THE HORIZONTAL-VERTICAL ILLUSION IN HAPTIC AND VISUAL SPACE

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by

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TABLE OF CONTENTS

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ABSTRACT

The vertical line of an inverted-T or L figure is judged visually to be longer than the horizontal line of equal length, an effect commonly called the horizontal-vertical illusion. This illusion has also been observed in touch perception, but the precise relationship between the haptic (tactile-kinaesthetic) and visual illusions is not clear. The present study is concerned with a clarification of this issue.

In the first series of experiments, constant errors in the haptic judgment of length in the horizontal plane were found to relate consistently to the time and velocity of limb movement. Radial movements, which are executed at a slower speed and for a longer time, are judged longer than tangential movements of equal length. The data were considered in relation to certain physiological and kinematic properties of the actively moving limb. Taken together with additional information on judgments of movement duration, the results suggest that the haptic illusion of length is governed by the perception of the difference in movement times. In this way, it is specific to properties of the moving limb and is thus quite unrelated to the analogous illusion in vision.

In the second series of experiments, the developmental function of the haptic L illusion was found to resemble that obtained for the visual L figure. It was concluded

that common developmental processes give rise to the similarity of the two illusions across age levels, and that such data could best be explained in terms of Piaget's account of perceptual development.

The final series of experiments were concerned with the illusion with the T figure. In line with observations on the visual figure, the haptic form of the illusion was found to diminish and consequently dissappear, when the dividing line was shifted from the midpoint of the divided line, to form an L or reversed-L, in the extreme. When the visual figure was exposed in a piecemeal fashion, an illusion was obtained only when the subject himself directed the exposure of the partial views, but not when the exposure of these was solely controlled by the experimenter. The haptic illusion was also found to be greater when the subject actively scanned the figure with the moving limb, compared with the condition where his limb movements were rendered passive. Taken in conjunction with the further finding that the illusion also occurs under line-drawing and walking conditions, it was concluded that the same central mechanism, ~~probably~~ possibly involving selective attention, governs the illusion in visual, haptic and locomotive space.

CHAPTER 1: INTRODUCTION

1.1 Visual and Haptic Illusions: a general statement of the problem.

Oppel in 1855 first described certain two-dimensional line drawings, which appeared variously distorted and attenuated, as "geometrical optical illusions". Since Oppel's first systematic studies, recent surveys (Over, 1968; Robinson, 1972; Weintraub, 1975; Zusne, 1968) indicate that the literature on such geometrical illusions is still steadily increasing and this area remains one of the most popular in perceptual research and theory.

Despite intensive experimental analysis, it is clear that most of these illusions still remain unexplained and that no theory to date has gained general acceptance (Over, 1968; Robinson, 1972). In contrast to the attempts of early researchers (e.g. Einthoven, 1898; Thiery, 1895-1896; Wundt, 1897) to explain all illusions in terms of a single theory, it is currently recognised that most visual illusions are multiply caused and contain a variety of peripheral and central determinants (Coren & Girgus, 1970, 1974; Robinson, 1972; Zusne, 1970). Broadly speaking, there are those theories that ascribe illusions to the structural properties of the optical and nervous system as opposed to theories based on the way visual information is processed in the higher centres. Structural theories contend that the illusory distortions arise from physiological sources associated with the normal optical and neural processing of visual inputs, while process theories attribute illusions to the cognitive processing of the perceptual inputs. The problem thus is to specify the level of operation of the specific processes that underlie the illusion and then to delineate the general features of such stimulation that may give rise to related classes of illusory effects. It will be shown below that one solution to this problem may lie in the study of the haptic analogues of these so-called geometrical illusions.

In vision, a number of techniques exist to elucidate the "peripheral" or "central" origin of a particular effect (Julesz, 1971; Turvey, 1973), but the application of some of these to the study of visual illusions is not without attendant problems (see: Day, 1961; Robinson, 1972). Also, as Turvey (1973) has pointed out, the distinction between peripheral and central loci in vision is necessarily vague, since the interface between visual sensory pathways and cortical structures is not a sharp boundary but rather, a gradual merger, as shown by the available electrophysiological evidence (see; Chung, 1968). On the other hand, if an effect expresses itself consistently across modalities, its central locus of operation is rendered more probable.

The widely accepted use of the term "optical" illusion has both implied that such spatial illusions are peculiar to vision and that it is sufficient to seek explanations of them solely in terms of the operating features of the visual system. This overlooks the fact that equivalent haptic illusions have also been obtained with many of the well known figures that give rise to visual illusions (Revesz, 1934). During haptic (tactile-kinaesthetic) inspection, a blindfolded subject is required to trace his finger over the raised contours of the figure. Tactual illusions, in which relief models of the figures are pressed onto the skin, have also been reported (Craig, 1931; Parrish, 1895; Revesz, 1934). However, as noted by more recent researchers (Fisher, 1968; Over, 1968) tactual illusions are of questionable reliability as both rapid adaptation of the skin and its relatively high two-point threshold render judgments difficult. On the other hand, haptic illusions which involve movement of the limb have been reliably demonstrated since the early work of Revesz (Over, 1967a, 1968).

In contrast to the intense experimental interest engendered by the visual illusions, the research on haptic illusions has been relatively sparse and sporadic. As with its visual counterpart, a proportionately large number of the available haptic studies are centred on the Mueller-Lyer figure (Bean, 1938; Frisby & Davies, 1971; Moses & Desisto, 1970; Over, 1966, 1967b, 1968; Patterson & Deffenbacher, 1972; Rudel & Teuber, 1963; Tsai, 1967; Wong, 1975a). Taking this illusion as a case in point, the available data on the haptic figure serve to endorse the view that the Mueller-Lyer effect is centrally determined. For both the haptic and visual figure, the line subtended by the outward-directed obliques ("fins") is consistently judged longer compared with that enclosed by inward-directed obliques ("arrows"). Stimulus features which affect visual judgments also similarly affect haptic judgments of the figure (Over, 1966; Rudel & Teuber, 1963; Wong, 1975a). Such data tend to refute the suggestion that quite different processes coincidently produce equivalent spatial illusions across the two modalities. Also, the fact that congenitally blind subjects manifest similar illusions with the haptic figure (Bean, 1938; Patterson & Deffenbacher, 1972; Tsai, 1967) argues against the view that haptic judgments of illusions are controlled

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A similar analysis can be made of other illusion figures provided that there are sufficient data to allow for such a comparative evaluation. Unfortunately, the available data on haptic illusions fall grossly behind the current wealth of information accumulated for the visual figures. Thus, the status of some theories of illusions cannot be adequately evaluated in terms of the theoretically important relationship between visual and haptic illusions. A general aim of the present study is to help redress this deficiency by carrying out a programme of haptic studies on another well known illusion — the so-called horizontal-vertical illusion, to which attention will now be turned.

1.2 The visual horizontal-vertical illusion and the visual field hypothesis.

The vertical line of an inverted-T or L figure is judged visually to be longer than the objectively by a perceptual framework acquired through visual experience. The data on the haptic Mueller-Lyer figure thus make it more compelling to accept a central explanation of the illusion couched in terms of processes that can share a common expression across modalities.

