TACTILE-KINESTHETIC PERCEPTION OF LENGTH

By Mei-Fang Cheng, University of Pennsylvania

Several theories of tactile-kinesthetic (*t-k*) space perception imply that there is a close correspondence between *t-k* and visual judgments of length. Berkeley claimed that there is no true visual space perception; such perception is due to associations between visual stimuli and *t-k* perceptions.[1] It also has been proposed that there is no true spatial perception other than visual; what appears to be *t-k* space perception is dependent on visual imagery.[2] Other writers admit that there is a genuine *t-k* space perception, but claim that such perception is continually being adjusted to match visual perception.[3]

If perception in one modality is derived from another modality, or adjusted to match another modality, there should be good agreement between perception in the two modalities. Thus, Reid's demonstration of a kinesthetic illusion analogous to the visual vertical-horizontal illusion seems to lend credence to such theories, as Reid himself points out.[4] If, however, the pattern of constant errors with *t-k* stimuli is different from that with visual stimuli, theories which attribute independent spatial attributes to each modality would be supported.[5] One such difference has been reported by Davidon and Cheng.[6]

In that experiment, blindfolded *O*s were asked to feel two styli which defined a fixed (standard) spatial extent, and then to adjust a variable extent until it seemed equal to the standard. It was found that a radial movement was consistently overestimated relative to a tangential one,

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[1] G. Berkeley, *A New Theory of Vision,* 1963, 13-86.

[2] S. H. Bartley, Perception of size and distance based on tactile and kinesthetic cues, *J. Psychol.,* 36, 1953, 401-408; S. H. Bartley, L. T. Clifford, and A. D. Calvin, Effect of visual imagery on tactile and kinesthetic space perception, *Percep. Motor Skills,* 5, 1955, 177-184; Irvin Rock, *The Nature of Perceptual Adaptation,* 1966, 222-237.

[3] C. S. Harris, Perceptual adaptation to inverted, reversed, and displaced vision, *Psychol. Rev.,* 72, 1965, 419-444.

[4] R. L. Reid, An illusion of movement complementary to the horizontal-vertical illusion, *Quart. J. exp. Psychol.,* 6, 1954, 107-111.

[5] G. Révész, *Psychology and Art of the Blind,* 1960, 33-36.

[6] R. S. Davidon and M. F. Cheng, Apparent distance in a horizontal plane with tactile-kinesthetic stimuli, *Quart. J. exp. Psychol.,* 16, 1964, 277-281.

whether the two movements were along perpendicular (Fig. 1, Condition A) or parallel paths (Fig. 1, Condition B). Since there is no corresponding visual illusion with parallel lines, this '*r-t* effect' is unique to the *t-k* modality. Moreover, since Davidon and Cheng showed that it is type of arm-movement, rather than the direction of movement that determines the direction of *t-k* errors, it seems that Reid's illusion actually is not an analogue of the visual vertical-horizontal illusion, but rather is an instance of a more general class of illusion specific to the *t-k* modality. The correspondence between the two modalities is certainly not perfect; for a full account of space perception, modality-specific characteristics must be taken into account.

Davidon and Cheng's experimental arrangement differed from Reid's experiment and from studies of the visual vertical-horizontal illusion in one respect that may be important: their standard and variable extents were separated by 90° instead of being adjacent to one another. It is possible that the *r-t* effect that was obtained is specific to this separation and would not occur with an arrangement like that used in the earlier studies. One purpose of the present study is to test this possibility. Another is to explore the effect on *t-k* judgments, and the interactions, of two other spatial parameters: proximity to *O* and direction from *O* (in front of him or at his side). The object then, was to obtain more comprehensive and systematic evidence pertinent to the view of visual and *t-k* perception as products of two independent systems, each with its own structure and characteristics.

Method

Conditions. The experimental conditions are diagrammed in Fig. 1. The variable and standard extents were in a frontal plane in Conditions 2 and 3; in a horizontal plane in all the other conditions.

Conditions 1-3 (Experiment I) were designed to determine whether radial extent would be overestimated relative to tangential extent when the two extents are adjacent. These three conditions also provide data on opposing predictions based, respectively, on the *r-t* effect and on the visual vertical-horizontal illusion: In terms of the *r-t* effect, the vertical extent in the frontal plane in Conditions 3 (tangential) should be underestimated relative to the radial extent in the horizontal plane in Conditions 1 and 2, and should be judged equal to the (tangential) horizontal extent in the frontal plane in Condition 3. By analogy with the visual vertical-horizontal illusion, the vertical extent in Condition 3 should be overestimated relative to any horizontal extent, whether radial (as in Conditions 1 and 2) or tangential (Condition 3).

