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Tactile apparent movement: The effects of interstimulus onset interval and stimulus duration*

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The effects of variations in stimulus duration and interstimulus onset interval on ratings of tactile apparent movement were determined for seven Ss with stimulators of very small diameter. Judgments of successiveness and simultaneity were also obtained. It was found that apparent movement increased as a power function of increases in stimulus duration. The function relating tactile apparent movement and stimulus duration was shown to be similar to that obtained by Kolers (1964) for visual apparent movement. Interstimulus onset interval also had a marked effect on apparent movement, and the optimal interval was influenced by stimulus duration in a manner similar to that reported by Sherrick and Rogers (1966).

This study was originally motivated by observations made in the course of research on a tactile display for speech. Since one aim of that research was to present spatiotemporal tactile patterns that could be perceptually integrated over time, an attempt was made to produce good apparent movement between successive stimuli. The need for spatiotemporal integration in tactile displays of speech and language and the relevance of apparent movement for such perceptual integration has been discussed elsewhere (Kirman, 1973).

Sherrick and Rogers (1966) had observed good apparent movement with very brief tactile stimuli similar to those employed in this research. Accordingly, an interstimulus onset interval (ISOI) was chosen which was very close to that reported by these researchers to produce optimal tactile apparent movement with such stimuli. Although some features of the tactile stimuli were different from those utilized by Sherrick and Rogers, it was not expected that the temporal conditions for good apparent movement would be affected. These authors had reported that virtually identical temporal intervals produced optimal apparent movement regardless of whether the stimuli were vibrotactile, electrocutaneous, or even visual. The observations with the tactile display were, however, disappointing. Instead of good apparent movement, Ss reported separated stimuli following each other in clear succession.

Neither the work of Sherrick and Rogers nor other studies of tactile apparent movement indicated any basis for the discrepancy in results. The few investigators that had successfully obtained tactile apparent movement were not in complete agreement on which stimulus variables are of major significance for the phenomenon. While Sumby (1955) had found ISOI to be important and had determined the optimal interval for one stimulus duration, Gibson (1963) reported that ISOI was not a variable of any consequence over a wide range of stimulus durations, including the duration studied by Sumby. Sherrick and Rogers (1966), investigating the same range of stimulus durations, observed ISOI to be a major variable for all durations, in contrast to Gibson's findings. Gibson (1963) also reported that the impressiveness of tactile apparent movement was strongly influenced by both interstimulus distance and stimulus duration, but did not report significant effects of either variable on optimal ISOIs. Sherrick and Rogers (1966), using a procedure that permitted a careful estimation of the optimal ISOI, observed that duration markedly affected the optimal ISOI, while distance did not. Their method, however, did not permit a quantitative evaluation of the effects of these variables on the impressiveness of movement.

It was therefore decided to investigate the stimulus conditions for good apparent movement with the stimulators that had been developed for the tactile display of speech. In order to evaluate the impressiveness of movement across a variety of stimulus conditions, a method was chosen in which Ss rated all stimuli on a scale from good movement to no movement. A pilot study with two Ss varied stimulus duration, interstimulus distance, ISOI, and site of stimulation. The results of this exploratory study indicated that within the range of interest (from .2 in. to 2.0 in.), distance had no major influence, nor did site of stimulation (fingertip or forearm). Both stimulus duration and ISOI, however, were decisive for the achievement of good apparent movement. The following experiment was accordingly designed to investigate the effects of these two variables on the impressiveness of tactile apparent movement and to determine the optimal temporal conditions for its appearance with the tactile speech display.

METHOD

Subjects

The Ss were seven undergraduates at Queens College of CUNY. Three other Ss were eliminated from the experiment because of the unreliability of their judgments. None of the Ss had any prior experience with experiments using tactile stimulation or apparent movement. All were paid by the hour for their services.

