Stimulus contrast in tactile resolution¹

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This experiment was designed to test the influence of contrast on tactile resolution by the use of different modes of distribution of pressure stimuli, with control of various factors such as intensity, area, rate, and time of application. The experimental task was two-point discrimination. The results showed that the use of annular stimuli result in a significantly higher number of resolutions than the use of circular stimuli, the intensity, total stimulating area, and pressure being controlled. The proposed interpretation of the results is that increase of stimulus contrast increases the resolving power of the somesthetic system.

The nature of the adequate stimulus for tactile sensitivity remains a controversial issue. Several theories have been proposed to define the stimulus, the earliest one probably being that of Meissner (1859), who suggested that tactile sensitivity depends on the contrast between stimulated and adjacent unstimulated area, and not on the stimulus per se. While Meissner derived his theory from introspective analysis, von Frey and Kiesow (1899), who used absolute threshold measurements, concluded that tension is the basic determinant of the sensitivity of the skin to mechanical stimuli. Holway and Crozier (1937) came to a different conclusion through the use of the differential threshold technique, by finding linear relations between pressure (and not tension) and tactile sensitivity. Unfortunately, the use of discrete additions of the stimulus force by von Frey and Kiesow vs a continuous addition of it by the latter authors does not permit a direct comparison of their opposing results. This point was stressed by Jenkins and Stone (1941) and is highlighted by numerous investigations which demonstrated the influence of the rate of application of the stimulus on the threshold (Grindley 1934 a,b; Wolf, 1937) and by the psychophysical and physiological experiments of Nafe and Wagoner (1941) and Nafe and Kenshalo (1958) who found pressure perception and cutaneous nerve activity only during progressive mechanical deformation.

In spite of the fact that the three above-mentioned theories differ, they have in common an attempt to correlate the areal distribution of the mechanical stimulus with its perception. These theories were formulated on the basis of psychophysical observations alone without consideration of the neurophysiological events in the receptors. Recently an attempt has been made by Ratliff and Hartline (1959) to investigate the effect of concomitant stimulation of several receptor units on the areal distribution of

the intensity of the local response. In a set of experiments done on the compound eye of the *Limulus* they have found that neighboring receptors exert inhibition on each other. This inhibition is an inverse function of the distance between the receptors and a direct function of the intensity of the stimulation applied to the inhibiting receptor. Ratliff and Hartline inferred that a similar state of affairs holds for a sensory organ endowed with more complex connections between the receptors, such as the vertebrate eye. For example, if a limited area of the eye is under uniform illumination, the amount of excitation in this area will not be uniform. The inner receptors in the area will be subjected to more inhibition than the peripheral ones due to the geometrical arrangement. Thus the effect of the stimulation will be maximal in periphery of the area, accounting for the apparent brightness of the edges. Moreover, since the inhibition in the surround is maximal around the edges, the resulting contrast will be enhanced ever further at this point, contributing to the apparent brightness of the edges.

The possibility of the existence of an analogous situation of spatial interaction of inhibition and excitation on the receptor level of the somatosensory system had been suggested by Yai (1959) and von Békésy (1959). Békésy (1960) elaborated the problem by postulating from psychophysical experiments a neural funneling unit model common to the eye and the skin senses which could explain spatial contrast phenomena. The model is based on the assumption that around the area of sensation there is a refractory area, and that the sensation magnitude is the result of the interaction of these areas. The model is in accord with the observations of Ratliff and Hartline on single receptors (Bliss & Macurdy, 1961). However, in the experimental demonstration of the model, both the sensation area and the refractory area involved many receptors. The demonstration of these areas on the skin makes them the psychophysical equivalents of the receptive field found in the somatosensory cortex by Mountcastle (1957).

In the psychophysical experiment, the neurophysiological mechanisms cannot be demonstrated directly because of complex stimulus-response relations. They can, however, be demonstrated indirectly by modifications of the stimulus arrangement which will correlate with a modification in the response in a way which will fit the neurophysiological concept. Comparisons can be made between responses to stimulation under alternative conditions where the interaction

of excitation and inhibition in the tested area is maximized or minimized, by changing the distribution of the stimulus. According to the Ratliff-Hartline model, annular stimulation should be discriminated better than circular stimulation of the same intensity due to the better contrast produced by the annular stimulus. The effect is two-fold: first, the stimulus gradient at the border of the area will be increased by the concentration of the intensity at the borders and by more inhibition of the surround; second, a further increase in the gradient is expected because of lack of inhibition from the center on the borders. The positive results of such a study might also support the hypothesis that tension, and not pressure, is the crucial determinant of tactile perception of pressure.

Method

The discrimination task selected in the present study was the two-point tactile threshold. This task possesses the advantage that it is simple and does not necessarily require the subject to make subtle comparisons between stimuli. Moreover, this task provides an experimental model which corresponds to that discussed above.