Conditions 4-7 (Experiment II) permit more detailed examination of the effects of separation between the standard and the variable. The angular separation was 45° in Conditions 4 and 5, 90° in Conditions 6 and 7. Conditions 8-11 (Experiment III) show whether apparent extent depends on closeness to *O* (the 'proximity-effect').

Differences between Conditions 8 and 9 and between Conditions 10 and 11 would reveal any interaction between proximity to *O* and radial *vs.* tangential movement. Differences between Conditions 8 and 10 and between 9 and 11 would reveal interactions between proximity and direction relative to *O* (front *vs.* side).

Conditions 12 (Experiment III) determines the relative magnitude of the *r-t* effect and the proximity-effect. Here the *r-t* effect and the proximity-effect should act in

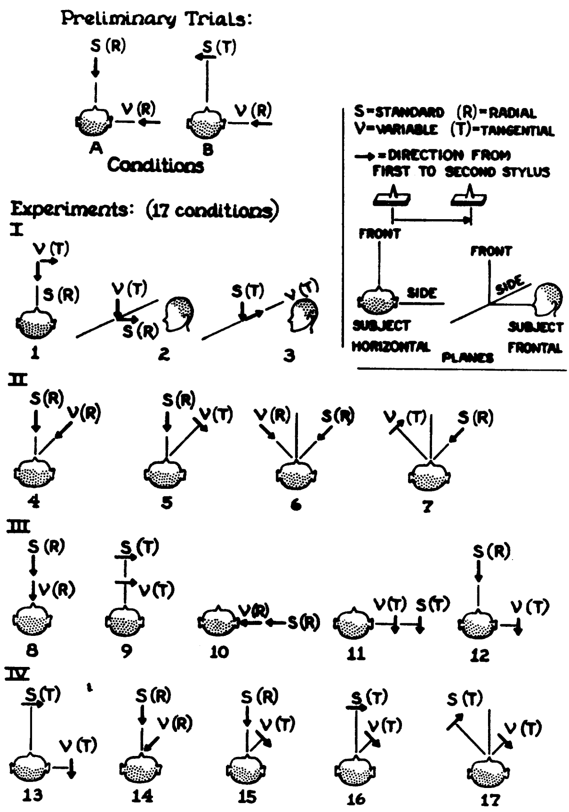

FIG. 1. DIAGRAM OF DIRECTION OF STANDARD AND VARIABLE STIMULI RELATIVE TO THE SUBJECT IN EACH CONDITION

opposite directions: the *r-t* effect alone should yield overestimation of the distant radial extent, while the proximity-effect should produce underestimation. Thus a net overestimation would indicate that *r-t* effect > proximity-effect; a net underestimation, *r-t* effect < proximity; and no error, *r-t* effect = proximity-effect.

Conditions 13 and 17 (Experiment IV) were designed to test the generality of the *r-t* effect, separation of standard and variable, proximity to *O*, and their interactions.

Observers. The *O*s were graduate and undergraduate women at Bryn Mawr

College. There were 18 *O*s in Experiment I. In each of the remaining three experiments, there were 12 *O*s drawn from a common pool of 24 *O*s.

Apparatus. In Experiments II-IV, there were pairs of pointed styli, 2 in. high and ¼ in. in diameter, on a table-top. One pair was fixed throughout the experiment, to provide a standard extent of 10 cm. The variable extent was defined by one fixed stylus and one which was free to slide between two parallel guides. In Experiment I, the styli were 1 in. high and could be arranged to define an extent in either a frontal or a horizontal plane. Only three styli were used, two fixed and one movable; the two fixed styli defined the standard extent of 13 cm., and one of these styli together with the movable stylus defined the variable extent.

Procedure. The method of adjustment was used. The blindfolded *O* was seated and her position and her chair-height so adjusted that the far stylus in front of her and the one at her side could be reached readily by the extended right arm at about shoulder-level. *E* guided the *O*'s hand to a point at which the tips of the thumb and fingers could surround first the top of one stylus of the standard pair and then the other. The hand then was guided to the movable stylus. The order is indicated by the arrows in Fig. 1. The *O* was asked to adjust the distance between the styli of the variable pair until it appeared equal to that between the standard pair. On a given trial, the two styli of a pair could be successively touched as often as desired. After an adjustment of the variable had been made, *O* was required to return to the standard and then to readjust the variable extent. A third observation of the standard was permitted on a given trial. The setting of the variable extent was measured to the nearest tenth of a centimeter. The effect of the order of experimental conditions within sessions was controlled by using balanced latin-square designs.