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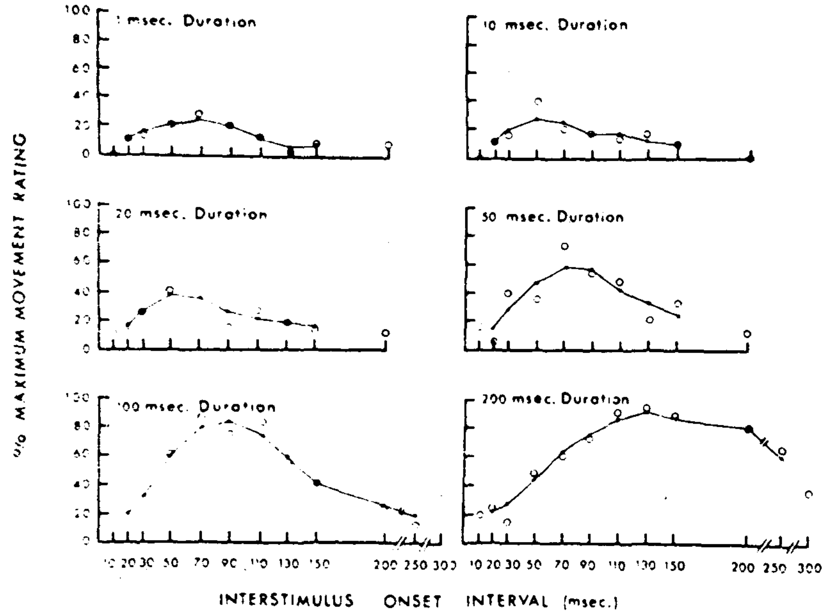

Fig. 1. Percent maximum rating of apparent movement as a function of interstimulus onset interval for six durations. The open circles represent the original data points.

Apparatus

The tactile stimulators that contacted the Ss' fingers were bronze rods, .025 in. in diam, rounded at the tip, which pushed up from 1/8-in. holes in a Plexiglas rest plate that served to maintain the finger surface in a constant position relative to the stimulators. These rods were direct extensions of the spring-loaded armatures of miniature solenoids (Electro-Mechanisms Corp., SP-18) which were vertically mounted below the Plexiglas plate. Two such solenoids and contacting rods were used in this experiment at a constant interstimulus distance of 1.4 in. The solenoids were activated by 1.5-msec square wave pulses of about 40 V, which produced clearly felt but not painful "taps" on the skin. Since the inactive position of the bronze rods was below the surface of the Plexiglas plate, they made only momentary contact with the skin at each pulse. Stimulus durations longer than a single 1.5-msec pulse were produced by a train of such pulses occurring at a rate of 100/sec. [For ease of presentation, all stimulus durations of two pulses or more will be referred to by the interval between the onset of the first pulse and the onset of the last pulse (omitting the constant additional duration of the last 1.5-msec pulse itself). For example, a stimulus described below as having a duration of 50 msec actually had a duration closer to 51.5 msec. In addition, a single pulse of 1.5 msec will be referred to below as having a duration of 1 msec.]

The activation of the two solenoids at appropriate intervals was controlled by a Datamec digital tape transport on which had been written as individual records each of the selected combinations of ISOI and duration.

Procedure

The S was seated, and his right index finger was positioned on the Plexiglas rest plate so that the two stimulators were under the two fleshy pads at the distal end of the finger. Ss were exposed to several examples of the stimuli to be used in order to acquaint them with the experience of tactile movement and to establish criteria for judgments. A stimulus of 200 msec duration with an ISOI of 130 msec was given as an example of good movement, and clearly simultaneous and successive stimuli were presented as well. Since it was evident that longer duration stimuli were also experienced as more intense, Ss were exposed to stimuli of 1 msec and 200 msec duration and instructed to avoid basing their judgments either on duration or on apparent intensity and to concentrate on the extent to which they perceived movement regardless of the intensity or duration of the stimuli. Similarly, Ss were exposed to stimuli with ISOIs of 10 msec and 200 msec and were asked to try to avoid being influenced by the "speed" of the movement in their subsequent judgments. Ss were asked to rate stimuli as follows: "A" if they clearly experienced impressive and continuous movement from one stimulating point to the other; "B" if the experienced movement was definitely present but was either unimpressive or discontinuous between the two end points; "C" if the movement was very partial or ambiguous; and "zero" if they definitely experienced no movement. Furthermore, they were asked to specify whether the "zero" movement was experienced as "successive" or "simultaneous." All Ss were given 10 practice trials before data were collected. In addition, a sample of stimuli was repeated at the end of the first session in order to check on the reliability of Ss' judgments. Three Ss were eliminated from the experiment at that time because of the extreme lack of reliability of their judgments.