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1.2 The visual horizontal-vertical illusion and the visual field hypothesis.

The vertical line of an inverted-T or L figure is judged visually to be longer than the objectively equal horizontal line, an effect commonly called the horizontal-vertical (HV) illusion. The background on the visual HV illusion is extensive, and a representative review of some of these studies can be found in Kunnapas (1955a), Zusne (1970) and Robinson (1972). In this section, only those visual studies that are central to the development and formulation of ideas for the present project will be considered. As only a handful of studies on the haptic illusion has been published, these will be discussed in greater detail in sections 1.3 and 1.4.

Fick (1851) first reported that the vertical component of an inverted-T figure is apparently longer than the horizontal of equal length. The magnitude of the illusion is usually about 10% (Avery & Day, 1969) but may be as much as 20%-43% depending on the figure used and the conditions of testing (Chapanis & Mankin, 1967; Piaget, Matalon & Bang, 1961). Following Fick (1851), Finger and Spelt (1947) and later Kunnapas (1955a), using both the inverted-T and L figures, showed that both the verticality of one line and its bisection of the other contribute to the effect. Thus, when bisection is eliminated, as in the L figure, the illusion is reduced, but the vertical still appears to be about 3%-5% longer than the horizontal.

Failure to differentiate between the separate contribution of the effects of verticality and bisection has led to some confusion in the interpretation of data (Deregowski, 1967). Accordingly, it is pertinent at this stage to reiterate Kunnapas' (1955a) point that "in the vertical-horizontal figures two different illusions appear: (a) the classical overestimation of the vertical line compared with a horizontal line of equal length, and (b) the overestimation of the dividing line. Together they produce the phenomenon that has, until now, been erroneously called the vertical-horizontal illusion." It is convenient, however, to continue to refer to the effect as the HV illusion but to clearly distinguish between the illusion with the T (HV-T) or L (HV-L) figures. For the remainder of this section and section 1.4, the discussion is primarily focused on the HV-L illusion while that for the HV-T illusion is deferred to Chapter 4.

One of the most widely cited explanations of the HV-L illusion is due to Kunnapas (1955b, 1957a, 1957b, 1958a, 1958b, 1959a, 1959b, 1963) who attributes the illusion to a frame effect imposed on the visual field by the natural elliptical orbit of the eye.

Kunnapas' visual field hypothesis is not precise with respect to the locus of the effective visual field.

Since the binocular visual field as chartered by a perimeter (see: Ruch & Fulton, 1960) is approximately a horizontal ellipse, the binocular visual field is wider than it is tall. Additionally, Kunnapas (1959a) has reported that the apparent length of a vertical line viewed through an artificial elliptical frame decreased as the frame was changed from a horizontal (i.e. similar to the natural frame imposed by one eye alone) to a vertical orientation. Since the illusion is present with either monocular or binocular vision (Avery & Day, 1969; Houck, et al, 1972), it will suffice to ascribe the visual field effect to the frame imposed by the natural elliptical orbit of the eye.

The visual field has a shorter vertical than horizontal axis. Phenomenally, an extent parallel to the vertical axis appears longer than one parallel to the horizontal axis. When the visual field was experimentally distorted (as in viewing through an artificial pupil), so that the vertical axis was equal to or longer than the horizontal one, overestimation of the vertical extent was significantly decreased (Kunnapas, 1975b, 1958b, 1959a).

However, as noted by Robinson (1972), Kunnapas' attempts at distorting the visual field by artificial means have merely reduced the magnitude of the illusion in a direction dictated by the hypothesis. If the frame effect is the sole determinant of the illusion, a reversal of the illusion is a necessary consequence when the vertical line is aligned with the longer component of the visual field as the axis of the imposed visual frame is made vertical. However, such a result has not been found. More recent studies also indicate that the visual frame may only play a minor role in its influence on the HV-L illusion (Avery & Day, 1969; Houck, Mefferd & Greenstein, 1972; Thompson & Schiffman, 1974). Thus, the current status of the visual field hypothesis remains uncertain, and as Robinson (1972, p. 100) puts it: "this is a fascinating theory still needing a crucial test."

1.3 The horizontal-vertical illusion in passive touch: evidence for a perceptual frame effect.

The major premise of the visual field hypothesis is that structural characteristics of the receptor organ can provide a perceptual framework for relational judgments to determine the apparent lengths. Recent studies indicate that this principle can also explain the occurrence of the HV illusion in passive touch. Fry and Craven (1972) obtained an illusion with the T figure by tracing a stylus through a template of the figure onto the outstretched palm of the subject. The bisector aligned with the longer proximal-distal axis was judged <u>shorter</u> compared with the bisected line traced at right angles to the bisector and located along the shorter lateral axis of the palm near the wrist. The illusion was found to vary from 9%-19% among children and adults. However, this illusion is a reversal of the effect found with a visual presentation of the HV-T figure in which the bisector is consistently judged to be <u>longer</u> than the bisected line (see studies reviewed in section 4.1 of Chapter 4).

The reversal of the HV-T effect in passive touch can be explained if one assumes that the illusion is solely governed by the elliptical skin surface provided by the outstretched palm in a manner analogous to the role played by the elliptical visual field (section 1.2) in the visual form of the HV-L illusion. This assumes that the bisection factor does not play a role in passive touch. Thus, the overestimation of the bisected line is accountable in terms of its alignment with the shorter lateral axis of the natural elongated frame of the extended hand.

This hypothesis was directly tested in a study by Wong, Ho and Ho (1974).* When a T figure was traced

* A full description of this study is given in Supporting Paper I in Appendix 1.1.

onto the outstretched palm, an illusion of 13.72% was obtained with the bisector along the longitudinal axis being judged the shorter. Having thus confirmed the previous finding of Fry and Craven (1972), four more experiments were then conducted to determine the effects of the elliptical skin surface provided by the forearm on judgments of both the T and L figures. The volar surface of the forearm was picked as a logical receptor site on account of its relatively even receptor surface and a greater polarity of outline shape as compared with that of the palm.

The study showed that rotation of the T figure over 180° on the volar surface of the forearm resulted in an illusion function, with a reversal of the effect at 90°. A similar function was obtained with the L figure, indicating the absence of a bisection effect. The component line along the shorter lateral axis was judged longer than that aligned with the longitudinal axis of the forearm. It was also found that the effect was independent of the degree of stimulation on the skin and that an inscribed circle was similarly affected and perceived as a lateral ellipse. Thus, it was shown that the HV illusion in passive touch is determined by the shape of the receptor organ, with a magnitude of about 6%-9% on the volar surface of the forearm irrespective of whether the T or L figure is used as stimulus. A discussion of the implication of the absence of a bisection effect in passive touch is deferred to sections in Chapter 4. A partial replication of the study with the L figure alone and using children of different ages, suggests that the effect of the receptor frame is operative from the age of 8 years and remains unchanged to adulthood (Wong, 1975b).*

These findings, taken together with the visual studies reviewed in section 1.2, indicate that the ratio of stimulus extent to the surrounding field, rather than the absolute value of the stimulus, determines the relative magnitude of the extents. Analogous relational determinants of perceived size have also been noted by Rock and Ebenholtz (1959). When the stimulus field is imposed by the natural shape of the receptor organ as in the studies in passive touch, the evidence for a perceptual frame effect is compelling. Indeed, it has even been suggested (Cheng, 1968) that relational stimulation in the "haptic field" involving limb movements may give rise to an illusion analogous to the visual HV-L effect, even in the absence of any objective structural boundary to delineate the field. Attention

* A full description of this study is given in Supporting Paper II in Appendix 1.2.

will now turn to this and other studies of the HV-L illusion involving active movements of the limb. This will be followed by an outline of the rationale that underlies the first series of experiments on the active haptic HV-L illusion. An evaluation of the general status of the perceptual frame hypothesis is deferred to section 2.7 in Chapter 2, following presentation of the findings of Experimental Series I.

