Apparent haptic movement¹

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When Os were presented with 150-Hz vibrotactile bursts at two loci on the skin of the thigh and permitted to adjust the time between burst onsets, they reported good apparent movement between the loci. The time between stimulus onsets for optimal movement was found to vary directly with the duration of the stimulus. Replication of the experiment with electrocutaneous stimuli at 1 KHz yielded similar results. Comparison of the data with results from a study of visual apparent movement revealed no difference between the two modalities for the relationship between stimulus onset intervals and stimulus duration. The significance of the results for hypotheses about the processes underlying perception of apparent movement is discussed.

Of the several early studies of apparent movement between two successively stimulated skin loci (Boring, 1942, pp. 599-601), the majority recorded only infrequent reports of optimal movement. Those investigators who found movement were impressed by its lability of appearance in comparison with visual apparent motion, often characterizing the movement as vague shiftings, flutterings, or "bow" movements in which "something" arced through space between the loci. As a result of this instability, it was seldom possible to quantify the relationships among such variables as magnitude, duration, and distance or time between stimuli. Bartley (1958, p. 270) has noted that the available quantitative relations among variables associated with haptic movement do not provide adequate means for deciding whether or not such movement is dependent on visual imagery. DeHardt (1961) attempted to isolate the conditions that produced bow or "off-skin" movements as against "on-skin" movements, but the percentage of trials in which her Os reported good movement was so small that no conclusive evidence could be adduced.

One common feature of the type of experiment reviewed by Boring and described by Bartley and DeHardt is the nature of the stimulus that generated movement. It consisted of transient pressures produced by dropping a weight on the skin and retrieving it electromagnetically. Nafe and Wagoner (1941) have demonstrated that such stimuli are not constant in sensory magnitude over time, and are seldom singular in character when both drop and lift operations are performed. It is therefore possible that much of the instability of haptic movement is owing to the inconstant character of the stimulus. This hypothesis is supported by observations of haptic movement made by Bice (Geldard, 1961, p. 82) in a study of compensatory tracking with vibrotactile stimuli. With six successively energized vibrators placed around his thorax, the O reported vivid

movement that might be labeled "haptokinetic" because it gives O the impression that he is at the focus of intense rotatory motion. Bice's brief vibrotactile burst differs markedly from the transient pressures produced by other investigators. It has more of the unitary character of a tone burst or a flash of light, and provides thereby a more stable basis for perception of movement.

In a formal study of conditions for apparent vibrotactile movement, Sumby (1955) varied the burst onset interval of a vibrotactile stimulus pair, and plotted the frequency of Os' reports of good movement as a function of that variable. The vibrators were located on the O's back, separated by distances of from 4 to 22 cm. For the 200-msec. vibratory bursts employed in his main experiments, Sumby found that the burst onset interval for most frequent reports of good movement was about 100 msec. Moreover, the frequency of reports of movement was most readily affected by changing this interval.

The present experiments were carried out as an extension of work begun as an undergraduate research project by the junior author in which the spatial, temporal, and intensive conditions for good vibrotactile movement were investigated. Only the variables having a primary influence on the perception of good haptic movement will be discussed.

EXPERIMENT I

Because Sumby had shown that the inter-stimulus onset interval (ISOI) strongly affected the O's reports of good movement, it was decided that this variable might best be manipulated by O to allow him to maximize the impressiveness of his perception of movement under each of the variety of other experimental conditions to be presented. Accordingly, the apparatus shown in Fig. 1 was assembled. It is a standard signalling system for vibrotactile or auditory studies, with small modifications. The oscillator signal is gated by the electronic switches, amplified and attenuated, and impressed on the vibrators. Figure 2 is an oscillograph trace of the motion of a V-47 vibrator to a 50-msec. burst at 150 Hz, the frequency of the signal for the experiments. The Tektronix equipment programs the duration, stimulus intervals, and presentation rate of the signal bursts of the electronic switches. The box marked "Observer's Control" contains three switches and performs as many functions. First, by pressing one switch, the O can trigger a single presentation sequence, in this case two vibrotactile bursts. Second, he can control the direction and extent of movement of the pulse delay dial drive on the third Tektronix 161

pulse generator, thereby changing the interval between burst onsets (ISOI). The time interval was read by means of a Hewlett-Packard 522-B counter, not shown. Third, he can, with the switching relay boxes, switch in either one of the two sets of pulse generators shown, thus instantly permitting comparison of two different ISOIs, or two different burst durations. He can also compare two different burst intensities when the alternate attenuators shown are switched in. The vibrators were the Goodmans type V-47, having a contactor of about 1/4 in. diameter surrounded by a fixed Teflon ring to stabilize contact with the skin. The O was seated comfortably in

a dental chair, and the vibrators were suspended from counterbalanced beams and allowed to contact the ventral thigh of the O with a force of about 100 gm. The output of a white noise generator provided a masker in the O's headphones during the observation periods.

