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ABSOLUTE IDENTIFICATIONS OF CUTANEOUS STIMULI VARYING IN BOTH INTENSITY LEVEL AND DURATION[1]

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INTRODUCTION

Alluisi (1) has pointed out that the amount of information transmitted in absolute discriminations will tend to be a maximum when there is (a) equal perceptual spacing of the stimuli, (b) an equal number of *S* and *R* categories, (c) immediate knowledge of results, and (d) a maximum physical range of stimulation. Inasmuch as varying the physical range will serve to limit the perceptual spacing possible with a given number of stimuli, conditions (a) and (d) above may be combined by use of the phrase "optimal spacing of the stimuli." Furthermore, variation of a parameter in the stimulus series other than that being judged can affect information transmitted (5). In addition, the experience of *O* has been shown to be of significance either with immediate knowledge of results (4) or without such feedback (5), and individual differences may be quite marked (1).

For many unidimensional absolute identifications, information transmitted (I_t) typically falls between 2.0 and 3.0 bits (10). Values less than 2.0 bits have been found for identifications of cutaneous stimuli varying in stridence[2] (subjective intensity of the tactual sensations) or in duration, even under the optimal conditions specified by Alluisi. Hawkes and Warm (7) found in the identification of electrical stridence levels, that I_t reached a maximum of about 1.7 bits when *Os* were furnished immediate knowledge of results. Although the gain in I_t produced by providing knowledge of results was not statistically significant in that study, the use of a physical range of stimulation including pain-eliciting intensity levels did yield significantly better performance than restriction of the range to lower levels. In the restricted range situations, I_t reached a maximum of only 1.4 bits. Absolute identification of electrical cutaneous stimulus duration was found by Hawkes (3) to result in I_t of up to 1.9 bits. If only stimuli of low stridence were used, however, duration identifications became

[1] Based on data recorded at the U.S. Army Medical Research Laboratory, Fort Knox, Kentucky.

[2] The word *stridence* was chosen to designate the subjective intensity of tactual sensations for the following reasons: (a) it refers in part to loudness (subjective intensity of acoustic stimulation); (b) it also refers to roughness (a tactual sensation), a word which has been used to describe auditory sensations; (c) its use has been relatively infrequent, but not rare; and (d) its sight and sound is harmonious with analogues in vision and audition, namely, brightness and loudness.

much more difficult, especially for inexperienced *Os*. In agreement with the results for identification of stridence levels, use of a relatively large physical range of stimulation resulted in significantly better performance than the use of a more restricted range. Relatively minor changes in perceptual spacing engendered by separation of the stimuli by an equal number of jnds or by equal apparent sensation magnitudes made no significant difference in information transmitted.

Many investigators have reported that far more than 3.0 bits may be transmitted if additional dimensions are used in the stimulus display. I_t with multidimensional identifications has been reported to range from approximately 3.0 bits when identifying combinations of pitch and loudness (11) to a very large number of bits when attending to speech, music, and other complex displays (2).

The present study investigated the channel capacity for multidimensional identifications of electrical cutaneous stimuli varying in both stridence and duration. Based on the reduction in efficiency found when identifying stimulus durations presented at a weak rather than a strong stridence level, particularly if inexperienced *Os* are used (5), it was predicted that performance in the multidimensional situation would not be a simple summation of I_t with these dimensions used singly. Both experienced and naive *Os* were used.

METHOD

The apparatus was essentially the same as that used previously (5). Alternating current at a frequency of 100 cps was applied to *O* through a 12-mm. diameter electrode resting on the index finger pad; a 25-mm. diameter inactive electrode rested on the palm. The intensity values of the stimuli were the same as the extended range values of Hawkes and Warm (7), i.e., intensity levels eliciting pain were included. Stimulus durations were the same as the extended range values used by Hawkes (5), 50 to 1500 msec.

Group 1 consisted of five *Os*, all of whom had participated in two different experiments involving absolute identification of electrical cutaneous stimulus duration (5). A second group of five *Os* had had no prior experience in studies involving absolute identifications. Both groups participated in all phases of the present investigation, and all *Os* were given a familiarization session in which electrical cutaneous stimuli were demonstrated in order to avoid any possible complication from the use of intensity levels eliciting pain. No emotional or other difficulities were reported.

