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Detection of tactile pulses*

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ROC curves were obtained by the rating-scale method for the detection of brief mechanical pulses presented to the finger and dorsal forearm to study differences in detection processes at the two sites. An adaptive psychophysical procedure was successful in equating detectability at the two sites when data were averaged across sessions. Criteria adopted by the Os appeared to depend on locus of stimulation, since fewer false alarms were given at the arm than at the finger. These findings were discussed with respect to continuous and multistate detection models.

The properties of the somatosensory system can be studied with both electrical and mechanical pulses applied to the skin. Evidence from psychophysical experiments (Rollman, 1969a, 1973) supports the suggestion that the first type of stimulus bypasses the cutaneous receptors and directly initiates an action potential in neighboring afferent nerve fibers, whereas a mechanical stimulus compresses cutaneous receptors which in turn excite the sensory nerves.

Several differences in performance are noted when the two types of stimuli are employed. For example, psychometric functions for electrocutaneous stimulation of the forearm are exceedingly steep and are accompanied by a low rate of false alarms on random catch trials. When brief tactile pulses are used, the psychometric functions are appreciably more shallow (closer to the slopes of such functions for vision and audition). Moreover, the slope of the tactile psychometric function is dependent on the locus of stimulation (Rollman, 1973). For example, the ratio of the standard deviation to the mean of the psychometric function (the coefficient of variation) is 0.26 for tactile pulses on the forearm (compared to 0.06 for electrical stimulation there) and 0.64 for tactile pulses on the fingertip. The median false alarm rates obtained for the two loci are 0% and 17%, respectively. Thus, locus of stimulation appears to be an important determinant of detection performance: on the hairy forearm, psychometric functions for mechanical stimulation are relatively steep and the false positive rate is low; on the glabrous fingertips, the ogives are shallower and the proportion of false alarms is quite high. Since these results from experiments within the framework of classical psychophysics suggest that the processes for discriminating signal from noise may be dependent on cutaneous locus, experiments based on signal detection theory procedures (Green & Swets, 1966) were performed to examine the nature of the decision processes involved in detecting such tactile pulses.

Although there is now a large literature on signal detection experiments (Egan, 1967; Swets, 1969), most of the studies have involved auditory or visual presentations. Those experiments which used some form of skin stimulation (e.g., Eijkman & Vendrik, 1963; Gescheider, Barton, Bruce, Goldberg, & Greenspan, 1969; Gescheider, Wright, & Polak, 1971; Gescheider, Wright, Weber, & Barton, 1971; Mountcastle, Talbot, Sakata, & Hyvarinen, 1969; Rollman, 1969b; Swets, Markowitz, & Franzen, 1969) employed either electrocutaneous or vibratory signals, and excited only a single site. In the present study, brief mechanical pulses were applied to the glabrous fingertips or the hairy dorsal forearm and a rating scale procedure was used to study the effects of locus on observer criteria and sensitivity.

METHOD

Apparatus

Tactile stimuli were produced by a Goodmans V-47 vibrator fitted with a circular plastic contactor with a diameter of 1 cm. A plastic surround with an o.d. of 2.6 cm and i.d. of 1.2 cm was mounted on top of the vibrator, flush with the contactor surface, to provide a rest when the finger was stimulated.

A Tektronix Type 162 waveform generator triggered two Tektronix Type 161 pulse generators, whose output was fed to a 500-ohm mixer circuit. A positive pulse displaced the vibrator tip towards the finger or arm. A smaller positive pulse to the vibrator followed at the offset of the first one to compensate for a small overshoot. This combined signal, adjusted to provide a unidirectional 3.0-msec pulse, was amplified by a Langevin Model 128-XJ amplifier and passed through a Hewlett-Packard Model 350D attenuator to a transformer which provided an impedance match for the Goodmans vibrator. Apparatus and the procedures for monitoring contactor displacement are described in an earlier

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paper (Rollman, 1973). A switching system was employed to control a starting light and a 1,000-Hz warning tone, which was superimposed on a constant white noise background presented through a headset.

Subjects

Three paid undergraduate males were given extensive training in psychophysical tasks and served in this experiment as well as an earlier one (Rollman, 1973).

Procedure

The O rested his right arm on a padded table before him. For finger stimulation, the middle finger was placed on the contactor and surround, which were mounted flush with the table top. For arm stimulation, the Goodmans vibrator was mounted on a microphone boom stand and positioned over the O's dorsal forearm about halfway between wrist and elbow. Small sandbags were placed on the arm at each side of the vibrator to minimize movements, and weights on the boom were adjusted so that the pressure of the vibrator against the skin was 20 g.

