OBSERVATIONS ON THE REACTION TIME TO CUTANEOUS THERMAL STIMULI

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The determination of the reaction time to a tactile stimulus is a standard exercise in the practical physiology class, but the student does not always realize just how little weight can be attached to the figures he obtains. Lele, Sinclair, and Weddell (1954) have stressed the great variability of measurements made under different conditions. For example, with a constant force, statistically significant differences occur between corresponding test sites in different subjects and between different test sites in the same subject. Conversely, significant differences in the figures obtained from a given site can be produced by altering the force. The present investigation was undertaken to find out whether a similar variability characterized the reaction times derived from contact thermal stimuli.

PROCEDURE

A copper cylinder with a circular tip 12.5 mm. in diameter was brought to the selected temperature by heating it electrically or by placing it in contact with ice. The temperature of the tip was measured by a thermocouple correct to $\pm 0.25^\circ$ C., and the temperature of the skin was taken with similar accuracy by a freely suspended thermoelectric junction of copper-constantan wire (Lele, 1954). When the instrument was applied, the stimulator tip made contact with a single strand of 40 s.w.g. copper wire laid on the skin just outside the test area, thereby closing a trigger circuit which started an electronic millisecond timer. A key operated by the subject stopped the timer, from which the reaction time could be read off directly. The results are

given in the Tables to the second place of decimals, though the third place was used in calculations.

Five subjects with no experience of sensory tests involving thermal stimuli were used, and on the left hand of each subject one or more test sites were stamped out with ink (Fig. 1). At each session the first step was to allow the skin temperature of the test site to come to equilibrium in a draught-proof room, and the next was to determine the sensory thresholds to cold and warm in the manner described by Lele (1954); as soon as these had been found reaction time measurements were started, the interval between two successive stimuli being varied randomly between two and six minutes. The subject was told that the stimulus might be warm, cool or thermally neutral, and that he was to press the key as soon as he could tell which it was, simultaneously stating his decision. The order in which different stimulus intensities were applied was made up beforehand, using a table of random numbers, and the stimulator was allowed to remain in position for 20 seconds unless the subject made his decision earlier. Readings

FIG. 1.—Position of test sites on the hand.

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in which the subject named the stimulus incorrectly were neglected, and the stimulus was repeated later in the series. Similarly, the subject was asked to report immediately if for any reason he felt that he had not responded properly, and the reading in such instances was also discarded. Stimulation was continued until for each stimulus intensity 10 admissible readings of the reaction time were obtained. If the subject felt tired or unable to concentrate, the session was terminated; no comparisons were made between different sets of reaction times unless they were obtained in a random sequence in the same session under identical conditions. Such comparisons were made by applying the *t* test to the logarithms of the reaction times, the 5% level of probability being selected as significant.

Throughout the investigation stimulus intensities were measured in terms of the observed threshold of the test site, and comparisons between different test areas were made using the appropriate threshold stimulus in each area.

OBSERVATIONS

Site Constant

Reproducibility.—When a constant stimulus was repeatedly applied to the same area, the individual reaction time values showed a scatter round the mean which varied considerably in different subjects. This scatter was greatest the more nearly the stimulus intensity approached the threshold, and became less as the intensity of the stimulus increased. In each of the five subjects an analysis was made of 20 readings derived from a constant stimulus applied to the same site. In none could any statistically significant difference be found between the mean of the first 10 readings and the mean of the second 10. There thus did not appear to be any systematic learning effect which might interfere with the validity of comparisons made at the same sitting. No attempt was made to study any more gradual training changes.

In each of two subjects mean reaction times were obtained for threshold warm and cold stimuli in a given site. On the succeeding day the reaction times

were again determined and the results compared (Table I). It was found that statistically significant differences in the reaction times to both warm and cold can occur from one day to another. The times obtained on the second day were not necessarily smaller than those of the first, as might have been expected if the effect were due to learning.