The O's absolute threshold for a 200-msec. vibrotactile burst at the distal thigh locus was the standard reference value for all sensory magnitudes described in the experiment. When this value was obtained, the signal was usually raised to a sensation level (SL) of 15 dB. The magnitude of vibration at the other skin locus was then matched to that of the reference locus.

Fig. 3. Plot of the mean values of burst onset interval for best movement as a function of burst duration (open circles). The filled squares are mean values for simultaneity of bursts, and the open squares mean values for successive-ness of bursts.

When the burst pairs were equated for magnitude the E would adjust the interval between successive bursts and ask the O to operate his control box to find the interval that produced the best movement for him. "Best movement" was defined as the longest uninterrupted feeling of movement between the first stimulus site and the second. The O was permitted to trigger the stimulus sequence as often as he liked, and to change the ISOI values in any way he chose. If he so desired, the O could switch in the alternate pulse generators to produce a movement previously arrived at as an adequate standard. Generally he required 2 to 4 min. to complete a single reading, during which time he presented himself with stimuli at the average rate of one every 2 sec. Four such trials made up a single session. The period over which training and data collection went on was about 14 months.

The haptic movement perceived by O was described as a powerful vibratory "gouging" that moved from one stimulus site to the other at a rate depending on the distance between sites and the time between onsets. At its best, the feeling was equivalent to that produced by actually moving a vibrating object smoothly along the thigh. Under less-than-optimal conditions, the movement was strong near one or both sites, with a weaker impression near the middle distance. This was particularly true when distances of over 30 cm were covered, or when joints intervened. The ISOI for best movement was not significantly affected by distance changes, however.

The variable having major significance for both the character of optimal haptic movement, and for the value of the ISOI, is that of stimulus duration. Four trained Os

were presented with burst pairs having stimulus durations ranging from 25 to 400 msec. They manipulated the ISOI to obtain optimal movement, as outlined in the procedure. The results are shown in Fig. 3. The filled and empty squares connected by dashed lines are the limits of good movement found by tracking the ISOI from the one extreme of simultaneity to the other of successive-ness of stimuli. The open circles and the solid line are the presently obtained mean values for optimal movement. The bracketed vertical lines indicate plus and minus one standard deviation about the mean. It should be noted that the durations of both stimuli were the same in the graph shown. When durations are unequal, the first stimulus determines the ISOI.

After the completion of the research described, the investigation of Neuhaus (1930) was found during a search of the literature on visual movement. Neuhaus put Korte's laws for visual apparent movement to rigorous test, and found that only stimulus duration, distance between stimuli, and interval between stimuli were closely interrelated. The significant relationship was that of stimulus duration and ISOI, in agreement with the present results. The agreement over the range of values was, in fact, striking, except that Neuhaus' data extended to a duration of 2.5 msec., at which point the deviation from the linearity shown in Fig. 3 was marked. For the sake of a complete comparison, the apparatus was re-arranged to generate a transient pressure as the lower extreme of duration of the vibrotactile burst. Figure 4 illustrates the character of the transient, which feels like a tap. The four Os were tested as before to determine the ISOI for good movement. In Fig. 5

Fig. 4. Oscillographic tracing of a transient pressure generated by impressing the rectified output of a simple tank circuit on the coil of the vibrator. Record made as in Fig. 2. Time: each large graticule division is 2 msec.

the results of Neuhaus and the present results are compared, with the new value for the transient tap included as a duration of 3 msec.

A study of apparent haptic movement between spatially separated electrocutaneous stimuli was made by Gibson (1963), who concluded that ISOI was not an important variable in perception of movement, but that electrode separation and stimulus duration were major variables.

Gibson presented to his Os trains of brief anodal electrocutaneous pulses through small active electrodes placed on the back, with a single large indifferent electrode on the plantar surface of the foot. Pulse trains were varied in duration and ISOI, along with inter-electrode distance. For each combination of variables Os were asked to judge "amplitude" of goodness of movement as if it were a prosthetic scale for

Fig. 5. Plot of stimulus onset interval against stimulus duration for optimal movement. Open squares, the data of Neuhaus for visual movement. Open circles, the present study.