Because the stimulating site and arm position could vary slightly from session to session, a preliminary threshold estimate was obtained using the PEST (Parameter Estimation by Sequential Testing) procedure (Taylor & Creelman, 1967). The parameters employed in selecting the decision rule bounds were P_t (the target probability of correct decisions in this two-alternative forced-choice task) = 0.75, W (a constant used in the equation for determining the sequential test bounds) = 1.5. The attenuation level indicated by this technique was then maintained throughout the session.

Approximately 300 trials were run in each session. On 150 of these, the tactile signal was presented 600 msec after the onset of a 1.2-sec warning period; on the remainder, no stimulus occurred. Eleven or 12 sessions per O were run for the fingertip condition and 12 to 15 sessions with the contactor on the forearm. O indicated his confidence that a signal had been presented following each warning tone by use of a 5-point rating scale. A "5" indicated that he was quite sure that there had been a stimulus; a "4," that he thought there was one; a "3," that he was unsure; a "2," that he believed no stimulus had occurred; and a "1" indicated that he felt quite certain that the stimulus was absent. Feedback was given following each response to indicate the nature of that trial. No restraints were imposed on the use of any rating category.

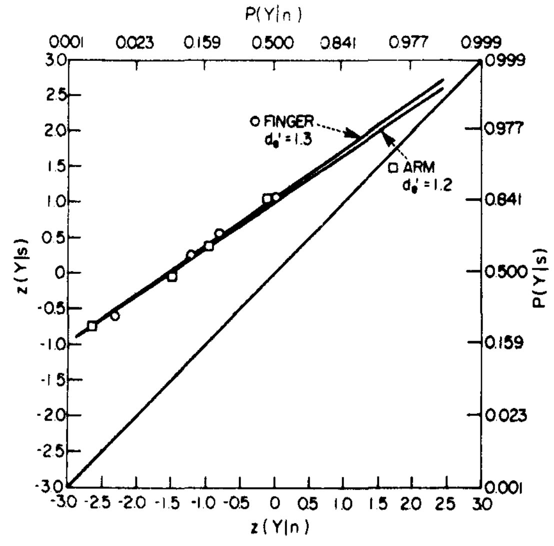

Fig. 1. Summary ROC function on normal deviate coordinates for the detection of tactile pulses on the fingertip and dorsal forearm.

RESULTS

ROC curves were determined for each session by considering each rating category, starting with "5," to be a criterion for a yes-no decision. If "5s" are taken to be "yes" responses while all other ratings indicate "no," the point closest to the origin is obtained. The second pont is derived by taking "5" or "4" to be a "yes" while lower resonses denote a "no," etc. Thus, four points can be obtained from a 5-point scale. These were plotted on normal deviate coordinates, with the hit rate, P(Y | s), on the ordinate and the false alarm rate, P(Y | n), as the abscissa. The points were well fitted by straight lines and a measure of sensitivity, d_e', was determined for each session by computing twice the absolute value of z(Y | s) or z(Y | n) for the point where the ROC function intersected the negative diagonal (Green & Swets, 1966).

To obtain summary ROC curves, ratings were averaged across Ss and sessions. Table 1 presents these data and indicates the coordinates of the points of the ROC curves which were derived from them. The resultant functions on normal deviate axes, are presented in Fig. 1. The sensitivity parameter, d_e', is 1.30 for detection on the fingertip and 1.20 on the arm. The slopes of the two functions are 0.67 and

Table 1
Number and Probability of Different Confidence Ratings Given Signal or Noise at the Finger and Forearm

		Rating					
		5	4	3	2	1	Total
Finger	S	1390	1659	566	726	686	5027
		.28	.33	.11	.14	.14	
	N	61	557	567	1581	2569	5335
		.01	.10	.11	.30	.48	
		(.01, .28)	(.12, .61)	(.22, .72)	(.52, .86)	(1.0, 1.0)	
Arm	S	1321	1637	707	1154	852	5671
		.23	.29	.13	.20	.15	
	N	27	373	671	2127	2866	6064
		.005	.06	.11	.35	.47	
		(.005, .23)	(.07, .52)	(.18, .65)	(.53, .85)	(1.0, 1.0)	

Note–Cumulative probabilities, giving coordinates of points on ROC curve, are indicated in parentheses.

0.65, respectively, indicating that the distribution of likelihood ratios for signal plus noise has a greater variance than the distribution for noise alone. The reciprocal of the slope yields an estimate of the ratio of the standard deviations of these two underlying distributions, 1/slope = σ_s/σ_n. These values are 1.49 for the fingertips and 1.54 for the arm.

DISCUSSION

A previous study (Rollman, 1973) revealed that false positives obtained during classical psychophysical procedures were much higher when stimuli were presented at the fingertips than at the forearm. The principal aim of this study was to use signal detection theory procedures to examine detection performance so that criterion components of the decision process at the two loci could be compared.