Influence of Stimulus Intensity.—In each subject several different stimulus intensities were applied to a selected site in the course of one session. One of these corresponded to the threshold value for cold and one to the warm threshold figure. Four were arbitrarily chosen suprathreshold stimuli, two being warm and two cold, and the remainder were thermally neutral stimuli inserted as controls. The stimuli were applied in a previously determined random order, and 10 readings for each thermally effective stimulus were obtained. The results are shown in Tables II and III. In each subject the mean reaction time to the strongest stimulus is significantly shorter than the mean reaction time to the weakest stimulus. The mean reaction time to the intermediate stimulus always occupies an intermediate position, and differs significantly from both the others throughout the data relating to cold. With warm stimuli the intermediate stimulus gave results significantly different from the others in seven instances out of 10. Many subjects remarked that the stronger stimuli appeared to have a "sharper onset" than the weaker ones, and that cold stimuli had a more easily recognizable onset than warm. When the mean reaction times were plotted against the logarithms of the intensity of the stimuli an approximately linear relationship was obtained in three of the five subjects for both warm and cold stimuli. No relationship could be worked out in the remaining two subjects because of the considerable differences in the variances of the figures obtained at threshold and suprathreshold levels.

TABLE I
REPRODUCIBILITY

Subject	Day	Site	Skin Temperature (°C.)	Threshold * (°C.)	Mean Reaction Time (sec.) †	Significance of Difference
<i>Warm Stimuli</i>						
W. T. 	1	A	32	+ 2	1.52 } 1.40 }	—
	2	A	31	+ 2		
L. P. 	1	B	31	+ 1.5	0.46 } 0.52 }	P < 0.05
	2	B	29	+ 1.5		
<i>Cold Stimuli</i>						
W. T. 	1	A	32	— 2	1.99 } 2.40 }	P < 0.05
	2	A	31	— 2		
L. P. 	1	B	31	— 2.5	0.54 } 0.59 }	P < 0.05
	2	B	29	— 2.5		

* Measured from the observed skin temperature. † Each mean is derived from 10 observations.

TABLE II

INFLUENCE OF STIMULUS INTENSITY: WARM STIMULI

Site	Subject	Stimulus Intensity (°C. above Skin Temperature)	Reaction Time in Sec. (Mean of 10 Observations)	Standard Deviation
A	W. T.	2 (threshold)	1.52	±0.23
		4	0.98	±0.07
		18	0.73	±0.03
	J. G.	1 (threshold)	0.74	±0.06
		4	0.65	±0.05
		18	0.54	±0.03
B	R. J.	1 (threshold)	2.14	±0.30
		5	1.35	±0.15
		10	1.27	±0.08
	L. P.	2 (threshold)	0.46	±0.03
		5	0.40	±0.01
		10	0.36	±0.01
C	D. T.	1 (threshold)	0.78	±0.05
		2	0.62	±0.03
		4	0.53	±0.02

Comparison of Cold and Warm.—In three of the subjects the thresholds for cold and warm were equally spaced on either side of the skin temperature, and it was thought legitimate to attempt to compare the effects of "thermally equivalent" warm and cold stimuli in these subjects, i.e., pairs of stimuli whose temperature was equidistant from the skin temperature. The results of this comparison are shown in Table IV. In one subject no statistically significant differences could be demonstrated between cold and warm reaction times, but in the other two the warm times were invariably significantly smaller than the cold times.

Site Variable

Comparison of Different Sites in Same Subject.—In three subjects the finger site B was compared with the hypothenar site A, using threshold stimuli for each site. Table V shows a tendency for the thresholds for both cold and warm stimuli to be higher on the finger, but no general trend among the reaction times. The only significant difference

TABLE IV

COMPARISON OF REACTION TIMES TO COLD AND WARM

Subject	Stimulus Intensity*	Reaction Time (Mean of 10 Values in Seconds)		Significance of Difference
		Warm	Cold	
J. G.	+1 -1	0.74	0.82	p<0.01
	+4 -4	0.68	0.72	p<0.01
	+18 -18	0.54	0.66	p<0.001
W. T.	+2 -2	1.52	1.99	—
	+4 -4	0.98	0.94	—
	+18 -18	0.73	0.52	—
D. T.	+1 -1	0.78	1.21	p<0.02
	+2 -2	0.62	0.71	p<0.05
	+4 -4	0.53	0.63	p<0.01

* The stimulus intensity is measured in °C. from the skin temperature.