Results

The basic data were the mean settings for each condition, averaged across all three experimental sessions (two judgments per session). Comparison of experimental conditions was made by an analysis of variance of the balanced latin square, and by Duncan's multiple-range test; the significance of the deviation from the standard was tested by a one-tailed *t*-test for each condition. All of the results are given in Table I.

The radial-tangential effect. Radial extents were overestimated relative to tangential extents when the two extents were adjacent (Conditions 1 and 2) thereby showing that the *r-t* effect found by Davidon and Cheng when the extents were separated does not depend on spatial separation of the standard and the variable. In Condition 3, with an arrangement which would reliably yield a visual vertical-horizontal illusion, there was essentially no error in judging the vertical extent relative to the horizontal extent (since both extents here were tangential, no *r-t* effect is expected). Thus, the *r-t* effect occurs in the frontal plane as well as in the horizontal plane, and it occurs when the two extents compared are adjacent as well as when they are separated.

Apparent extent as a function of angular separation. In line with

Davidon and Cheng's findings, a radial extent was overestimated relative to a tangential extent when the two extents were separated by 90° (Condition 7) and also when separated by 45° (Condition 5). That these over-

TABLE I

VARIABLE EXTENT JUDGED EQUIVALENT TO STANDARD EXTENT IN EXPERIMENTS I, II, III, AND IV

Experiment	Condition	Number of Subjects	Physical Size of Standard Extent	Mean Error of Variable Extent†	t*	P	F	P
I	1	18	13	+1.6	1.89	<0.050		
	2	18	13	+4.0	4.03	<0.005	88.58	<0.005
	3	18	13	0.0	0.28	>0.400		
II	4	12	10	−0.3	0.70	>0.250		
	5	12	10	+1.8	5.87	<0.005	34.34	<0.001
	6	12	10	0.0	0.04	>0.500		
	7	12	10	+2.0	5.53	<0.005		
III	8	12	10	−0.2	0.09	>0.500		
	9	12	10	−1.6	4.47	<0.005		
	10	12	10	0.0	0.07	>0.500	35.70	<0.001
	11	12	10	−1.9	2.00	<0.050		
	12	12	10	+1.1	3.96	<0.050		
IV	13	12	10	−0.3	0.65	>0.300		
	14	12	10	0.0	0.13	>0.500		
	15	12	10	+0.3	0.66	>0.300		
	16	12	10	−0.9	2.39	<0.025		
	17	12	10	0.0	0.08	>0.500		

* One-tailed t-test.

† An entry of +2 with standard of 10 means that 0 set the variable at 12; −2 means that she set it at 8.

estimations were due to the *r-t* effect rather than simply to separation of standard and variable is shown by the lack of any significant errors in Condition 4 and 6 (the error in Condition 7 was significantly greater than in Condition 6, $p < 0.05$; that in Condition 5 was significantly greater than in Condition 4, $p < 0.05$). There was no significant difference between Conditions 5 and 7, indicating that the *r-t* effect is the same whether standard and variable are separated by 45° or by 90°; in contrast to this finding, the visual vertical-horizontal illusion has been found to be maximal when the two compared extents are 90° apart, but negligible with a separation of 45°.[7]

The effect of proximity to O. When both extents were tangential, the farther extent was consistently underestimated relative to the nearer (Conditions 9 and 11). Radial extents, however, were judged equal regardless of their distance (Conditions 8 and 10). The analogous visual finding would be a breakdown of size-constancy with maintenance of distance-constancy, but the experimental data actually show the opposite: under similar conditions, there is no constant error when both visual extents are tangential, but a tendency to overestimate the nearer extent when both are radial.[8]

The effect of direction from O. The farther of two tangential extents was underestimated regardless of whether the two extents were in front of the *O* (Condition 9) or at his side (Condition 11); there was no significant difference between the two conditions. Likewise, the proximity-effect was absent for radial extents whether the stimuli were in front of the *O* (Condition 8) or at his side (Condition 10); again, there was no significant difference between the two conditions. It is likely, therefore, that this interaction between proximity to *O* and type of movement (radial *vs.* tangential) holds true for all comparisons in the horizontal plane of tactile-kinesthetic space.