The stimuli to be judged varied in both stimulus duration and ISOI. Each of 6 durations (1, 10, 20, 50, 100, and 200 msec) was combined with each of 10 ISOIs (10, 20, 30, 50, 70, 90, 110, 130, 150, and 200 msec), making a total of 60 stimulus conditions. (In addition, stimuli with ISOIs of 250 and 300 msec and durations of 100 and 200 msec were presented to four of the Ss in order to estimate apparent movement over that extended range of ISOIs.) The 60 stimuli were presented to Ss in a random order during each of two sessions. After each set of 10 judgments, Ss were presented with the standard stimuli for good movement, successiveness, and simultaneity to which they had been exposed during their introduction to the experiment.

RESULTS AND DISCUSSION

The Ss' ratings of apparent movement are given in Fig. 1. Before plotting Fig. 1, several different weightings for the apparent movement ratings of "A," "B," and "C" were evaluated, but all resulted in curves of the same general shape. It was therefore decided simply to count judgments of "A" as 3, "B" as 2, and "C" as 1 and to average these ratings across Ss for each stimulus condition. Figure 1 shows these ratings aspercentages of the maximum possible rating for each condition. Thus, if all Ss rated a stimulus condition as 3 (the best rating), it was plotted as 100%; if the average rating across Ss was 2, it was plotted as 67%, etc. Figure 1 gives these average ratings as well as curves drawn through the data points. These curves were smoothed by calculating a running average across sets of three adjacent points.

It is evident from Fig. 1 that for each of the six stimulus durations, the degree of apparent movement varies as a function of ISOI and the function at first rises and then falls as ISOI increases. The effect of ISOI was shown to be significant in a three-way analysis of variance [$F(9,354) = 20.00$, $p < .005$]. Figure 1 also indicates that as stimulus duration is increased, the optimal ISOI for apparent movement at first decreases and then increases. The shift in ISOI with increasing duration is shown more clearly in Fig. 2, which plots the optimal ISOI (taken as the maximum of each of the smoothed curves of Fig. 1) as a function of stimulus duration. The reliability of this shift in ISOI is supported by a significant interaction between ISOI and stimulus duration [$F(45,354) = 4.18$, $p < .005$]. As an additional check, individual optimal ISOIs for each duration were determined for each S, and a separate analysis of variance performed on these optimal ISOIs was also significant [$F(5,30) = 22.26$, $p < .005$].

It should be noted that the present study used a rating procedure quite different from the method of Sherrick and Rogers (1966) but similar to Gibson's (1963) method of magnitude estimation. The results are nevertheless clearly in agreement with those of Sherrick and Rogers both with regard to the importance of ISOI as a major variable and with regard to the shape of the function relating optimal ISOI and stimulus duration. Figure 2 shows the data obtained by Sherrick and Rogers as well as the present results. The parallel between the two sets of data points is evident. In this connection, it is worthy of note that Gibson, who reported in 1963 that ISOI had no significant simple effect on apparent movement, did nonetheless obtain a significant interaction between ISOI and stimulus duration which may have reflected a similar dependence of ISOI on duration. In a more recent description of this experiment, Gibson (1968) remarked that optimal ISOI did increase with longer stimulus durations, though he also stressed in this paper that, with long duration stimuli, good movement could be obtained with a broad range of ISOIs. It is clear from the present data that averaging across selected durations for a certain range of ISOIs could result in the obscuring of the influence of ISOI as a main effect. When the interaction between optimal ISOI and duration is kept in mind, it is more evident that ISOI is a variable of importance.

Not all research reports on apparent movement describe the temporal intervals between stimuli in terms of ISOI. Apart from the fact that the interval between stimulus onsets is often referred to as stimulus onset

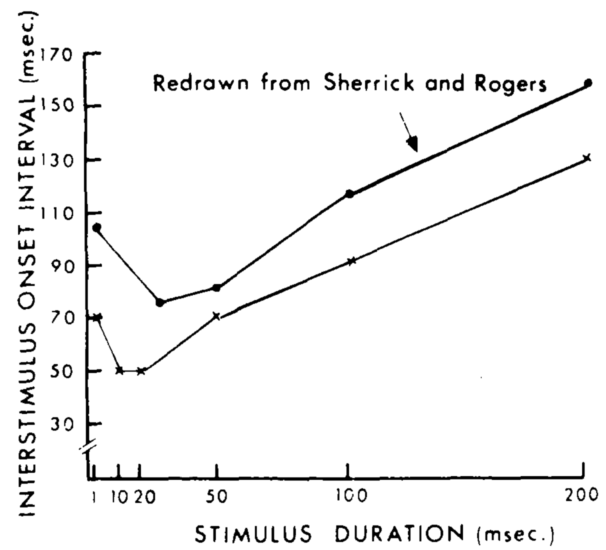

Fig. 2. Optimal interstimulus onset interval as a function of stimulus duration. The lower curve gives the data from the present study, while the upper curve is redrawn from Sherrick and Rogers (1966).