1.4 The active haptic horizontal-vertical illusion with the L figure, and statement of the problem.

In a study on haptic judgments of extent, Reid (1954) required blindfolded subjects to move a stylus a standard extent to the corner of a square frame in the horizontal plane, and then to reproduce an apparently equivalent extent on the adjacent side. "Vertical" (medial) extents were overestimated relative to "horizontal" (frontal) ones in the same plane. The result was taken as evidence for a haptic illusion complementary to the visual HV-L illusion and it was suggested that the former might account for the latter. However, as noted by Davidon and Cheng (1964), Reid's experiments had confounded the orientation of the distances to be judged with the type of arm movement. Specifically, "vertical" distances were indicated by a radial movement, involving mainly flexion or extension at the elbow, whereas "horizontal" distances were denoted by a tangential movement to an arc with the observer as centre and involving mainly abduction or adduction at the shoulder joint. In support of this analysis, Davidon and Cheng (1964) showed that radial movements, i.e. toward and away from the body were consistently greater in apparent extent than tangential movements. Thus, an extent in the median axis is apparently longer than an equal parallel extent to one side; the first involves radial movement and the second tangential. Cheng (1968) extended these experiments and confirmed the overestimation of radial extents relative to tangential and reported also that this difference held regardless of the separation between the two extents. As radial movements are specific to the horizontal plane, no relative overestimation of haptic extent is expected when the L figure is presented in the vertical plane, fronto-parallel to the subject. Cheng (1968), in a coordinated series of experiments, failed to obtain an illusion in the vertical plane, but Over (1966), Fisher (1968) and Reid (1954) have reported such an effect. However, it should be noted that the illusion reported by Over (1966) was not supported by statistical data while Reid's (1954) claim was made without supporting data altogether. In following up these studies, more recent investigations confirm the earlier reports (Cheng, 1968; Davidon & Cheng, 1964) on the radial-tangential effect with movements in the horizontal plane, and also the absence of the illusion when the L figure is presented in the vertical plane, involving only tangential movements (Day & Avery, 1970; Day & Wong, 1971; Deregowski & Ellis, 1972).

It thus appears that while a haptic HV-L illusion does in fact occur when the figure is appropriately placed and oriented, it is not obviously related to the visual HV-L illusion. Whereas in vision the effect is governed by visual mechanisms (Avery & Day, 1969; Kunnapas, 1955b, 1957a, 1957b), in haptic perception the illusion depends on the direction of movement of the limb relative to the observer. Although the mechanisms that underlie the visual and haptic illusions are obviously distinct, there remains the question of whether a common relational principle can be invoked to account for both effects. It is possible that the processes underlying haptic and visual illusions are similar in principle but different in operation (Over, 1966). An instance of this has already been outlined in terms of a common perceptual frame effect to explain the illusion in both vision and passive touch (see sections 1.2 and 1.3). Can a similar principle of relational judgments be applied to the HV-L illusion under active haptic conditions ? An explanation in these terms, as outlined below, has in fact been proposed by Cheng (1968).

Unlike visual space, the full "haptic field" is not instantly given; it is defined by successive movement. The horizontal haptic field at the waist level permits less radial than tangential movement. "The radial extent of the t-k (tactile-kinaesthetic) 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. .....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 it and the maximal extent for the same type of movement, the greater it will appear. 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" (Cheng,1968).

If Cheng's "haptic field hypothesis" is tenable, then a _general_ explanatory principle can be invoked for the HV-L illusion across conditions of visual, passive haptic (tactile*) as well as active haptic stimulation. Not withstanding the modality-specific features of the peripheral stimuli, perceptual information can thus be seen to be similarly distorted by centrally organized field effects.

However, there is a notable difference between visual and tactile representation of the stimulus on the one hand, and active haptic representation on the other. In the former case, relational judgments are said to be modulated by _given_ structural features of the receptor organ. In the latter, such features are _defined_ by the spatial activity of the limb. The attribution of a perceptual field to defined activities of the limb seems more circuitous and thus less convincing than that given directly by receptor characteristics. If it can be shown that the haptic HV-L illusion is directly governed by the dynamic properties of radial and tangential movements per se, then the hypothesis of an inferred haptic field will be rendered spurious. Experimental Series I, reported

* Operatively, "tactile" is used here to denote cutaneous presentation of the stimulus whereby the figure is traced onto the skin surface via a template and stylus, as described in Wong, Ho & Ho (1974).

in Chapter 2, was conducted with this specific aim in mind, viz. to determine if the haptic illusion is functionally related to the dynamic properties of radial and tangential movements.

CHAPTER 2: EXPERIMENTAL SERIES I: DYNAMIC PROPERTIES OF RADIAL AND TANGENTIAL MOVEMENTS AS DETERMINANTS OF THE HAPTIC HORIZONTAL-VERTICAL ILLUSION WITH THE L FIGURE*

2.1 Introduction to Experimental Series I.

The general aim of Experimental Series I was to determine if the constant errors derived from radial and tangential limb movements, and by implication the haptic HV-L illusion, could be related directly to specific stimulus features of the moving limb.

In active touch it is reasonable to assume that variation in the dynamic properties of limb movement makes a difference in perceived extent. Such an analysis was suggested by Brown (1846/1964) and more recently by Reid (1954), who both argued but without supporting data, that the slower the speed in traversing a distance, the greater the distance appears. Such a relationship was in fact demonstrated by Wapner, Weinberg, Glick, and Rand (1967), who found that with passive movement of the limb, a relatively faster (slower) speed gives rise to an apparently shorter

* These experiments have been accepted for publication in The Journal of Experimental Psychology: Human Perception and Performance (publication date: about February, 1977).

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(longer) distance. More recently, Ono (1969) has found the same relationship with active movement in line drawing tasks wherein the longer lines are those drawn at the slower speed for a longer time. In these two studies, the speed of arm movement was the independent variable. With passive movement, the limb was moved at various speeds through its attachment to a movable finger plate, and with active movement the subject was instructed to draw lines at relatively fast or slow speeds.

From the available evidence, it seems reasonable to assume that the apparently longer radial movements are executed at a slower speed and for a longer time, compared with tangential movements of equal lengths. Experiments 1.1 and 1.2 confirmed this relationship as well as providing additional information on the judgment of haptic length in different planes of movement. Experiments 1.3 and 1.4 were then conducted to seek further information on the specific dynamic components of the movement that might underlie the difference in perception of radial and tangential lengths.

