Facilitatory spatial interaction with percutaneous electrical stimuli¹

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To measure the effect of a rectangular percutaneous conditioning shock to one finger on subjective magnitude of a suprathreshold test shock to an adjacent finger, Ss equated a contralateral matching stimulus to the test shock. The conditioning shock generally increased the apparent intensity of the test shock. This facilitation was a negatively accelerated function of test-shock current. Larger conditioning stimuli produced greater facilitation. Over limited intervals, time between conditioning and test or test and matching stimuli had no systematic effects.

Psychophysical studies of somesthesia with percutaneous electrical shocks have demonstrated sensory inhibition. Schmid (1961) showed that a suprathreshold conditioning shock (CS) to one finger raised the absolute threshold for a test shock (TS) to a nearby finger. Maximal inhibition occurred at all CS intensities when the CS just preceded the TS. Increased time between the two stimuli or decreased CS intensity reduced the effect. Like Schmid, Uttal (1961) also found that a smaller distance between CS and TS increased the inhibition. Finally, as a limiting case, delivering both stimuli to one locus produced the greatest and most enduring rise in absolute threshold for the TS (Rosner, 1964). Increased interstimulus interval or decreased CS intensity again diminished this phenomenon.

All of these previous results have demonstrated the effect of a CS on threshold for a TS. The present experiments, however, studied the effect of a CS on apparent magnitude of a suprathreshold TS. Interstimulus interval and intensity of the CS were varied.

METHOD

Stimulating Equipment and Electrodes

Stimulating equipment and electrodes were essentially the same as Schmid's (1961). Stimulators were constant-current units. The electrodes were 8-mm silver discs filled with electrode cream. Stimulus pulse duration was 0.5 msec.

Subjects

Four graduate students and postdoctoral fellows in psychology were Ss. Two were female and two were male. All received extensive practice in the experimental task before formal collection of data.

General Procedure

The CS and TS stimulated, respectively, the index finger and the middle finger of the right hand. A third, matching stimulus (MS) was delivered to a finger of the left hand. All stimuli were presented to the most distal phalanges, with the cathode proximal. The S manipulated with his left hand a 10-turn potentiometer which logarithmically increased the intensity of the MS. A trial began with stimulation of the right hand and subthreshold matching shocks to the left hand. Stimulus combinations occurred every 3.2 sec thereafter. The S varied the potentiometer until the intensity of the MS subjectively equalled that of the TS. The E then terminated all stimuli, recorded the MS setting, returned the MS intensity to below threshold, and started the next trial.

Experiment 1

The MS was delivered to the little finger of the left hand. Intensity of CS was 12.0 mA. Ten TS intensities between 1.0 and 9.5 mA were used. Two CS-TS intervals (Δt_{CT}) were employed: CS preceded TS by 2 msec (+2 msec) and TS preceded CS by 10 msec (-10 msec). Schmid (1961) had found the greatest and the least inhibition, respectively, at these values. The TS and MS came simultaneously. Control conditions consisted of presentation of each TS intensity without any CS. Each of the 10 TS intensities occurred on five trials at each of the two Δt_{CT} 's and under the third, control condition of no CS. Stimulus combinations came in random order over this total of 150 trials, which occupied two sessions of 75 trials each.

Experiment 2

The MS now stimulated the middle finger of the left hand. Two TS-MS intervals (Δt_{TM}) were examined: TS preceded MS by 50 and 0 msec. The Δt_{CT} was +2 msec. Ten TS intensities from 1.3 to 9.5 mA were used at each of two CS intensities, 5.9 and 12.0 mA. A separate set of four sessions was run for each CS intensity. Each session of 40 trials used all 10 TS intensities under each of four conditions: Δt_{TM} of 50 msec with CS, Δt_{TM} of 50 msec without CS, Δt_{TM} of 0 msec with CS, and Δt_{TM} of 0 msec without CS. A condition occurred as a block of 10 trials, one for each TS intensity. Within blocks, order of TS intensities was random. These arrangements were replicated across the four sessions to give a total of 160 trials at each CS intensity. Thus, four trials were run at each TS intensity for each condition. Within sessions, order of conditions was random.

RESULTS

Figure 1 shows the results of Experiment 1 at the two values of Δt_{CT} . The difference between median intensity matching the TS in the presence of CS (I_{mc}) and median intensity matching the TS without CS (I_m) is plotted against TS intensity. A difference of zero indicates no change in matching stimulus intensity in the presence of CS. A positive value of ($I_{mc} - I_m$) indicates elevation of subjective TS magnitude when CS is present. For both Δt_{CT} 's, facilitation generally occurred at the TS site. The effect is significant beyond the .05 level by sign tests for all Ss except RW at a Δt_{CT} of 2.0 msec. As TS intensity approached threshold, the facilitation tended to vanish. Suprathreshold TS values showed clear and generally large facilitation. The effect leveled off or even decreased again as TS intensity became still higher. A Friedman analysis of variance confirmed the presence of this negatively accelerated function. Friedman analyses showed no significant effect of Δt_{CT} except for S RW.

Figure 2 presents the data from Experiment 2. An examination of the results showed no differences as a function of Δt_{TM} values of 50 or 0 msec; therefore, data for both values were pooled. The abscissa and the ordinate are the same as in Fig. 1. Figure 2A shows results for a CS of 5.9 mA while Fig. 2B shows those for a CS of 12.0 mA. Two Ss who showed statistically significant facilitation by sign tests with the 5.9-mA CS displayed larger effects with the 12.0-mA CS. S SN showed no facilitation with the 5.9-mA CS but did so significantly with the 12.0-mA CS.