asynchrony (SOA) rather than as ISOI, the temporal relationship between stimuli has frequently been characterized in terms of the interval between the termination of the first stimulus and the onset of the second. This interval, called an interstimulus interval (ISI), may be determined for the present data by subtracting stimulus duration from ISOI. Since this experiment was designed with the same set of ISOIs replicated across the various stimulus durations, it is not possible to recover the same set of ISIs for each stimulus duration used, and the data shown in Fig. 1 could not reasonably be replotted in terms of ISI. However, since any ISOI may be translated into its equivalent ISI, Fig. 2, which shows the optimal ISOI for each duration, can easily be plotted in terms of optimal ISI as a function of stimulus duration. Figure 3 shows the curve that results from such a translation. As can be seen, the influence of duration on the optimal ISI is more marked than is its influence on ISOI. For the shortest to the longest duration, the optimal ISI changes from 70 msec to minus 70 msec (that is, an overlap of 70 msec), a shift of 140 msec as compared with a maximum spread of 80 msec when the data are plotted in terms of ISOI. Furthermore, the reversal in the ISOI graph at 1 msec duration (see Fig. 2) does not occur in the ISI plot, although, as Fig. 3 shows, there is a similar deviation from linearity at the three shortest durations. The major difference, however, between the two plots is that the optimal ISOI in general increases as stimulus duration increases, while the optimal ISI decreases. These ISOI and ISI plots are equally valid alternative descriptions of the present data, but since the experiment was designed with a constant set of ISOIs (but not ISIs) replicated across durations, the remaining results will be described in terms of ISOI only.

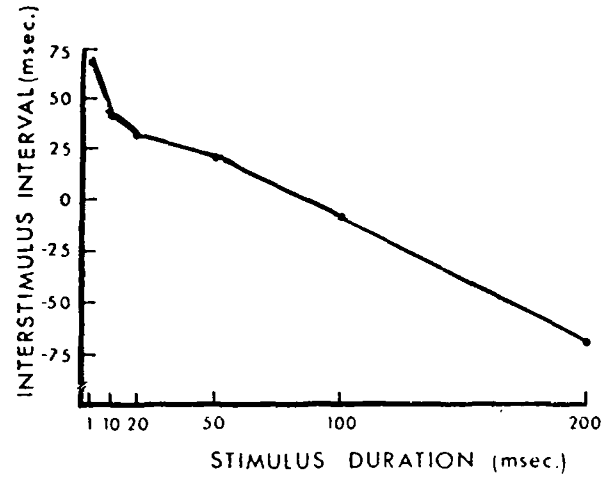

Fig. 3. Optimal interstimulus interval as a function of stimulus duration.

The major difference between the present results and those of Sherrick and Rogers (1966) is that optimal ISOIs were consistently lower in the present study for each stimulus duration. [This difference accounts for the initial failure to obtain apparent movement with the stimulators used here. While Sherrick and Rogers found optimal movement for a stimulus duration of 1 msec with an ISOI of about 110 msec, at that duration the optimal ISOI with the present stimulators was 70 msec, and an ISOI of 110 msec resulted in about 75% judgments of successiveness (see Fig. 4).] It is likely that this downward shift in optimal ISOIs is due to the differences between the tactile stimuli used. While Sherrick and Rogers used vibrotactile stimulators .25 in. in diam applied to the thigh and energized by ac, the present study used stimulators .025 in. in diam applied to the fingertip and energized by square wave pulses. It is possible that the important difference is that of body locus, although both the pilot work done prior to the present study and the report of Sherrick (1968) indicate that body locus does not exert a major influence on ISOI. It is more likely that the discrepancy in optimal ISOI is due to the difference in contactor size and the sharpness of localization of the resulting tactile sensations. Verrillo (1968) has reported evidence that small contactors (very similar to those used in the present experiment) engage a different set of mechanoreceptors than do large contactors. In addition to their small diameter, other factors may have operated to produce very narrowly localized sensations in the region of the present stimulators. The use of square wave pulses and the placement of contactors so that contact with the skin occurred only momentarily during each pulse produced "tapping" stimuli with very rapid onsets rather than smoothly varying sinusoidal vibration. Békésy (1967) has shown that sharp taps on the skin result in more funneling and sharper localization of sensation than when sinusoidal stimulation is used. It is not unreasonable that two stimuli which are sharply localized should require different time delays between their onsets to produce apparent movement of the