The relative magnitude of the radial-tangential effect and the proximity-effect. When both the *r-t* effect and the proximity-effect were present and acted in opposite directions, the direction of judgmental error was in line with the *r-t* effect. Condition 12 yielded a significant positive error ($p < 0.05$), indicating that *r-t* effect is greater than the proximity-effect.

Predictions derived from the radial-tangential effect and the proximity-effect. Given the above findings on the *r-t* effect and the proximity-effect, it would be possible to predict judgments of novel and more complex configurations of standard and variable extents. The assumptions derived from these findings are:

(1) Radial extents will be overestimated relative to tangential ones (the *r-t* effect) regardless of the separation between the two extents.

(2) Of two tangential extents, the one farther from *O* will be underestimated relative to the nearer one (the proximity-effect) regardless of whether they are in front of *O* or at his side. With radial extents, there will be no proximity-effect;

[7] W. T. Pollock and A. Chapanis, The apparent length of a line as a function of its inclination, *Quart. J. exp. Psychol.*, 4, 1952, 170-178.

[8] N. Schupf, unpublished observations.

equal radial extents at different distances from *O* will be judged equal regardless of their locations.

(3) The *r-t* effect will be larger than the proximity-effect.

Since conditions 13, 16, and 17 involve only tangential extents, the prediction in all cases is that the farther extent will be underestimated, yielding negative errors (Assumption 2). If there were no *r-t* effect—that is, if a radial and a tangential extent at the same distance from *O* appeared equal—negative errors also would be predicted for Condition 15; however, radial extents are overestimated relative to tangential ones (Assumption 1), leading us to expect a positive error in this condition (Assumption 3). Condition 14, involving two radial extents, is expected to show neither an *r-t* effect nor a proximity-effect, and hence no significant error.

All five conditions yielded results in the predicted directions, though not significantly so for Conditions 13 and 17. The results from all 17 conditions can be harmonized by adding a fourth assumption: that the proximity-effect decreases with increasing angular separation between standard and variable extents, being maximal when the two are lined up (Conditions 9 and 11), smaller when they are separated by a 45° angle (Conditions 15 and 16), and zero when the separation is 90° (Conditions 12, 13, and 17).[9] With this assumption, a large negative error is expected only in Conditions 9 and 11. A smaller proximity-effect, and hence a smaller negative error, is predicted for Condition 16. The same smaller proximity-effect is expected for Condition 15, but here a larger positive radial-tangential effect cancels it out. No proximity-effect, and hence no significant error, is predicted for Conditions 13, 14, and 17.

Discussion

The data of the present study do not support the view that *t-k* space-perception is derived from or calibrated in terms of visual space perception, or that *t-k* perception is the basis of all space perception. Rather, the evidence suggests that the two modalities are independent, each with characteristics of its own. The relevant findings on *t-k* judgments of relative extents are:

(1) Radial extents are overestimated relative to tangential extents (the *r-t* effect). Although this effect produces a judgmental error that is analogous to the visual vertical-horizontal illusion when the extents compared are both in a horizontal plane, it differs from the visual vertical-horizontal illusion in two ways: It is unaffected by amount of separation between the two compared extents (whereas the visual illusion is maximal with a 90° separation but negligible with a 45° separation); and there is no error with a vertical line in the frontal plane and a horizontal line in the horizontal plane (since both are tangential). (2) Of two tangential extents,

[9] This additional assumption actually was made before observations were made under Conditions 16 and 17; these conditions were studied as a test of the assumption, for which there is other experimental support. The proximity-effect has been found with variable and standard extents in line (Bartley, *op. cit.*, 401-408; D. Liddle and B. M. Foss, Tactile perception of size: Some relationship with distance and direction, *Quart. J. exp. Psychol.*, 15, 1963, 217-219), but not with the two extents separated by 90° (Schupf, unpublished observations).

the farther is underestimated relative to the nearer. The analogous visual phenomenon would be a breakdown in size-constancy, which is not found for visual stimuli under comparable conditions.[10] (3) Equal radial extents are judged equal even when one is farther from *O* than the other, whereas, with comparable visual stimuli, the farther is underestimated relative to the nearer.