In three sessions, identifications were made of stimulus combinations of equal numbers of stridence levels and durations (2×2, 3×3, or 4×4). An additional six sessions were devoted to identification of stimulus combinations with either more stridence levels than durations, or the reverse (2×3, 3×2, 2×4, 4×2, 3×4, 4×3). Order of presentation was counterbalanced. In order to determine whether or not errors in the 4×4 session could be due to relatively close (perceptual) spacing of the stimuli, in an additional session *Os* again identified combinations of two stridencies and two durations. In this tenth session, the stimulus values were the same as the two middle values used in the 4×4 session. In each session, *O* was given a chart showing the number of stridence levels and durations to be used in the particular session, and the code number to be used to identify appropriately each combination. All stimulus combinations used in a given session were demonstrated prior to absolute identification by *Os*.

RESULTS

Figure 1 presents mean amounts of information transmitted (I_t) for those sessions involving equal numbers of stridencies and durations. Note that none of the *Os* made errors when presented combinations of two stridence levels and two durations. Further, none of the *Os* made errors in the 2×2 session in which the stimulus values were the same as the two middle values of the 4×4 session. The data on which Figure 1 is based were tested by analysis of variance to determine the influence of Complexity (amount of information available to *O*), Experience, and the interaction of $C \times E$. Of these, only Complexity proved to be statistically significant ($P < .001$). The maximum information transmission for these sessions was nearly 3.0 bits.

Mean amounts of information transmitted in sessions that used unequal numbers of stridence levels and durations are presented in Figure 2. There appears to be a tendency for experienced *Os* to transmit more information than naive ones, and for performance to be more efficient for identifications of stimulus combinations with more durations (W_D) than levels of stridence (W_I). The data of Figures 1 and 2 are combined in Figure 3 to illustrate general trends.

The results of an analysis of variance of the data of Figure 2 are summarized in Table 1; it is apparent that both the experience of *O* and the amount of information available to *O* significantly affect I_t. The highly significant influence of the kind of stimulus combinations presented indicates that performance is more efficient for identification of duration than of stridence (see Figure 2). None of the interactions were statistically significant.

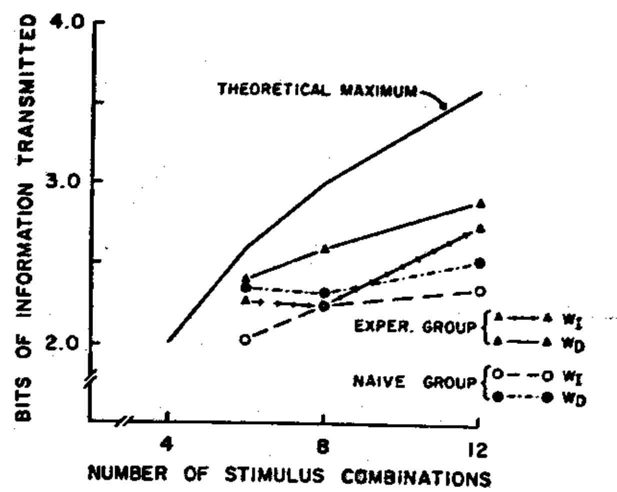

FIGURE 2. Mean information transmitted when identifying combinations with either more stimulus intensities than durations (W_I) or the reverse (W_D).

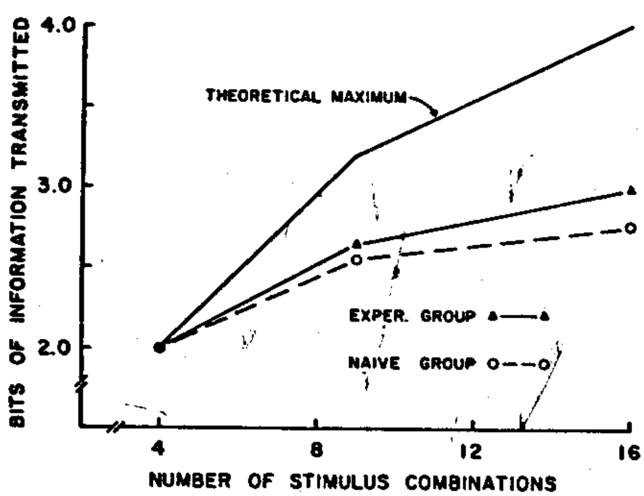

FIGURE 1. Mean information transmitted when identifying combinations with an equal number of stimulus intensities and durations.