Subjects. Six university students were used in this experiment. All of them were in good health (by self-report) and had intact somatosensory mechanisms (as judged by routine neurological examination). Each of the Ss had had six previous training sessions with the task of two-point discrimination. The first four sessions were carried out with the aid of the conventional manual compass, while in the last two sessions the apparatus designed for this experiment was utilized.

Apparatus. An electromechanical stimulator (Carmon & Dyson, 1967), providing for control of pressure, duration, and locus of application of two simultaneously presented tactile stimuli, was used. The stimuli were the flat tips of stainless steel rods. Each rod had a length of 2.63 in. and had two small shoulders projecting horizontally 1/2 in. from one end. The rods were supported by 1 in. long nylon

Table 1. The geometrical and the physical properties of the stimuli.

SERIES	NO.	GEOMETRICAL FORM OF STIMULATING SURFACE	DIAMETER (inches)	AREA (sq. in)	WEIGHT (grams)	PRESSURE (gm/sq. in)
A	1	Circular	10/64	0.019	3.680	192
	2	Annular	10/64 (6/64)*	0.012	3.680	300
	3	Circular	8/64	0.012	3.680	300
	4	Circular	10/64	0.019	5.750	300
B	1	Circular	15/64	0.043	9.450	219
	2	Annular	15/64 (9/64)*	0.028	9.450	342
	3	Circular	12/64	0.028	9.450	342
	4	Circular	15/64	0.043	14.800	342

* Internal Diameter

sleeves which were attached to a scissor-like device (Fig. 1). The distance between the tips of the two rods was controlled by a calibrated scale on the opposite side of the scissors. The center pivot of the scissors was attached to the center of the plunger of an electromagnet of 5 lbs lifting capacity. Power supply to the electromagnet was in series by 115V rectifier. A 124 Hunter interval timer was connected in parallel to the power supply. A vertically adjusted base was directly beneath the electromagnet, which was mounted on horizontally moving rails. A large curtain in front of the apparatus obstructed the S's view of the apparatus and the face of the E.

Eight pairs of rods were used, four in each of two series. In each series there were three pairs of rods with tips of the same external diameter. Two of those had flat surfaces, while the third had an annular surface. The fourth pair had a smaller flat surface which was equal to the surface of the annular tips. The weight of the annular tipped rods, those with the smaller flat surface, and one of the equidiametric flat tip rod were the same. The other pair of rods with a larger flat surface had the same

Fig. 1. The scissor-like device of the apparatus.

Fig. 2. Close-up of the stimulating rods before stimulation.

weight per unit area as the rods with the annular surface. The geometrical and weight relationships in the two series are presented in Table 1.

Experimental Procedure. Two experimental sessions with each series of stimulators were conducted. The method of constant stimuli was used to determine the number of two-point resolutions. Twenty four stimulations for each pair of stimulators, in distances varying from 1 to 12 mm in a random order, in 1 mm steps, 12 to each hand, were given twice in each session. The ABCDDCBA order was utilized for counterbalancing the order of the different stimulators in each series. Stimulation of the right and left hands was counterbalanced in the ABBA order.

In each session S was seated opposite E and inserted his hand, with the palm up, through the curtain and rested it on the vertical moving base. The E moved the base upward until the desired area for stimulation on the palm was 1-2 mm beneath the stimulating tips (Fig. 2). Horizontal adjustments were made by manipulation of the horizontally moving supporting rails and by rotatory movement of the central pivot of the scissors. By activating the time interval generator, the current to the electromagnet was interrupted and the plunger descended for 1/4 in. The stimulating rods remained supported by the palm in the sleeves while their weight was pressing the area selected for stimulation (Fig. 3).

The area chosen for stimulation was on the palm, and was kept constant by using selected landmarks of the palms as limiting boundaries. The stimuli were applied in a transverse plane parallel to the second horizontal fold of the palm. Duration of each stimulation was 1 sec. The stimuli were presented in rapid succession with a space of 5 sec between them in each set of 24 stimuli.

Each session of approximately 1 h duration consisted of 202 stimulations; thus each S received a total of 808 stimulations over the experiment. No control stimulations (i.e., one-point stimuli) were included in the program. This decision was based on the consideration that the primary data were derived from "within"

Fig. 3. Close-up of the stimulating rods during stimulation.

Fig. 4. Percentage tactile resolution as a function of the inter-stimulus distance. Data for the four types of stimulators of series A (cf. Table 1).

comparisons in a treatment by Ss design. Thus, it could be assumed that any bias toward false positive responses on the part of the S would affect responses to different types of stimulator to an equal degree and hence have no influence on the comparisons among stimuli.