2.2 Experiment 1.1: Confirmation of the radial-tangential effect.

By rotating the L figure in 15° increments over

90°, Deregowski and Ellis (1972) showed that the haptic HV-L illusion is a special case of the more general radial-tangential effect (Cheng, 1968) wherein the two components of the L figure are contrasted maximally by radial and tangential movements. This, as well as related past studies (see section 1.4) on the illusion, have all employed comparative judgments where responses were made with reference to the standard component of the figure. If the effect is intrinsic to the properties of the moving limb, a more direct assessment can be made by instructing the subject to move the limb along standard distances prescribed verbally by the experimenter. Experiment 1.1 was conducted initially to confirm the occurrence of the radial-tangential effect under conditions where the subject made operative judgments of length in response to a verbal, rather than an objective, standard. The generality of the effect was also assessed by including in the design a factorial combination of some parameters of limb movement.

Method

Apparatus. The details of the apparatus are depicted in the upper half of figure 2.1. Essentially, it consisted of two No. 11 gauge polished steel rods, each 45 cm long, a 180° protractor and a 40-cm pointer rule graduated in mm. One rod could be rotated and secured along any orientation through 170°, while the other rod was fixed and aligned at 180°. The pointer rule was affixed at one end such that it could be swivelled at the point of intersection of the rods, to an alignment below either of the rods. A 1.5 mm long tubular marker made of soft plastic was inserted through each rod. The marker could be slid along the rod effortlessly by the tip of the extended index finger, and it could maintain its rested position even when the rod was affixed in the vertical plane. The apparatus could be secured to a testing table through clamps and presented to the subject either in the vertical or horizontal plane.

Subjects. There were 42 unpaid volunteer subjects: 23 males and 19 females. Their age range was 17-32 years, with a mean age of 20 years. The subjects were randomly assigned to one of three experimental conditions, each consisting of 14 subjects.

Experimental design and procedure. In the first condition (Horizontal-Front), the apparatus was placed horizontally on a low table in front of the subject, so that movement of the index finger (in contact with the marker) along the rod at 90° was radial, and movements along the rod at 0° (to the rule graduated in mm. One rod could be rotated and secured along any orientation through 170°, while the other rod was fixed and aligned at 180°. The pointer rule was affixed at one end such that it could be swivelled at the point of intersection of the rods, to an alignment below either of the rods. A 1.5 mm long tubular marker made of soft plastic was inserted through each rod. The marker could be slid along the rod effortlessly by the tip of the extended index finger, and it could maintain its rested position even when the rod was affixed in the vertical plane. The apparatus could be secured to a testing table through clamps and presented to the subject either in the vertical or horizontal plane.

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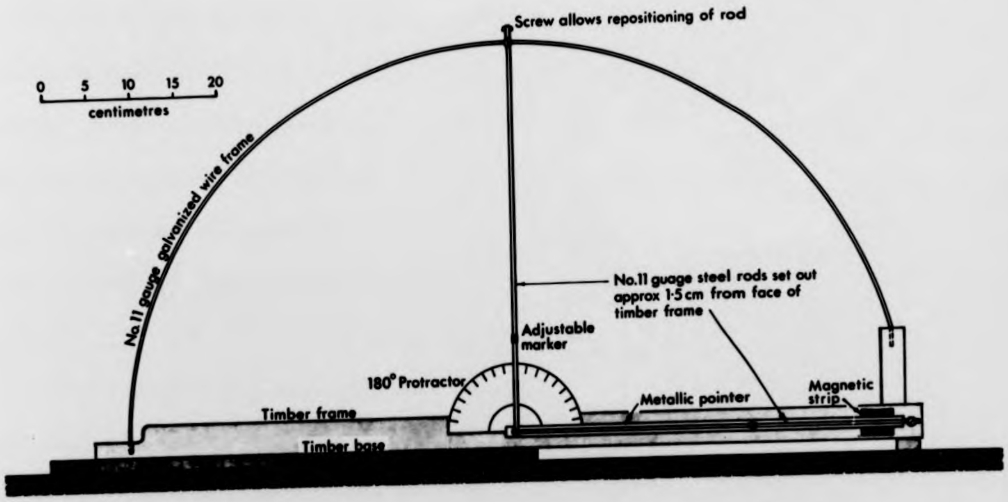
FIGURE 2.1

Upper half depicts apparatus employed in Experiment 1.1. One rod could be rotated and secured along any orientation through 170°, while the other rod was fixed at 180°. Lower half shows arrangements to obtain photographic records of subject's limb movements in Experiment 1.2 and 1.3. Polaroid camera recorded movement of light (from stroboscope) reflected off ballbearing attached to subject's finger tip.



Screw allows repositioning of rod
0 5 10 15 20
centimetres
No.11 gauge galvanized wire frame
No.11 guage steel rods set out approx 1·5 cm from face of timber frame
Adjustable marker
180° Protractor
Timber frame
Metallic pointer
Magnetic strip
Timber base

subject's right) were tangential. In the second condition (Horizontal-Side), the apparatus was placed horizontally on a low table at the subject's right side, again such that radial movements were executed along the rod at 90^{o} and tangential movements at 0^{o} (toward the subject's front) and 180^{o} (toward the subject's back). In the third condition (Vertical-Front), the apparatus was placed in the vertical plane fronto-parallel to the subject at the distance of the outstretched arm and index finger, so that movement of the finger along the rods was tangential at all orientations.

For each condition, judgments were made in accordance with a factorial combination of seven rod orientations and four prescribed movement extents. The rod orientations were set at 0^{o}, 30^{o}, 60^{o}, 90^{o}, 120^{o}, 150^{o} and 180^{o}, whereas the verbally prescribed extents were for movements of 3 in., 6 in., 9 in. and 12 in. (7.5 cm, 15.2 cm, 22.8 cm and 30.5 cm respectively) along the rod. The standards were prescribed in inches as the subjects were not fully conversant with metric units; however,the judgments were recorded to the nearest millimetres. Each factor combination was repeated four times, so that each subject was presented with a total of 112 trials. A different random order of presentation trials was subject's right) were tangential. In the second condition (Horizontal-Side), the apparatus was placed horizontally on a low table at the subject's right side, again such that radial movements were executed along the rod at 90° and tangential movements at 0° (toward the subject's front) and 180° (toward the subject's back). In the third condition (Vertical-Front), the apparatus was placed in the vertical plane fronto-parallel to the subject at the distance of the outstretched arm and index finger, so that movement of the finger along the rods was tangential at all orientations.

For each condition, judgments were made in accordance with a factorial combination of seven rod orientations and four prescribed movement extents. The rod orientations were set at 0°, 30°, 60°, 90°, 120°, 150° and 180°, whereas the verbally prescribed extents were for movements of 3 in., 6 in., 9 in. and 12 in. (7.5 cm, 15.2 cm, 22.8 cm and 30.5 cm respectively) along the rod. The standards were prescribed in inches as the subjects were not fully conversant with metric units; however, the judgments were recorded to the nearest millimetres. Each factor combination was repeated four times, so that each subject was presented with a total of 112 trials. A different random order of presentation trials was employed for each subject.

