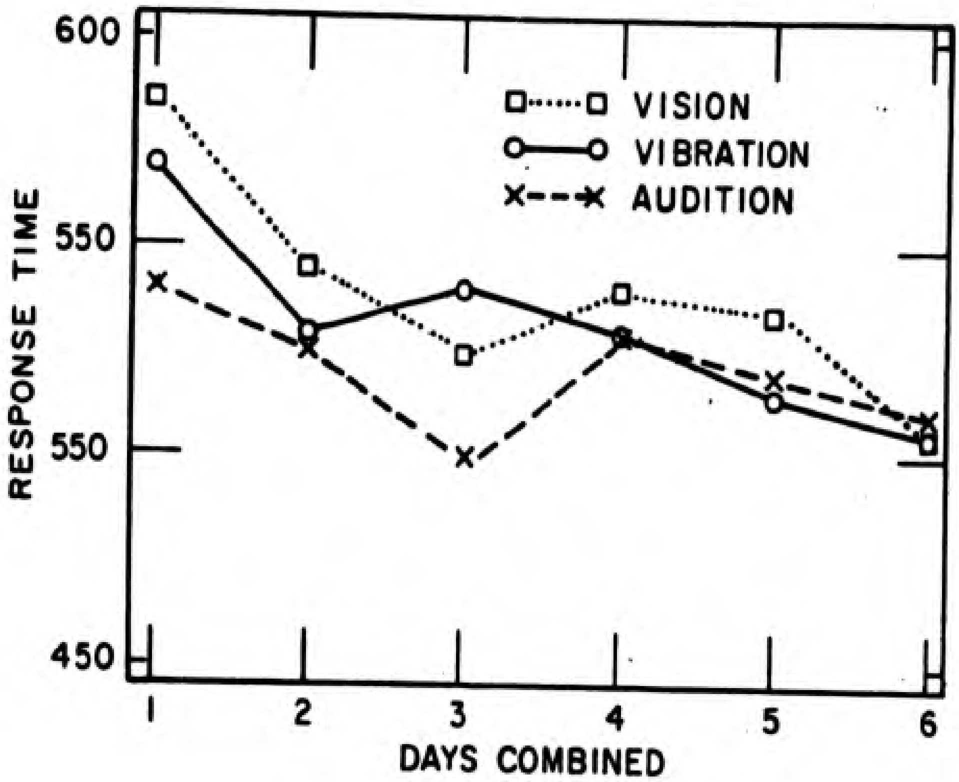

Fig. 3. Response latencies for each modality combined over sessions.

For example, the scores made by the four Ss who began with audition on day one were combined with the scores made by four different Ss who began audition on the seventh day, and with the remaining four Ss who began with audition on the thirteenth day, to make up the overall mean score for session 1 of Fig. 3. Days two, eight, and fourteen were combined in the same manner and plotted as "session 2" and so forth. While the curves for audition reach an asymptote somewhat earlier than the curves for the other modalities, all three curves reach approximately the same level during the latter sessions.

Table 3 is a tabulation of response frequencies and response accuracy. The numbers across the top represent the intensity of the stimulus, (1) being the stimulus of greatest intensity and (3) the least. The numbers along the side represent the response categories. Response category (none) indicates the number of occasions when no response was made to a stimulus presentation. In such cases the S did not make the discrimination in the allotted time which was 1.5 secs. Each section represents a single modality.

The percent accuracy associated with each section of the table is presented in the lower half section. It is interesting to note that even though percentage accuracy is lowest for vibration, the number of stimuli completely missed when a vibratory stimulus was presented is only a little more than half of the auditory and visual stimuli missed. This finding suggests a strong attention-demanding quality of the vibratory stimulation. The number of stimuli for which no response was made decreased systematically with an increase in intensity.

The results of an information analysis of the response accuracy data are also presented for each modality in terms of the amount of information transmitted, H(T), in bits per stimulus uncertainty. With three stimulus alternatives, the maximum stimulus uncertainty is 1.58 bits per stimulus presentation. Paralleling the lower percentage correct score, a lower information transmitted score is obtained with the vibratory stimulus values employed than with the stimuli used for the other senses.

Table 3

Stimulus-Response Relationships

Vibratory Stimuli				
Response	1	2	3	Σ
1	3879	1176	80	5135
2	1180	3479	752	5429
3	117	482	4295	4894
none	116	137	165	418
Σ	5292	5292	5292	15876

Percent accuracy 74%

No response made 03%

H(T) 0.62 bit per stimulus presentation

Auditory Stimuli				
1	4636	280	83	4999
2	381	4367	436	5184
3	48	401	4526	4975
none	227	244	247	718
Σ	5292	5292	5292	15876

Percent accuracy 85%

No response made 05%

H(T) 0.97 bit per stimulus presentation

Table 3 cont'd

Visual Stimuli

1	4690	401	76	5176
2	302	4342	1085	5729
3	61	298	3878	4237
none	239	251	253	743
$\sum$	5292	5292	5292	15876

Percent accuracy 81%

No response made 05%

H(T) 0.86 bit per stimulus presentation

Figure 4 presents the changes in response latencies as a function of the temporal position within each stimulus tape. Each point on the abscissa represents the overall median derived from a group of nine consecutive responses made to each set of nine stimuli on each tape. The first point represents the average latency of responses made to stimuli one through nine. The second point represents responses ten through eighteen, and so forth. The ordinate indicates the median reaction time in msecs.