TABLE III

INFLUENCE OF STIMULUS INTENSITY: COLD STIMULI

Site	Subject	Stimulus Intensity (°C. below Skin Temperature)	Reaction Time in Sec. (Mean of 10 Observations)	Standard Deviation
A	W. T.	2 (threshold)	1.99	±0.26
		4	0.94	±0.14
		18	0.52	±0.03
	J. G.	1 (threshold)	0.82	±0.05
		4	0.72	±0.03
		18	0.66	±0.03
B	R. J.	3 (threshold)	1.52	±0.16
		5	1.42	±0.18
		10	1.02	±0.06
	L. P.	3 (threshold)	0.54	±0.14
		6	0.44	±0.17
		12	0.36	±0.01
C	D. T.	1 (threshold)	1.21	±0.20
		2	0.71	±0.03
		4	0.63	±0.01

was that in subject W.T. threshold cold stimuli gave longer times from the finger than from the hypothenar eminence.

Comparison of Similar Sites in Different Subjects.—Wide differences were sometimes observed. A threshold warm stimulus applied to the finger test site produced in one subject a mean reaction time of 0.46 seconds, and in another a mean time of 2.14 seconds (Table II). Similarly, the response to threshold cold stimulus on the hypothenar site took 0.82 seconds in one subject and 1.99 in another (Table III). Both these differences are statistically significant.

DISCUSSION

Evidently the reaction time to touch is not unique in its capacity to vary grossly with the experimental conditions, for we have shown that alterations in the intensity of the stimulus can cause statistically significant alterations in the reaction times to both cold and warm stimuli. We have also found that, when comparisons are based on threshold stimu-

TABLE V

COMPARISON OF REACTION TIMES DERIVED FROM DIFFERENT SITES

Subject	Site A		Site B	
	Threshold	Reaction Time	Threshold	Reaction Time
<i>Warm Stimuli</i>				
R. J. ..	+3	2.20	+1	2.14
W. T. ..	+2	1.52	+4	1.60
L. P. ..	+1	0.51	+2	0.46
<i>Cold Stimuli</i>				
R. J. ..	-1	1.48	-3	1.52
W. T. ..	-2	1.99	-4	3.32
L. P. ..	-2	0.59	-3	0.54

The thresholds are given in °C. above or below skin temperature; the reaction times are the mean of 10 readings in seconds.

lation, the reaction time at a given site need not be constant from day to day, that the reaction time to stimulation of the corresponding site in different individuals can vary significantly, and that the reaction times to cold stimuli can vary significantly from one test site to another in the same subject. The use of threshold stimuli for such comparisons requires some comment.

When stimuli of gradually increasing temperature are applied to the skin, they are at first appreciated as cold, then thermally neutral, then warm, and finally painful. At either end of the thermally neutral zone lie the thresholds for warm and cold. Now Lele (1954) has shown that the position of this neutral zone on the thermometric scale varies fairly closely with the skin temperature of the test area, which may fluctuate from time to time and from place to place. Cold and warm thresholds, measured in terms of a fixed temperature scale, are thus extremely labile, and a stimulus of a given temperature applied to a given area might be perceived as cold, neutral or warm according to the local condition of the skin. On the other hand, thresholds measured in terms of the skin temperature remain more or less constant over a wide range of temperatures (Lele, 1954). Now at threshold intensity we may conceive that the obstacles lying between the stimulus and the end-organs which it is to activate have been overcome, and enough energy has arrived at the nerve terminals to arouse a propagated disturbance of a kind which will be interpreted on arrival at the brain as a thermal sensation. Further increases in the amount of energy arriving will be interpreted as increases in the intensity of the sensation, and the threshold is thus the logical zero point for any scale of measurement of intensity of either sensation or stimulus. Exactly the same considerations apply to stimuli involving other modalities. It is probable that the tactile threshold, for example, varies with the local conditions, and so we are not justified in comparing results obtained in different areas or at different times by the use of stimuli measured in absolute and not in relative terms. Little attention has been paid to such matters in the past, and perhaps some of the numerous discrepancies in work on skin sensation stem from this cause.