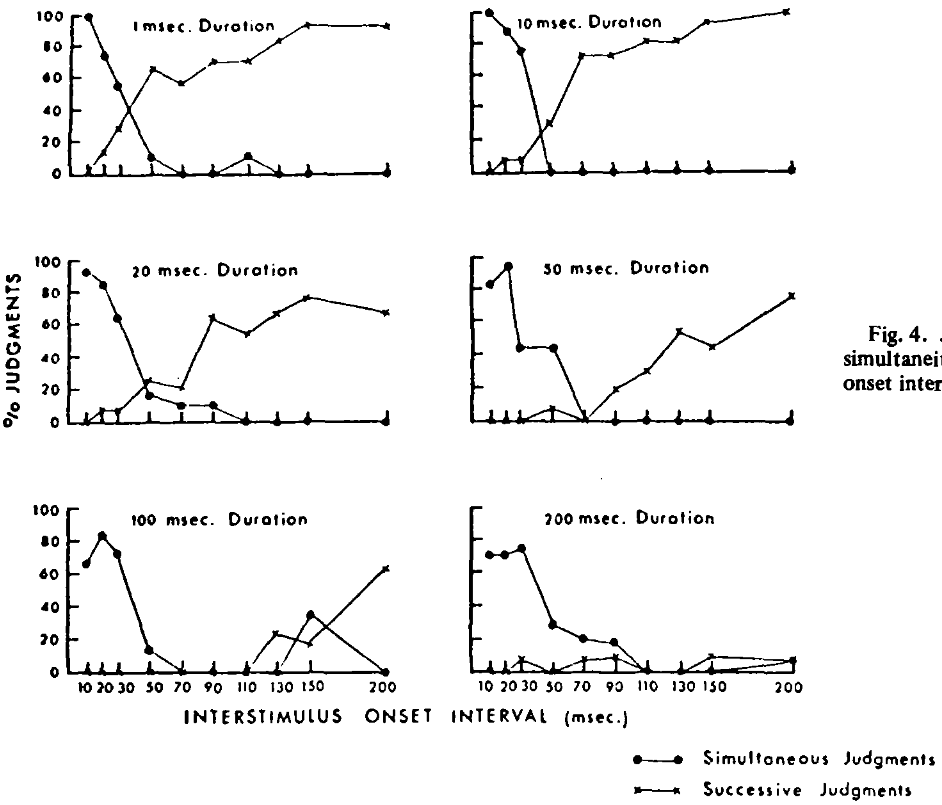

Fig. 4. Judgments of successiveness and simultaneity as a function of interstimulus onset interval for six durations.

sensation between them than would two more diffusely localized stimuli. If so, it would be interesting to investigate if it is the physical size of the contactor that is decisive or whether the same effect could be found by varying only the rapidity of stimulus onset, holding contactor size constant.

Figure 4 gives the average percentage of judgments of simultaneity and successiveness for each stimulus condition. It is clear, as would be expected, that increases in ISOI resulted in decreased judgments of simultaneity [$F(9,354) = 133.50$, $p < .005$] and increased judgments of successiveness [$F(9,354) = 44.15$, $p < .005$]. Figure 4 also shows that as stimulus duration is increased, judgments of successiveness decrease markedly [$F(5,354) = 67.77$, $p < .005$], and there is a shift of the curves toward longer ISOIs [interaction between duration and ISOI was significant; $F(45,354) = 4.04$, $p < .005$]. The overall percentage of simultaneous judgments, however, did not change with increases in duration [$F(5,354) = .30$], although there was a slight flattening of the curves relating judgments of simultaneity and ISOI as duration increased [interaction between duration and ISOI was small but significant; $F(45,354) = 1.88$, $p < .005$]. The increase in apparent movement with longer stimulus durations is accompanied by large decreases in successiveness judgments but only minor changes in simultaneous judgments. The major tradeoff then is between apparent movement and successiveness judgments.