Although the spatial pattern of *t-k* constant errors thus differs from the visual pattern, there may be a perceptual principle that applies to both modalities. Several aspects of visual perception have been found to depend on the ratio between some attribute of the stimulus and of the surrounding field, rather than on the absolute value of the stimulus itself.[11] Rock and Ebenholtz have shown that this is true for visual perception of size when a surrounding field of specific size is provided.[12] There is some evidence that when no stimulus defining the surrounding field is presented, similar effects are produced by the natural border of the visual field itself, as in the vertical-horizontal illusion.[13] The vertical axis of visual field is shorter than the horizontal axis; a given vertical line therefore is longer relative to the vertical axis than an equal horizontal line is relative to the horizontal axis, and, indeed, a vertical line typically is seen as longer than a horizontal one.[14] Moreover, Künnapas has shown that when the horizontal axis of the visual field is artificially shortened, overestimation of the vertical extent is conspicuously decreased.[15]

Is there a *t-k* counterpart of this relational influence on perceived extent? The radial extent of the *t-k* field for one arm is defined by a movement that starts with a finger tip at the shoulder and extends outward to arm's length; this distance is constant for any radial direction from *O*. The maximal tangential extent at arm's length in the horizontal plane is an arc of at most 120°; since the perimeter of a circle is $2\pi r$, it is clear that this maximal tangential extent must be larger than the maximal radial extent. The maximal linear extent for a tangential movement far from the body is greater, however, than that for tangential movement closer to the body. Thus, most of the experimental data can be shown to fit the relational assumption that, for a given physical extent, the larger the ratio between

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[10] Schupf, unpublished observations.

[11] T. M. Künnapas, The vertical-horizontal illusion and the visual field, *J. exp. Psychol.*, 53, 1957, 405-407; Irvin Rock and Sheldon Ebenholtz, The relational determination of perceived size, *Psychol. Rev.*, 66, 1959, 387-401; Hans Wallach, Brightness constancy and the nature of achromatic colors, *J. exp. Psychol.*, 38, 1948, 310-324; The perception of motion, *Sci. Amer.*, 201, 1959, 59-60.

[12] Rock and Ebenholtz, *op. cit.*, 387-401.

[13] Künnapas, *op. cit.*, 405-407.

[14] Künnapas, *op. cit.*, 405-407.

[15] Künnapas, The vertical-horizontal illusion in an artificial visual field, *J. Psychol.*, 47, 1959, 41-48.

it and the maximal extent for the same type of movement, the greater it will appear.[16] In conclusion, the same relational principle applies both to visual and to *t-k* space-perception, but each modality has its own characteristics which determine two different, modality-specific patterns of constant errors.

How general is the conclusion that *t-k* and visual space perception are different? In addition to the present experiments on judgment of relative extent, several experiments by other methods support the same conclusion.[17] For example, it has been shown that a power function gives a good description of the relation between physical length and both visual and *t-k* length, but the exponents are different for the two modalities. Harris found an exponent of 1.05 for vision and 1.18 for *t-k* judgments of distance between the forefingers.[18] In subsequent experiments with several different methods, the *t-k* exponent ranged from 1.1-1.3.[19] Similarly, using radial extents, Davidon found power functions with different exponents: 1.1 for *t-k* judgments and 1.5 for visual.[20] In agreement with the present findings, then, there seem to be general features shared by the modalities—a psychophysical power function describes both—but there are also modality-specific characteristics.

Summary

*O*s matched, by touch, a variable length and a constant length, with various spatial relations between the two stimuli. Three main effects were found: (1) Radial extents are overestimated relative to tangential extents, regardless of the separation between the two extents. (2) Of two tangential extents, the farther is underestimated relative to the nearer. (3) Equal radial extents are judged equal even when one is farther from *O* than the other. Since these findings differ from those in comparable experiments on visual size-constancy and on the visual vertical-horizontal illusion, it may be concluded that tactile-kinesthetic perception has modality-specific characteristics which are different from those of visual perception. The results do not support theories which hold that perceptions in one modality are derived from or calibrated in terms of perceptions in another. Some general perceptual principles that apply to both modalities are, however, suggested.

[16] The finding that the proximity-effect for a tangential movement varies with separation between the comparison stimuli cannot be accounted for by this principle.
[17] See, for example, C. S. Harris, Adaption to displaced vision: A proprioceptive change, University Microfilms, No. 63-8162, 1963.
[18] Harris, *op. cit.*, 1965, 419-444.
[19] Personal communication from C. S. Harris.
[20] Personal communication from R. S. Davidon.