The subjects were seated and wore blindfold goggles. Before each trial the experimenter placed the tip of the subject's outstretched index finger onto the plastic marker at the 0-mm setting and instructed him to slide the marker along the rod over the verbally prescribed standard distance. The distance traversed was recorded through a visual alignment of the farther edge of the marker with the reading on the pointer rule immediately below. The recorded distance constituted the subject's operative judgment. This procedure was repeated over the 112 trials for each of the 14 subjects in each of the three experimental conditions.

Results and discussion

The mean operative judgments and standard deviations for the stimulus conditions are shown in Table 2.1. The deviation of the mean judgment from the prescribed standard was calculated and expressed as a percentage. An operative judgment less than the prescribed standard indicated an overestimation of the movement and this was expressed as a positive percentage. The percentage scores served as convenient indices to depict the patterns of constant errors, and these are shown in Figure 2.2.

Table 2.1

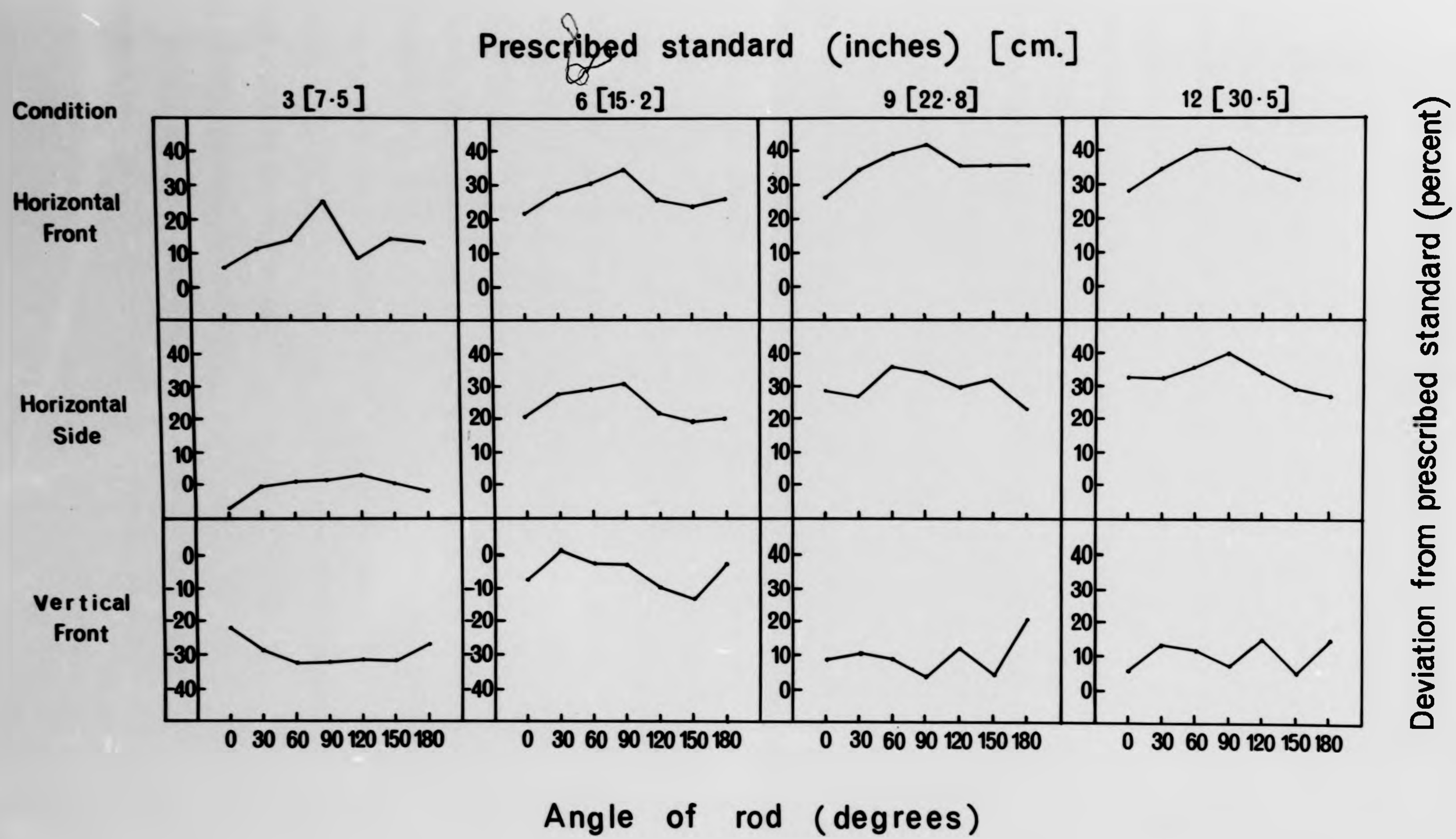
Mean and Standard Deviation of Operative Judgment (in cm) as a Function of Extent and Orientation of Movement of the Arm along Different Planes of the Body in Experiment 1.1

Bodily Plane	Prescribed standard in inches		Orientation of Movement						
			0°	30°	60°	90°	120°	150°	180°
HF	3	M	6.56	6.62	6.44	5.58	6.76	6.45	6.51
	(7.5cm)	SD	2.47	2.26	2.06	1.53	1.73	1.54	1.99
	6	M	11.91	11.03	10.57	9.97	11.30	11.61	11.25
	(15.2cm)	SD	3.74	3.49	4.27	2.50	3.34	3.89	2.12
	9	M	16.77	14.96	13.91	13.42	14.73	14.66	14.71
	(22.8cm)	SD	5.46	4.93	3.43	4.60	4.86	3.99	4.39
	12	M	21.88	19.89	18.30	18.25	17.99	19.85	20.89
	(30.5cm)	SD	7.06	6.26	4.78	5.47	4.70	6.33	6.75
HS	3	M	8.10	7.53	7.47	7.37	7.30	7.49	7.59
	(7.5cm)	SD	3.72	3.03	2.92	2.92	3.07	3.00	3.61
	6	M	12.06	11.09	10.80	10.63	11.97	12.34	12.12
	(15.2cm)	SD	4.54	3.93	3.27	4.77	3.44	4.03	3.56
	9	M	16.32	16.78	14.69	15.09	16.13	15.63	17.48
	(22.8cm)	SD	5.72	6.81	3.98	5.34	6.58	5.09	5.80
	12	M	20.51	20.70	19.72	18.52	20.10	21.58	22.25
	(30.5cm)	SD	5.50	7.41	6.89	5.01	7.05	5.98	5.76
VF	3	M	9.15	9.66	9.93	9.95	9.90	9.90	9.53
	(7.5cm)	SD	3.10	3.48	3.59	4.36	4.28	3.55	4.18
	6	M	16.27	15.06	15.61	15.64	16.72	17.22	15.63
	(15.2cm)	SD	3.58	4.89	5.79	4.84	5.02	4.93	4.93
	9	M	20.86	20.52	20.94	21.97	20.16	21.90	18.17
	(22.8cm)	SD	6.31	4.65	6.85	5.12	6.23	5.72	4.41
	12	M	28.95	26.66	27.10	28.50	26.02	29.02	26.07
	(30.5cm)	SD	6.65	6.11	6.42	7.16	6.96	6.00	5.60

Note: Abbreviation: HF = Horizontal front condition, HS = Horizontal side, VF = Vertical front.