Fig. 6. Same as Fig. 5, but with data for electrocutaneous stimuli at frequency of 1 KHz added (open triangles). Additional points from Neuhaus' data have been added at the shorter durations.

which magnitude could be estimated. An unspecified standard of movement, assigned the modulus 10, was generated between two active arm electrodes with the plantar electrode already mentioned as indifferent. The radical differences in procedure forbid a close comparison of the present results with those of Gibson. Nevertheless, it was felt that a replication of the present procedures was necessary. An electrocutaneous stimulus was substituted for the vibrotactile burst on the chance that this aspect of the situation might account for the obvious discrepancies.

EXPERIMENT II

The apparatus was arranged as in Fig. 1 except that the matching transformers and vibrators were replaced by new matching transformers and wet concentric electrodes of the type described by Tursky, Watson, and O'Connell (1965). The area of the annular electrode was 6.8 cm² and that of the center disk was 0.5 cm². The skin was contacted by felt pads moistened with a 5% saline solution, presenting under these conditions an impedance to the 1 KHz signal of 5 to 7 kilohms at current levels near threshold. The current through the electrodes was measured by a Hewlett-Packard Model 456A clip-on ammeter, read on an oscilloscope. The electrodes were placed on the ventral thigh at the same loci as in the previous experiment, and the O's absolute threshold was obtained as before to a 200-msec. burst of the 1 KHz signal. The stimulus was then raised to 3 dB SL, roughly equivalent to the vibrotactile magnitude of 15 dB SL, and the second stimulus was equated to the first for magnitude.

The quality generated by the electrical stimulus was reported as vibratory with a mild "abrasive" element for the longer stimulus durations, and pressury for the shorter values. If pain was felt, the electrodes were

moved laterally 1 or 2 cm, but this was seldom necessary. The O proceeded to determine the ISOI for best movement as in the first experiment, but for durations of 5, 25, 50, 200, and 400 msec. The results are shown in Fig. 6. The 400-msec. duration is not shown, but the mean value for electrocutaneous movement was 223 msec., SD 97 msec., compared to the vibrotactile value at this duration of 246 msec., SD 86 msec. Neuhaus' data and the vibrotactile data are included for comparison. Two facts are in evidence in this graph: first, mechanical vibration and electrocutaneous stimulation do not require significantly different conditions for perception of apparent movement, and second, the temporal conditions for good apparent movement are not modality-bound, under the present experimental procedures.

An interesting parallel to these findings arises from a study by Hirsh and Sherrick (1961). When the O was asked to judge the temporal order of two brief stimuli in either the visual, auditory, or cutaneous systems, he required about a 20-msec. interval between them to be correct 75 percent of the time. The authors stated:

"To be sure, the time intervals used in the visual experiment lay in a range where sometimes apparent movement was seen and there the judgment of 'which came first' may have been deduced from 'in what direction did the light move' (1961, p. 432)."

This is not to imply that movement is a necessary condition for the perception of temporal order, nor that order must be perceived for movement to occur. These events co-exist over a range of stimulus intervals, along with the perception of simultaneity, unordered duality, and clearly ordered successiveness. Whether all these events are mediated at a level above the primary sensory areas of the cortex is not certain, but it would appear that perceived order and perceived apparent movement

are. The evidence for the latter statement is simply that the visual, the auditory, and the tactual systems all require the same inter-stimulus interval for the limen of ordered duality, and the visual and tactual systems require the same inter-stimulus onset interval for the judgment of optimal movement, and furthermore exhibit the same variation in ISOI when stimulus duration is varied. Whether the auditory system would yield similar relationships for apparent movement is uncertain, since the appropriate experiments have not, to our knowledge, been performed.

Bartley (1958, p. 270) has discussed at some length the hypothesis that visual imagery has a marked influence on the perception of haptic movement. In earlier studies, the reports of "bow" movement were thought to have their origin in this phenomenon, and therefore movement was not perceived so much as it was inferred by the O. A proponent of this hypothesis might conclude that his belief is confirmed by the present results, i.e., that visual imagery alone can account for the quantitative agreement between Neuhaus' and the present results. The Os in the present investigation were never exposed to visual motion, real or apparent, under any conditions, nor did they experience it at any time prior to the investigation. If visual imagery is the sole common element for the observed agreement between the two systems, it must be credited with a precision of determinacy that, for similar relationships, is unequalled in the history of perception! The present authors are disposed to agree with Bartley, who has said (1958, p. 270) that visual imagery may be con-

sidered an influence if the movement is not felt along or beneath the surface of the skin. In the present experiments, a fundamental part of the Os' criterion was movement along or within the skin surface for all or at least the better part of the space between stimuli.

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Notes

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