Fig. 1. A. Effect of 12.0 mA conditioning stimulus on subjective magnitude of test stimulus occurring 2.0 msec later. Abscissa: Intensity of test stimulus. Ordinate: Matching stimulus current with conditioning stimulus present (I_{mc}) less matching stimulus current when conditioning stimulus absent (I_m). Matching stimulus to little finger of left hand. B. Test stimulus precedes conditioning stimulus by 10 msec.

Friedman analyses demonstrated a significant effect of CS and TS intensities on facilitation. Finally, S ES felt inhibition of the TS at both CS intensities.

Figure 2B replicates Fig. 1A except for location of the MS. S ES reported on inquiry that the MS finger for Experiment 2, where she showed inhibition, had sustained damage at an earlier time. The MS finger for Experiment 1, where she showed facilitation, was normal. Randomization tests on the data for the other three Ss, however, yielded no significant differences in facilitation as a function of MS location.

DISCUSSION

Previous studies of cutaneous two-point interaction have found inhibitory effects. Our experiments demonstrated marked facilitatory ones. Like inhibition, facilitation depends on CS intensity. Presumably, it also depends on Δt_{CT} , although our limited data do not show this. Two methodological facts seem to explain why facilitation has not been observed before. First, most previous investigators studied the effect of a conditioning stimulus on a threshold test stimulus. Facilitatory interaction is weak or absent at low values of the test stimulus, but inhibition seems largest around test stimulus threshold. Second, in experiments with suprathreshold test stimuli (Békésy, 1967), the stimuli were not particularly

intense. Furthermore, the S did not equate an independent matching stimulus to the test stimulus. Thus, procedures of previous experiments were not sensitive to facilitation.

The data in Figs. 1 and 2 generally follow a negatively accelerated course. Beck and Rosner (1968) found that magnitude estimations for electrocutaneous stimuli obey Stevens's law: $\psi = a(I - I_0)^k$. One might assume that inhibitory effects raise the threshold constant I_0 and that facilitatory effects increase the exponent k . A little mathematical analysis shows that these assumptions cannot predict the form of our data. Instead, it predicts a positively accelerated function for $(I_{mc} - I_m)$ plotted against intensity of the test stimulus. The proof runs as follows:

Assume Stevens's law for the test stimulus alone (T), the test stimulus in the presence of the conditioning stimulus (CR), and the matching stimulus (M):

$$\begin{aligned}\psi_T &= a_T(I - I_{0T})^{k_T} \\ \psi_{CT} &= a_{CT}(I - I_{0CT})^{k_{CT}} \\ \psi_M &= a_M(I - I_{0M})^{k_M}.\end{aligned}\quad (1)$$

Let us set all scale factors a equal and let

Fig. 2. A. Same as Fig. 1A, except matching stimulus to middle finger of left hand. Conditioning stimulus intensity equals 5.9 mA. B. Conditioning stimulus now 12.0 mA.

$$k_{CT}/k_M \equiv k_{CTM} \quad (2)$$

$$k_T/k_M \equiv k_{TM}.$$

If $\psi_T = \psi_M$ by matching,

$$I_m = (I - I_{0T})^{k_{TM}} + I_{0M}. \quad (3)$$

Similarly, if $\psi_{CT} = \psi_M$,

$$I_{mc} = (I - I_{0CT})^{k_{CTM}} + I_{0M}. \quad (4)$$

It follows that

$$D \equiv (I_{mc} - I_m) = (I - I_{0CT})^{k_{CTM}} - (I - I_{0T})^{k_{TM}}. \quad (5)$$

The second derivative of D is

$$\frac{d^2D}{dI^2} = \frac{k_{CTM}(k_{CTM} - 1)}{(I - I_{0CT})^{2-k_{CTM}}} - \frac{k_{TM}(k_{TM} - 1)}{(I - I_{0T})^{2-k_{TM}}}. \quad (6)$$

If the second derivative is positive, then D must be positively accelerated. This would not fit the negatively accelerated data of Figs. 1 and 2. Now we plotted test stimulus values against matching stimulus values for each S in both experiments. All plots had slopes of unity or were positively accelerated. Thus, $k_{TM} \geq 1$. If we assume $k_{CTM} > k_{TM} > 1$ and $I_{0CT} > I_{0T}$, then

$$\begin{aligned} k_{CTM}(k_{CTM} - 1) &> k_{TM}(k_{TM} - 1) > 0 \\ (I - I_{0CT})^{2-k_{CTM}} &< (I - I_{0T})^{2-k_{TM}}. \end{aligned} \quad (7)$$

Accordingly, d^2D/dI^2 must be positive and D should be positively accelerated. The data of Figs. 1 and 2 thus contradict the simple notion that the conditioning stimulus causes uniform increases in I_0 and k for the test stimulus.

Application of the power law to the present experiment suggests another procedure for detecting facilitation. Ss could give magnitude estimations for the TS alone and for the TS in the

presence of the CS. Facilitation should increase magnitude estimations when the CS occurs. We originally performed our preliminary experiments with this procedure and found clear facilitatory effects at moderate intensities of the test stimulus. Thus, detection of facilitation does not require use of a contralateral matching stimulus. Since standard magnitude estimation proved to be a relatively crude method, we turned to the matching procedure used in the present study.

Inhibitory two-point interaction presumably increases spatial acuity. Ruch (1961) has proposed a model in which each of the two stimuli produces its own distribution of excitation in a higher nervous center. The distributions are unimodal and overlap as the stimuli approach each other spatially. Inhibition would suppress the tails of the distributions and thereby decrease overlap. Facilitation should increase simultaneously the modal height of each distribution, making discrimination between them easier. Thus, the facilitatory effects described here may aid two-point spatial discrimination.

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NOTES

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