FIGURE 2.2

Operative movements from Experiment 1.1, expressed as percentage deviations from verbally prescribed standards, as a function of orientation of the arm from the body along different planes. Positive percentages reflect movements shorter than prescribed standard and indicate overestimation of movement extent.



Prescribed standard (inches) [cm.]
Condition
3 [7·5]
6 [15·2]
9 [22·8]
12 [30·5]
Horizontal Front
Horizontal Side
Vertical Front
40
30
20
10
0
-10
-20
-30
-40
0 30 60 90 120 150 180
Angle of rod (degrees)
Deviation from prescribed standard (percent)

It would be expected that the apparently longer radial movements should show relatively more positive percentage scores. An examination of Figure 2.2 indicates that the functions obtained for the Horizontal-Front and Horizontal-Side conditions conform to expectation in that the percentage scores are generally more positive at 90^{o} than at 180^{o} and 0^{o}. However, this general trend is not evident among the data obtained for the Vertical-Front condition.

Separate analyses of variance were carried out for each of the three conditions. (The full statistical analyses are given in tables in the appendices.) For the Horizontal-Front condition, both orientation of the rod, $F(6,351) = 4.915$, $p < .0005$, and prescribed standard, $F(3,351) = 316.701$, $p < .0005$, were significant factors, but the orientation x prescribed standard interaction was not significant, $F(18,351) < 1$, $p > .05$. Similarly for the Horizontal-Side condition, both orientation, $F(6,351) = 3.567$, $p < .0005$, and prescribed standard, $F(3,351) = 372.818$, $p < .0005$, were significant factors, but the interaction between them was not significant, $F(18,351) < 1$, $p > .05$. For the Vertical-Front condition, orientation, $F(6,351) = 5.899$, $p < .0005$, prescribed standard, $F(3,351) = 555.951$, $p < .0005$, and the orientation x prescribed standard interaction, $F(18,351) = 6.991$, $p < .0005$, were all significant factors.

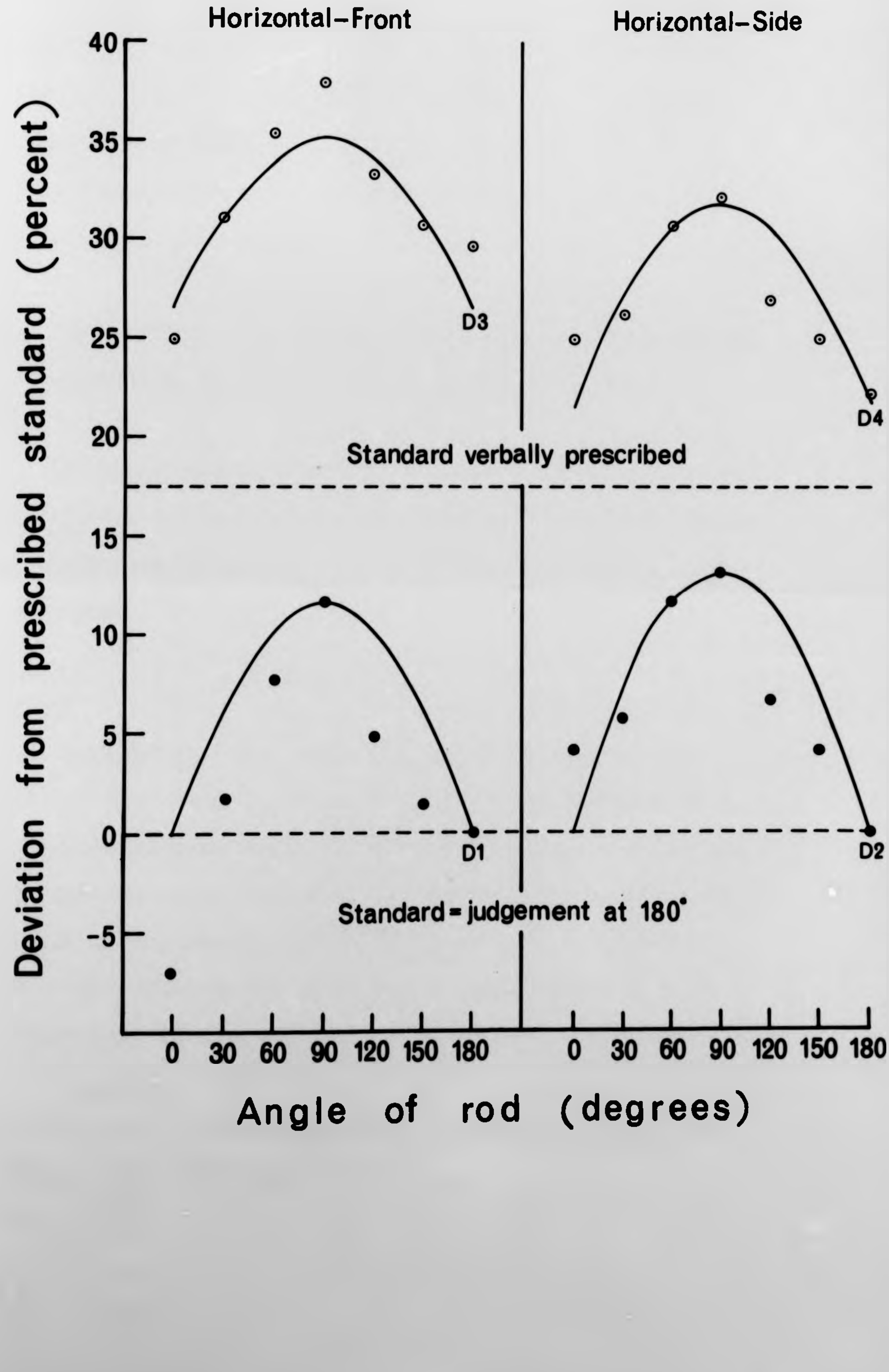
The mean operative judgments, pooled across the four prescribed standards, were further analysed to determine the nature of the function across the seven rod orientations. For the Horizontal-Front and Horizontal-Side conditions respectively, only the quadratic trend components were significant, $F(1,178) = 17.284$, $p < .001$; and $F(1,178) = 12.833$, $p < .001$. The absence of a significant linear trend for either condition indicates that the radial-tangential effect is symmetrical about the maxima at 90°.

In keeping with the approach adopted by Deregowski and Ellis (1972), it may be assumed that a radial movement is always overestimated by a constant factor K and that a perceived extent is a sum of the prescribed extent and its illusory radial overestimation. Thus, in the Horizontal-Front condition, the ratio of the radial movement extent at 90° (a) to the tangential component at 180° (b) is given by: $a/b = (1 + K \sin\alpha)/(1 + K \cos\alpha)$, where α is the angle of the component rod to the subject's saggital plane. The same equation can be applied to the Horizontal-Side condition where α is the angle of the component rod to the subject's coronal plane. Given the values a and b from the obtained data, the value of K could be determined and used in predicting values of operative judgments at other angles. These theoretical curves, D_1 and D_2, are shown in the lower half of Figure 2.3, together with the percentage scores calculated with respect to the arbitrary standard judgment at 180^o. These results can thus be directly compared with previous studies involving comparative judgments. Similar functions, D_3 and D_4, were also derived using the operative judgments directly. These are shown in the upper half of Figure 2.3. It can be seen that the theoretical functions provide reasonable fits to the empirical data points.