Across sessions, the preliminary adaptive psychophysical procedure (PEST) was quite successful in selecting stimulus conditions which would equate detectability at the two sites, since Fig. 1 shows that d_e' is essentially the same at the finger and arm. This also confirms the often reported finding of exquisite sensitivity at the fingertips. The mean contactor displacement there was 0.8 microns compared to 23 microns at the arm.

While the lines which describe sensitivity at the two sites overlap, the individual points, whose location is determined by both sensitivity and criterion, do not. Table 1 and Fig. 1 show that the probability of a "5" or "4" response, given a blank trial, was about twice as high on the finger as on the arm [$P(5 \mid n) = .011$ vs .005 for the two sites, respectively, $P(4 \mid n) = .104$ vs .062, and $P(5 \text{ or } 4 \mid n) = .116$ vs .066]. Thus, the Os tended to give more false alarms (reporting high confidence that a signal had occurred when, in fact, it had not) for sessions when the contactor was at the fingertip than when it rested on the dorsal forearm. Signal detection theory interprets such results as indicating that subjective criteria were placed further towards the mean of the noise disribution when Ss were detecting signals in their fingertips. The parameter, β, which describes the criterion location (the ratio of the ordinate of the signal-plus-noise distribution to the ordinate of the noise distribution for a given hit and false alarm rate) is clearly less conservative for the two highest criteria when stimulation is at that locus (11.18 and 1.97) compared to when it is at the arm (23.17 and 3.10).

These results confirm those which were obtained earlier (Rollman, 1973) from random catch trials in the method of constant stimuli. The detection performance changed with shifts in site of stimulation. Furthermore, this appears to have occurred because of a change in criterion. Signal detection theory provides for such changes, noting that motivational aspects of the experiment such as payoffs or knowledge of a priori signal probabilities can alter criterion location. Various strategies, such as maximizing the expected value of the performance (Green & Swets, 1966), may be adopted. However, the present findings suggest that β is not determined solely by such motivational variables, since the criteria changed with locus even through the instructions and other experimental conditions remained constant. Therefore, alternative theories may better account for the dependence of criterion on body location.

A model with a very large number of discrete states is indistinguishable from signal detection theory and subject to the same criticisms. A two-state model such as Luce's (1963) low-threshold theory, which suggests that both signal and noise can cause detections, could account for the false alarm differences, but it includes assumptions which seem to be violated by the results of experiments in vision (Nachmias & Steinman, 1963; Rollman & Nachmias, 1972), audition (Lindner, 1968), and somethesis (Rollman, 1969b). Therefore, a multistate model incorporating several states (e.g., Norman, 1962, 1964) may provide the most satisfactory account of the data. For example, if there are several fixed states or thresholds rather than several movable criteria, the state corresponding to "4" in the ratings could be entered by noise more often when the S is attempting to detect displacements at the finger than at the arm. An earlier paper (Rollman, 1973) discusses some possible physiological bases for such effects.

At the moment, such models have not been developed as fully as the continuous or the two-state theories, perhaps due in part to the difficulties inherent in attempting to measure or estimate a low threshold and because existing theories which place a low threshold somewhere within the noise distribution arrive at predictions similar to those of signal detection theory regarding the location of points on the ROC curve, and the results of second-guess and rating experiments (Swets, 1961; Green & Swets, 1966). Nonetheless, since the existing continuous theory does not offer a satisfactory explanation of the dependence of criterion on locus when a priori probabilities and payoffs are unchanging, further attention to multistate models seems warranted.

An additional feature of these data merits attention. The slope of the ROC function on normal deviate coordinates is interpreted as the inverse of the ratio of the standard deviation of the signal-plus-noise distribution to the standard deviation of the noise distribution alone. While in the simplest case signal detection theory assumes these values to be equal, in most modalities the standard deviation of the distribution for signal plus noise has proved to be the larger. This is also the case for tactile detection. The value of σ_s/σ_n is 1.49 on the finger and 1.54 on the arm. Thus, locus does not seem to affect this ratio. The mean value of σ_s/σ_n for electrical stimulation of the skin was 1.40 (Rollman, 1969b). Considerable evidence (Rollman, 1974) suggests that electrical pulses bypass the cutaneous receptors and directly excite afferent nerve fibers. However, mechanical pulses, such as those used in this study, first compress the receptors, thus initiating generator potentials. Therefore, the neural sequence following mechanical stimulation is more elaborate and complex than that which follows an electrical pulse.

The similarity of σ_s/σ_n ratios for the two forms of cutaneous stimulation suggests that the variability of response of the receptors is quite small, since their presence in the neural communication process does not add appreciably to the variance of the signal-plus-noise distribution. Werner and Mountcastle's (1968) observation that one of the most striking differences between the peripheral and central nervous systems is the increased variability of spontaneous discharges in the latter supports such a conclusion from these data.

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