Results

The number of resolutions per fixed scale of distances between the two stimulators was utilized as an index of sensitivity. The percentages of combined resolutions for the six Ss along the scale of distances are given in Fig. 4 for Series A and in Fig. 5 for Series B.

The number of resolutions reported with the annular pairs of stimuli was greater than the number of resolutions for any of the other pairs in the case of every S in both series. This was found in 21 out of 24 comparisons by Ss, hands and replications. Analysis of variance was done in a three factor repeated measurements design. Comparison of the number of resolutions achieved with the annular pairs with the number of resolutions achieved with the other pairs showed the difference in favor of the annular pairs to be significant at the .001 confidence level ($F=340.756$, $df=1/5$). Both interactions of this comparison between the two series and between the two hands were not significant ($F=0.552$, $df=1/5$, and $F=3.192$, $df=1/5$, respectively).

There were also more resolutions with the heavier than with the lighter circular stimuli in 14 out of 24 comparisons across hands and replication in series. The effect of intensity (weight) was significant in the analysis of variance at the .05 level ($F=7.673$, $df=1/5$).

Discussion

The results show that a higher percentage of resolutions was achieved when a fixed intensity of a stimulus was transmitted to the border of a fixed area than when the same intensity was distributed

Fig. 5. Percentage tactile resolution as a function of the inter-stimulus distance. Data for the four types of stimulators of series B (cf. Table 1).

over the whole area. Furthermore, in the present arrangement the borderline (annular) stimulation proved to be more efficient, as determined by the number of resolutions, than when stimuli with equal pressure (intensity per area) were transmitted to the total area. When the borderline application was compared with stimulation of equally stimulated area (but with smaller diameter) by the same intensity, again the annular stimulus was shown to be resolved with significantly higher frequency. Thus, the data show that stimulation of the border of an area is more efficient for resolution than stimulation of the total surface of such an area.

Two effects are achieved by this arrangement. First, the sensation gradient on the border of the stimulated area is increased. Second, the mutual inhibition within the stimulated area is decreased, since this type of distribution disperses the components of stimulation of such an area. Alpern and David (1959) have demonstrated a similar mechanism in vision. By using different combinations of inhibiting light stimuli, they showed that the sum of the inhibitions of these lights is greater than the inhibition produced by the sum on the spatial dimension of those lights. The present experiment presents a similar situation. Here also a compact stimulating area is divided, and the components are arranged adjacently in a circle. If we regard the resolution to be also a function of the surround inhibition (i.e., inhibition of the interstimulus area), then the results are in agreement with the findings of Alpern and David. Further indirect support for the present findings is derived from the results of Jenkins (1938) who investigated the effect of configuration of the stimulated area on thermal sensitivity and who found that with annular configuration of the same area. Verrillo (1962) found lower vibratory thresholds with an annular contact surface of the vibrator than with a circular contact surface.

Returning to the original observation of Meissner (1859) that contrast determines discrimination, the results of the present study provides experimental

support for this. Although no direct answer is provided with respect to the controversy about the dependence of tactile discrimination and sensitivity on tension as compared to pressure, some indirect evidence from the present study supports the first idea, namely, that tactile sensitivity and discrimination are related more closely to tension than to pressure. By changing the distribution of the stimulus from a circular to an annular configuration, while keeping the overall diameter of the stimulated area constant, tension is increased as well as pressure, and this resulted in a higher number of resolutions. On the other hand, increase of the pressure alone, by the use of heavier stimulators with the same diameter, did not improve the resolution to the same extent. Thus it would seem to be the increase in tension which is more responsible for the increase in resolving power. However, since still another variable, i.e., total intensity, was also changed in this situation, this finding permits only a tentative conclusion. The use of the two-point resolution task prevents a direct comparison with the Holway and Crozier study in which a differential threshold task was employed. However, it is still possible to make inferences about the basic mechanisms involved in tactile discrimination since these mechanisms can be approached from different directions.

Békésy (1959) suggested that a sharply localized stimulus will create around itself an area of summation. If the presently used stimulators are regarded as sharply localized, no difference in the responses to the various types of stimulators used should be found, as they were of the same intensity (except A₄ and B₄; cf. Table 1). The findings of the present study do not support von Békésy's hypothesis (which could be considered to be tenable by retaining the null hypothesis in this experiment) but rather point to mutual interactions by summation and inhibition within a stimulated area, in accordance with neurophysiological and psychophysiological data in other sensory systems.

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Notes

1. Adapted from an M.A. Thesis, Department of Psychology, University of Iowa. This investigation was supported by Research Grant NB-00616 and Program-Project Grant NB-03554 from the National Institute of Neurological Diseases and Blindness. The author is indebted to Prof. A. L. Benton, Departments of Psychology and Neurology, University of Iowa, for his valuable guidance and advice.
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(Accepted for publication December 1, 1967.)