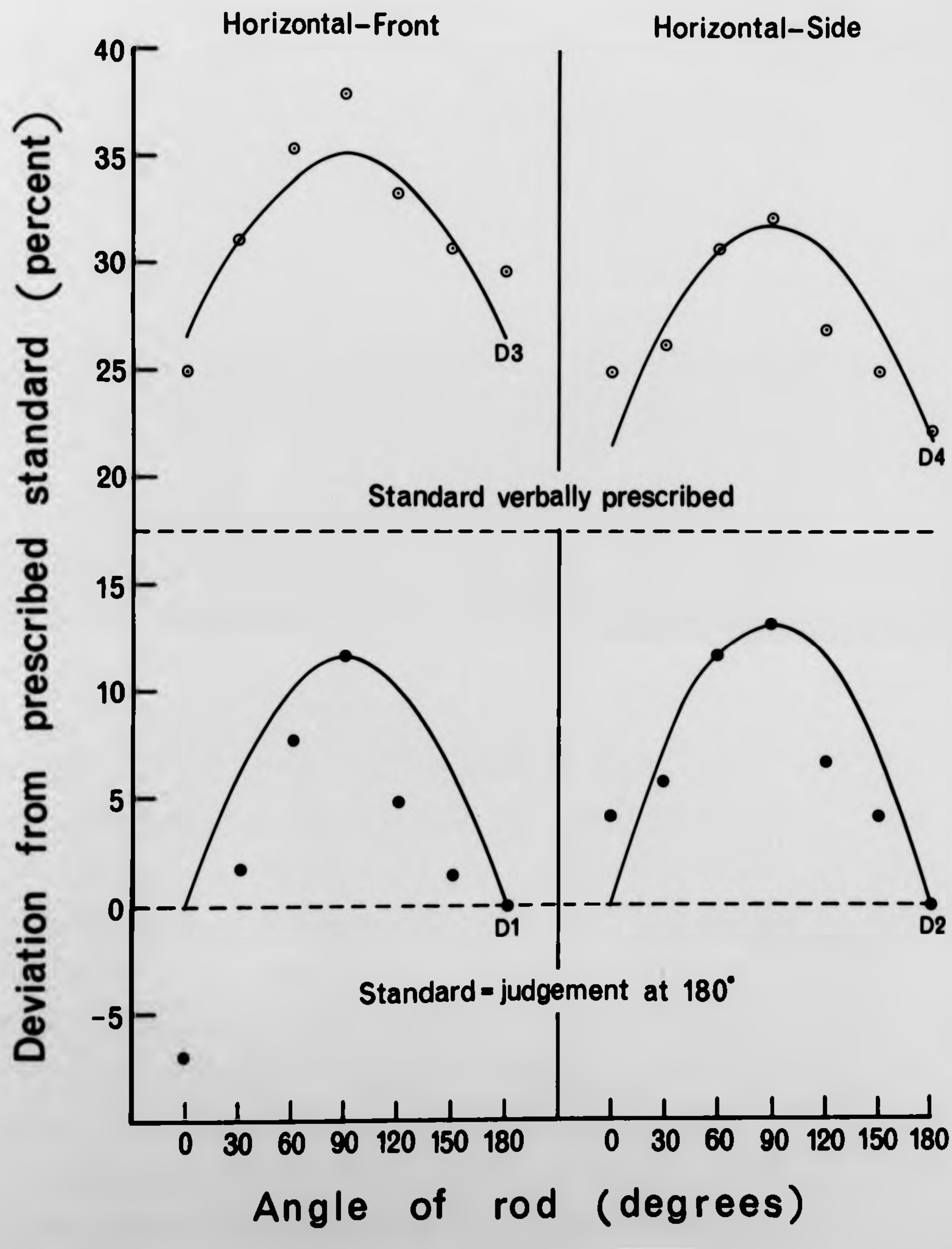
As judgments were made operatively, the patterns of constant errors can be ascribed directly to the intrinsic action of radial and tangential arm movements such that the extent is perceived as longest when the movement is purely radial and shortest when purely tangential. These results corroborate those of earlier studies (Davidon & Cheng, 1964; Day & Wong, 1971; Deregowski & Ellis, 1972) in which comparative judgments were employed. The significant orientation and orientation x prescribed standard effects obtained for the Verticl-Front condition merit a further comment. This orientation effect in the vertical plane cannot be related to the operation of any systematic factor (see Table 2.1 and Figure 2.2).

FIGURE 2.3

Mean operative movements from Experiment 1.1, expressed as percentage deviations from verbally prescribed standards (upper half), and from standards obtained from judgments at 180^{o} (lower half). Curves D_1, D_2, D_3 and D_4 are theoretically derived functions as described in the text. Apparently longer movements are indexed by larger percentage scores.



Horizontal-Front
Horizontal-Side
40
35
30
25
20
15
10
5
0
-5
Deviation from prescribed standard (percent)
D3
D4
Standard verbally prescribed
D1
D2
Standard = judgement at 180°
0 30 60 90 120 150 180
0 30 60 90 120 150 180
Angle of rod (degrees)



Horizontal-Front
Horizontal-Side
Deviation from prescribed standard (percent)
40
35
30
25
20
15
10
5
0
-5
D3
D4
Standard verbally prescribed
D1
D2
Standard = judgement at 180°
0 30 60 90 120 150 180
0 30 60 90 120 150 180
Angle of rod (degrees)

Taken in conjunction with its significant interaction with the degree of executed movement, the orientation effect probably reflects the fortuitous influence of local constraints (and therefore affects the speed) of the arm in transit.

2.3 Experiment 1.2: Relationship between the speed of movement and the radial-tangential effect.

Keeping to the paradigm adopted in Experiment 1.1, Experiment 1.2 was conducted to determine if the speed of radial movements is less than that for tangential movements.

Method

Apparatus. The apparatus was essentially the same as that used in Experiment 1.1 except the rods were painted a matt black, and the tubular markers and pointer rule were removed. To record the duration and length of movement, a Land Polaroid camera (model 350 with close-up kit 563) and a transistorized stroboscope (Tourostrob type 551 XW) were used.

Subjects. There were 50 unpaid volunteer subjects: 32 males and 18 females. Their age range was 18-26 years, with a mean age of 20 years.

Experimental design and procedure. Both the Horizontal-Front and Horizontal-Side experimental conditions as described in Experiment 1.1 were employed with the following modifications: For each condition, the subject was required to make only one operative judgment of 6 in. (15.2 cm) at each rod setting of 0°, 45°, 90°, 135° and 180°. A different random order of presenting the rod settings was used for each of the 25 subjects in each condition. For each judgment, a record was obtained of both the length and duration of operative movement described below.