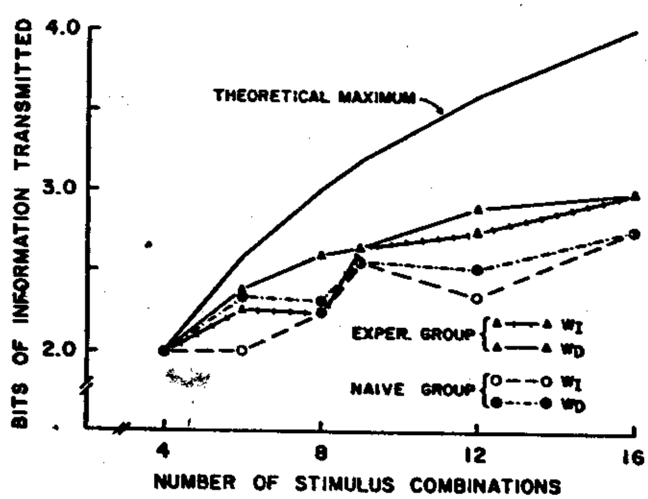

FIGURE 3. Mean information transmitted as a function of the complexity and type of stimulus display.

TABLE 1

Summary of Analysis of Variance of Information Transmitted When Identifying Stimulus Combinations Containing an Unequal Number of Durations and Stridence Levels.

Source	*df*	*MS*	*Error Term*	*F*	*P*
1. Subjects (S)	8	855.33	—	—	—
2. Complexity (C)	2	7264.27	13	36.93	.001
3. Experience (E)	1	7020.02	1	8.21	.05
4. Weighting (W)	1	5980.02	12	27.06	.001
5. C × E	2	920.47	11	—	—
6. C × W	2	59.27	10	—	—
7. E × W	1	3.75	11	—	—
8. S × C	16	155.53	10	—	—
9. S × W	8	187.13	10	—	—
10. S × C × W	16	237.93	—	—	—
11. E × C × W	2	788.60	—	—	—
Pooled Error Terms					
12. 10 + 9	24	221.00	—	—	—
13. 10 + 8	32	196.73	—	—	—

TABLE 2

Summary of Analysis of Variance of Information Transmitted When Identifying Combinations of an Equal Number of Intensities and Durations.

Source	*df*	SS	*MS*	*F*	*P*
Between Ss	9	3362.69			
Experience (E)	1	760.04	760.04		
error (b)	8	2602.65	325.33		
Within Ss	20	43662.68			
Complexity (C)	2	38968.07	19484.04	74.69	.001
C × E	2	520.46	260.23		
error (w)	16	4174.15	260.38		
Total	29	47025.37			

TABLE 3

Information Transmitted (Bits) by Each O Identifying Combinations of Equal Numbers of Stridence Levels and Durations.

Subject	*Number of Stimulus Combinations*		
	Experienced Group		
	4	9	16
1	2.00	2.65	3.26
2	2.00	2.80	3.05
3	2.00	2.45	2.75
4	2.00	2.80	2.76
5	2.00	2.49	3.01
Mean	2.00	2.64	2.97
	Naive Group		
6	2.00	2.15	2.59
7	2.00	2.70	2.92
8	2.00	2.63	2.66
9	2.00	2.43	2.98
10	2.00	2.79	2.66
Mean	2.00	2.54	2.76

TABLE 4

Information Transmitted (Bits) by Each O Identifying Combinations of an Unequal Number of Stridence Levels and Durations.

Subject	*Number of Stimulus Combinations* 6		8		12	
	W_I*	W_D**	W_I*	W_D**	W_I*	W_D**
			Experienced Group			
1	2.25	2.58	2.40	2.57	2.76	3.00
2	2.26	2.40	2.50	2.63	2.97	3.29
3	2.15	2.38	2.32	2.48	2.67	2.71
4	2.38	2.29	2.03	2.78	2.56	2.75
5	2.26	2.22	1.95	2.48	2.67	2.64
Mean	2.26	2.37	2.24	2.59	2.73	2.88
			Naive Group			
6	1.93	2.28	2.20	2.13	2.40	2.34
7	2.05	2.50	2.30	2.68	2.39	2.86
8	2.17	2.16	2.24	2.32	2.43	2.60
9	1.91	2.22	2.14	2.31	2.11	2.26
10	1.98	2.58	2.32	2.13	2.39	2.51
Mean	2.01	2.35	2.24	2.31	2.34	2.51

* More Intensities Than Durations
** More Durations Than Intensities

DISCUSSION AND CONCLUSIONS

Comparison of the results of the present study to performance measures with unidimensional stimuli indicates that information transmitted (I_t) with multidimensional cutaneous stimuli may be a little less than the simple summation of the I_t for the dimensions used singly. This is consistent with the results of other studies reviewed by Miller (10). The mean amount of I_t in the most complex display of the present investigation (a matrix of 4 stridence levels × 4 durations) was 2.97 bits for the experienced group. In previous studies of experienced groups, when *Os* were asked to identify four durations, I_t was about 1.45 bits for stimuli presented at 1.6 db (re: absolute threshold), and some 1.70 bits for stimuli at 6.0 db (5); this averages to about 1.58 bits per stimulus duration. When four stridence levels were presented for identification, I_t was about 1.60 bits when immediate knowledge of results was furnished, and 1.45 bits without such knowledge, and the difference was not statistically significant. This averages to about 1.52 bits per stimulus stridence. The simple addition of these values, then, furnishes a predicted I_t in the multidimensional situation of about 1.58