As stimulus duration is increased, there is a marked increase in the impressiveness of apparent movement [$F(5,354) = 65.15$, $p < .005$]. This can be seen in Fig. 1, but is plotted more clearly in logarithmic coordinates in Fig. 5, which shows the relationship between ratings of apparent movement and stimulus duration for the optimal ISOI as well as for the average of all ISOIs at each duration. With the exception of the shortest (1-msec) and longest (200-msec) durations, both sets of data points are well fitted by straight lines with slopes of approximately .5, indicating that the data are well described by power functions. The deviation of the 1-msec duration suggests that it is not very different functionally from a 10-msec duration. This is in accord with the existence of a minimum perceptually effective interval in the vicinity of 10 msec below which all durations are equivalent. Although one might expect some amplitude summation within that interval (in the present experiment different stimulus durations were not equated for subjective intensity), the fact that there was so little difference between the 1-msec and the 10-msec condition indicates that such amplitude summation had little or no effect on apparent movement. This would be in agreement with Sherrick's (1968) report that variations in sensory magnitude from 6 to 30 dB had no influence on apparent movement.

Figure 5 also shows data relating apparent movement and stimulus duration replotted from Gibson (1963) and Kolers (1964). The Gibson data were obtained by a

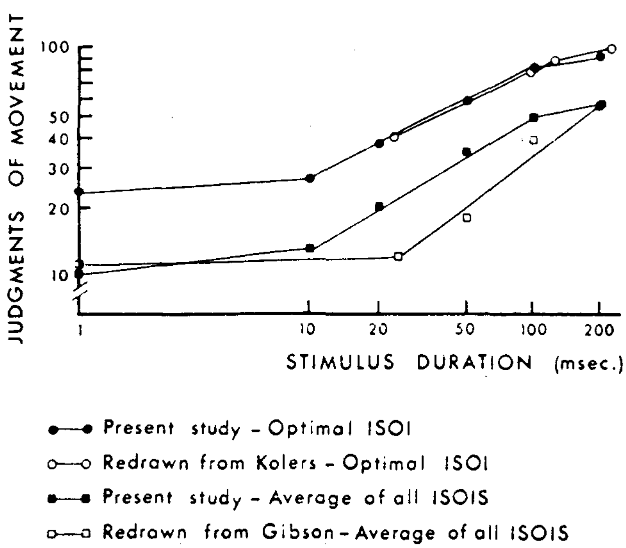

Fig. 5. Judgments of apparent movement as a function of stimulus duration. Data are given for the optimal ISOI at each duration as well as for the average of all ISOIs at each duration. The ordinate should be understood as percent maximum movement rating for the results of the present study. Its meaning for the data plotted for Kolers (1964) and Gibson (1963) is explained in the text.

magnitude estimation procedure using electrocutaneous stimuli that were matched for subjective intensity across the various stimulus durations. His data points were multiplied by a constant factor before being plotted here in order to equate his maximum estimation of movement with the maximum rating obtained in the present study. The slope of the line drawn through these points, however, is the same as that presented in his original graph. Gibson also observed that all of his data points, except for the shortest duration (.5 msec), were well fitted by a power function. The deviation of the .5-msec duration was also interpreted by him as indicating that stimuli below 10 msec in duration are equivalent. There is, in general, good agreement between Gibson's data and those of the present study, with the exception that the slope of his function is somewhat steeper. This difference in slope may be due to differences between mechanical and electrical stimulation.

Kolers' data were obtained from an experiment on visual apparent movement. They represent the probability of obtaining reports of visual movement at the optimal ISOI for each of four stimulus durations. The points replotted in Fig. 5 are Kolers' original values. The agreement between his data for visual apparent movement and the corresponding tactile apparent movement ratings at optimal ISOIs is noteworthy. Both sets of points fall virtually on the same line, and both show a similar departure at the maximum duration. It is reasonable to interpret this deviation in both curves as evidence that a maximum degree of apparent movement (either probability of report or rating of impressiveness) is reached with a stimulus duration less than 200 msec. Both fitted lines point to about 150 msec as the duration beyond which apparent movement (at the optimal ISOI) no longer improves. Sherrick and Rogers called attention to the fact that their obtained function relating optimal ISOI to stimulus duration was strikingly similar to the equivalent function for visual apparent movement. Figure 5 indicates that the function relating degree of apparent movement to stimulus duration is also very similar for the visual and tactile modalities. This lends further support to the view expressed by Sherrick and Rogers that the temporal conditions for apparent movement are independent of modality.

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