The latencies for each modality increase somewhat as the sequences are processed. The differences among the modalities noted previously hold up fairly well during the task with only two inversions occurring. It is interesting to note that almost immediate recovery

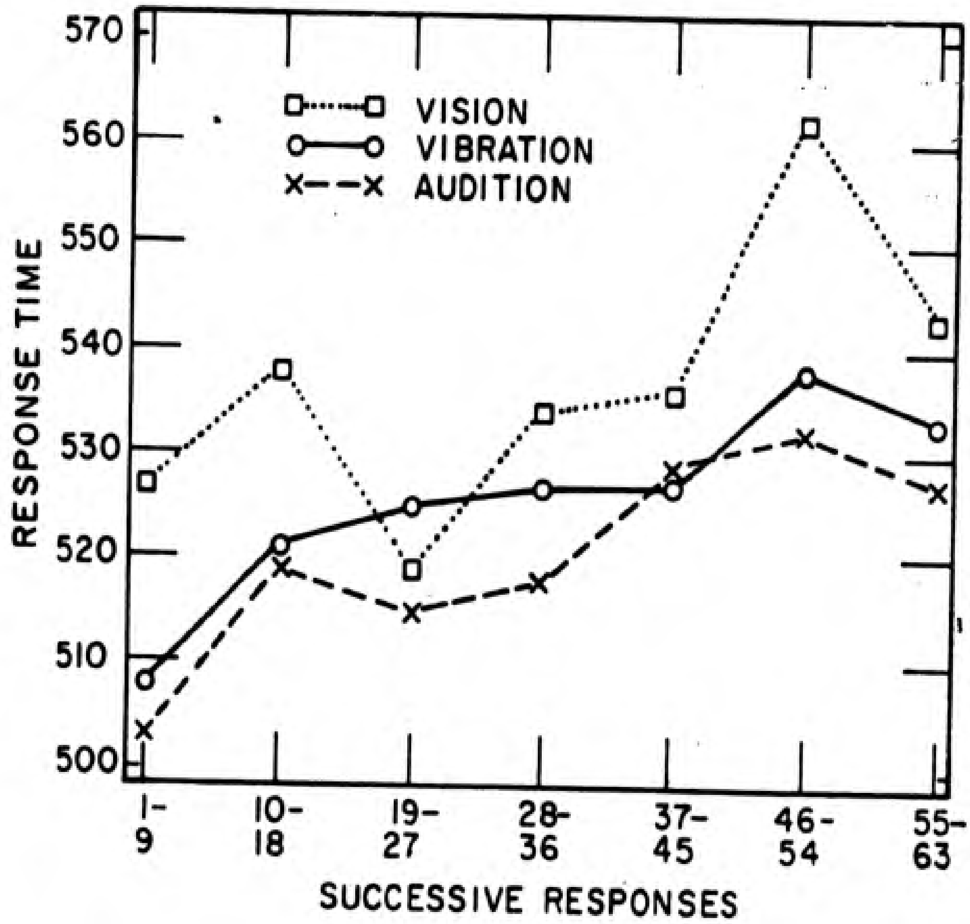

Fig. 4. Response latencies as a function of temporal position within stimulus sequence.

is shown in the latency scores when a new sequence tape is begun. There were only negligible differences between the first, second and third tapes in each series set of three tapes, except for the visual tests. For vision the latencies progressively got larger from the first to the third tapes. The number of errors, on the other hand, does not vary apparently with time during the time interval required to complete one tape.

The coefficients of correlation between the latency scores and the percent of correct responses for each response tape are shown in Table 4 for each of the three modalities. The median latency for each sequence was paired with the percentage of responses made correctly for that sequence. The N in each correlation was approximately 1300.

Table 4

Correlation Coefficients between

Latency Scores and Per cent Correct Responses

Vision	-.48
Audition	-.44
Vibration	-.40

The trend for response accuracy to decrease as the latencies decrease is apparent.

Discussion

The major interest in the research reported was to explore the potential of a vibrotactile stimulus for low information coding as compared with auditory and visual stimuli. The results demonstrate that an individual will respond to a tactual signal as delivered with about the same latency as with either of the other modalities. The response accuracy, however, was somewhat poorer with the vibrotactile signal. This, however, probably reflects an unfortunate bias attributable to the selection of the stimulus values when unlimited judgment time was allowed rather than an inability on the part of the subjects to discriminate such signals. It might also reflect a general unfamiliarity with the nature of the stimulus which certainly could be overcome with time.

Of major interest is the finding that a vibrotactile signal appears to be at least as attention-demanding as the other two types in this relatively simple situation. That is, the probability of a response being made to a vibrotactile signal is of the same magnitude as or greater than either vision or audition. The implications here are important. With the other senses highly preoccupied during the critical phases of a flight or other system operation, this result suggests that vibrotactile signals could be profitably incorporated into such systems to be used as possible warning devices or other low information messages.

Summary

A comparison of discriminative reaction latencies and accuracy to auditory, visual, and vibrotactile stimuli is reported. Response latencies were somewhat shorter for the auditory and vibrotactile signals than for the visual. Responses were made with more accuracy for both audition and vision than for vibration which simply might reflect a possible artifact of the stimulus values chosen. Of principal interest is that a vibratory stimulus appears to be at least as attention-demanding as either of the other two. This statement is based on the finding that fewer responses were missed when a vibrotactile stimulus was presented than when a visual or auditory signal was presented. The implications of this finding to operational communication systems are briefly discussed.

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