+ 1.52 or 3.10 bits per stimulus combining duration and stridence; the value of 2.97 bits found herein is just a little below this value. Some of the stimuli of the present study were of a low stridence level, and it has been demonstrated that duration identification becomes less efficient when weak stimuli are presented (5); on the basis of this, as well as Miller's general conclusion, it would not be expected that I_t with combinations of stridence and duration would equal or exceed the simple sum of average I_t values.

The significantly better performance when identifying combinations that used a larger number of durations compared to efficiency with combinations having a greater number of stridencies is of considerable interest, especially since the total possible range of stridency was used. Efficiency of performance when identifying unidimensional stridence levels is approximately equivalent to that for stimulus durations (5, 7). In those studies, stimulus separation along these two dimensions was not greatly divergent in terms of number of just noticeable differences (jnds), and it has been found that changes in stimulus separation on the order of a jnd do not affect I_t (see 5). It cannot be concluded, however, that these two dimensions are fully interchangeable on the basis of the apparent simple summation of I_t when these two dimensions are combined, as discussed in the preceding paragraph. This number of jnds for stridence (about 26 or so according to Hawkes (6) is perhaps quite limited when compared to the possible jnds for duration (cf. 8), where a vastly greater physical range of stimulation may be used.

It is suggested that when *Os* are identifying combinations with opportunity for a choice in attention between duration and stridence, detection of duration is easier and thus becomes the preferred dimension. Békésy (3) has reported that there is a variation in apparent area of cutaneous sensations as stimulus intensity is changed. Further, some of the intensity levels of the present study elicited sensations of pain plus tingle, and others only tingle. It is possible that some of these sensational variations may have affected identifications in the present experiment, with the variations being more closely correlated with stridence than duration. McGrath (9) has reported that when attention sharing is required between two modalities in a vigilance task, detection of easy signals improves while detection of difficult signals is unaffected or declines. A similar mechanism might be operative when *Os* are asked to identify cutaneous stimulus combinations with an unequal number of stridence levels and durations.

Békésy also has pointed out many similarities between the operation of the auditory and cutaneous nervous systems. Note in this connection that although I_t for identifications of unidimensional stridencies or durations is less than comparable performance with acoustical stimuli, efficiency with stridence-duration combinations appears to be about the same as reported by Pollack (11) for identifications of patterns of pitch and loudness, about 3.0 bits. In spite of (or perhaps because of) the relatively primitive state of development of the cutaneous nervous system, in some situations it may be about as efficient as the auditory apparatus.

This study indicates that the *kind* of stimulus display used (in this case, use of more durations than stridence levels in the combinations presented) can significantly increase the amount of I_t. A previous study (5) indicated that the perceived stridence can affect I_t with duration identifications. In previous studies of cutaneous identifications, neither immediate knowledge of results nor relatively minor changes in stimulus spacing significantly affected transmission of information, whereas relatively gross changes in stimulus spacing resulting from manipulation of the physical range of stimulation did significantly affect channel capacity.

In addition to the conditions specified by Alluisi (1) as influencing channel capacity in a particular study, it may be concluded that experience in tasks of similar nature will have a significant effect both in multi-dimensional (as in the present study) and undimensional absolute identifications (4, 5).

SUMMARY

The number of possible absolute identifications of electrical cutaneous stimuli varying in both stridence and duration was investigated for both experienced and naive *Os*. In some sessions, an equal number of stridencies and durations were used; in others there were more stridence levels than durations or the reverse.

Maximum transmission of information was with combinations of four stridence levels and four durations. The channel capacity was about 2.97 bits for the experienced *Os* and 2.76 bits for the naive ones. Experience was not a statistically significant factor when an equal number of durations and stridence levels were used. In sesssions with unequal numbers of durations or stridencies, experienced *Os* transmitted significantly more information and both groups were more efficient when identifying combinations with more durations than stridence levels.

Experienced *Os* identifying stimuli varying in stridence or duration under conditions comparable to those of the present study have been reported to transmit about 1.45 to 1.7 bits in each of these (unidimensional) situations. The value of 2.97 bits of this study was just a little less than the simple sum of the performances obtained with the dimensions used singly, but it was also apparent that the dimensions are not fully interchangeable.

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