In the present investigation the cold and warm thresholds were usually spaced equidistant from the skin temperature, and measurements of stimulus intensity are given in degrees measured from the skin temperature. Where the thresholds are equivalent we may tentatively assume that suprathreshold stimuli equidistant from the thresholds are also equivalent, and so compare the reaction times to

cold and warm. Such evidence as we have suggests that under these experimental conditions there is a tendency for the reaction time to a warm stimulus to be shorter than the reaction time to a cold stimulus of equivalent intensity. This is in contrast to the findings of Jenkins (1938) under different experimental conditions.

The variability of the reaction time to thermal stimuli has not received much attention in the literature. Bazett, McGlone, Williams, and Lufkin (1932) used reaction time measurements to determine the depth from the skin surface of the receptors for warm and cold, but the assumptions made in their calculations must now be considered unwarranted. In 1937 Hardy and Oppel noticed that the threshold for warm depends on the area of the stimulus, and in 1938 Jenkins found that the reaction time to warm is affected by stimulator size, though curiously he did not observe any such effect with cold stimuli. Lele (1954) has shown that both warm and cold thresholds vary according to stimulus size, and this may be correlated with the work of Wright (1951) who found that the reaction time to a radiant heat stimulus varies with the size of the stimulus. Wright (1951) also showed that for radiant heat the reaction time depends on the intensity of the stimulus, and both these findings have since been confirmed by Lele, Weddell, and Williams, (1954).

Perhaps the most important implication of our present extension of these investigations is that thermal reaction times are so dependent upon experimental conditions as to make it unjustifiable to use them to allocate specific conduction velocities to thermal sensations. The same has already been demonstrated for touch sensibility (Lele, Sinclair, and Weddell, 1954) and is probably also true for painful sensations. Reaction time measurements have in the past provided one basis for the idea that specific sensory modalities are carried in specific ranges of fibre sizes to the central nervous system, and that the "pain fibre" is distinguishable from the "touch fibre" by its size. It is true that the thermal reaction times we have reported in this paper are in general somewhat longer than the touch reaction times we reported elsewhere (Lele, Sinclair, and Weddell, 1954), but this cannot be taken to mean that thermal sensations are in general carried in smaller and more slowly conducting sensory fibres. The reaction time is the sum of many smaller times; the time taken for initiating conduction, for conduction itself, for perception and judgment, for synaptic crossings, and for traversing the efferent pathway (Michon, 1939; Monjé, 1934). Only if it is assumed that the conduction time alone is variable can any estimate of the conduction velocity be made, and this

assumption we have no right to make. Indeed, for touch stimuli it has been shown clearly to be false (Lele, Sinclair, and Weddell, 1954).

SUMMARY

Reaction times in response to warm and cold contact stimuli can be shown to vary according to the intensity of the stimulus.

It is desirable, and for thermal stimuli essential, to express stimulus intensities by measuring them from the threshold intensity and not from an absolute zero. Only in this way can legitimate comparisons between different areas, different sessions, and different subjects be drawn.

Using threshold warm and cold stimuli it can be shown that thermal reaction times may vary from

day to day, from site to site, and from subject to subject.

It is not legitimate to use thermal reaction times to derive figures purporting to represent conduction velocities for thermal sensations.

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