A polished steel ball bearing of 6.35-mm diameter was attached to the tip of the subject's index finger nail with dark plasticine. In a darkened room and with both the Polaroid camera and flashing stroboscope placed at vantage positions, a photographic trace of the movement could be obtained through the reflected light of the ball bearing. The experimental arrangements are illustrated in the lower half of Figure 2.1, except here an L figure (for Experiment 1.3) is shown. Preliminary observations indicated that items in the stimulus field barring the ball bearing had to be adequately blacked out to produce an optimal photographic record. This precaution included covering the subject's limb with a long black nylon glove so that only the index finger tip with the attached ball bearing was

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On the signal "start" from the experimenter, the subject moved the tip of his index finger along the rod to delimit an apparent extent of six in. (15.2 cm). The experimenter activated the camera instantaneously upon giving the signal and terminated the exposure when the subject ceased movement and said "stop". The subject was instructed to move at a moderate speed that was comfortable to him. For each subject, the five operative movements were recorded on black and white film (Land film type 107) using the same exposure frame so that the finished print showed all five movement extents. These were measured to the nearest 1/4 cm by using a small divider to calibrate the recorded movement extent against a photographic print of a 30-cm rule exposed at precisely the same five rod orientations. The duration for each movement extent was measured to the nearest 1/10 sec by counting the total number of light dots that delineated the respective extent. This could be readily accomplished with the naked eye, but where necessary a magnifying glass was used.

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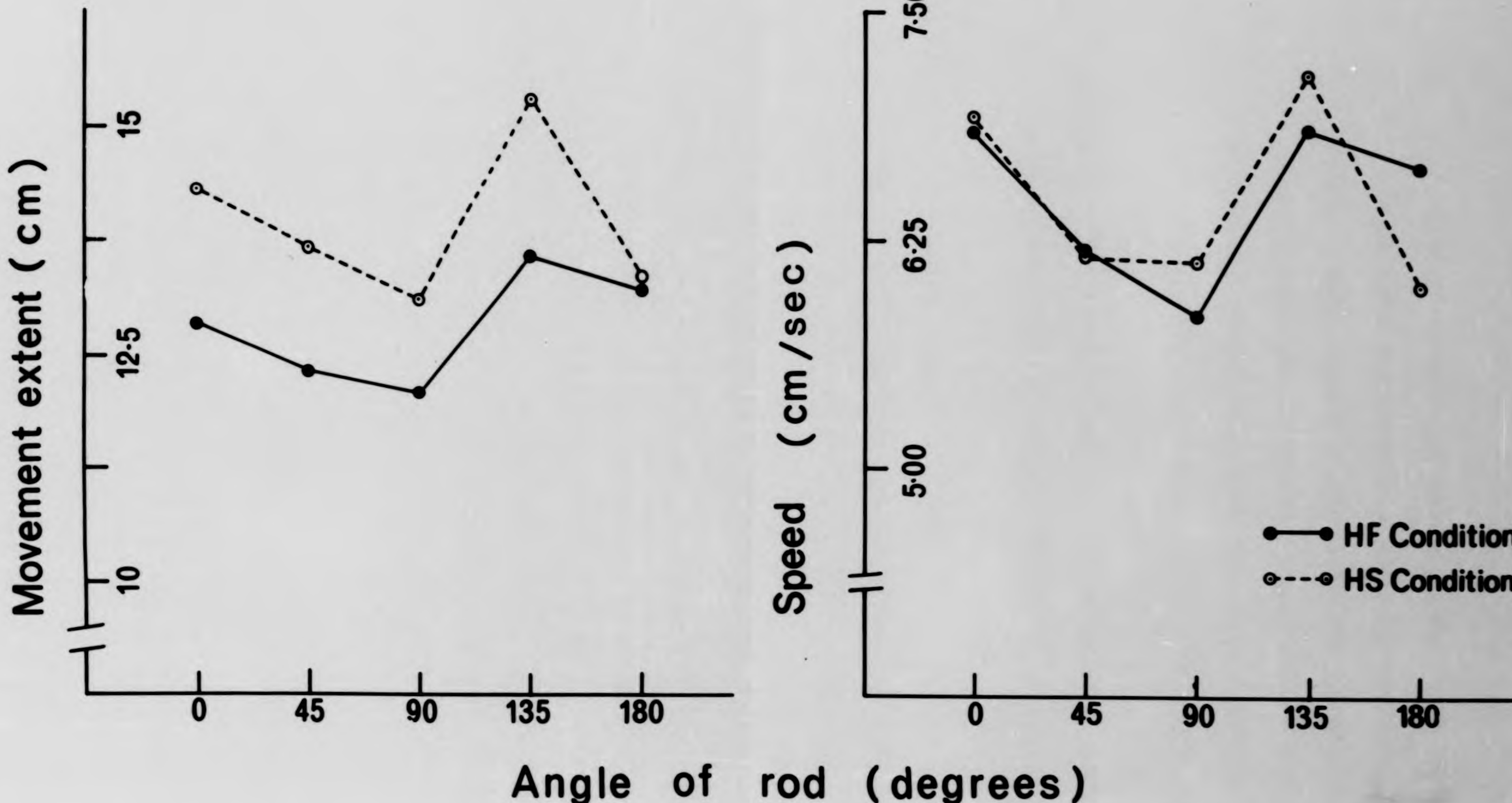
Results and discussion

The mean operative judgments (movement extents) and corresponding movement speeds across the five orientations of the rod are shown in Figure 2.4. These data support those obtained in Experiment 1.1 in showing that the maximally radial movement component at 90° for both the Horizontal-Front and Horizontal-Side conditions was judged longer than the movement components departing from 90°. The respective analyses of variance indicated values of $F(4,96) = 3.762$, $p < .01$, and $F(4,96) = 5.718$, $p < .001$. The functions relating the speed of movement to the orientation of the rod indicate that radial movements at 90° were executed slower than movements departing from 90°, with the sole exception of the component at 180° for the Horizontal-Side condition. The forms of the functions relating movement distance and speed, respectively, to movement orientation are essentially similar.

By analysing the data in terms of a covariance design with randomised blocks (Kirk, 1968, p. 475), three correlation coefficients could be computed between operative judgments and the speed of arm movement across the five movement directions. For the Horizontal-Front condition; the overall correlation, $rT(123) = .413$, $p < .01$, the correlation between

FIGURE 2.4

Obtained functions of operative movement length and speed of movement of the arm along different orientations in the horizontal plane, in Experiment 1.2. HF denotes movements in front of the subject, HS to the right side. Apparently longer extents are indexed by shorter operative movements.



Movement extent (cm)
10
12·5
15
Speed (cm/sec)
5·00
6·25
7·50
0
45
90
135
180
Angle of rod (degrees)
HF Condition
HS Condition

treatment level means, $rB(4) = .900$, $p < .05$, and the weighted average correlation, $rW(24) = .400$, $p < .05$, were all significant. Similarly, significant results were obtained for the Horizontal-Side condition: $rT(123) = .518$, $p < .01$; $rB(4) = .924$, $p < .01$; and $rW(24) = .495$, $p < .01$.

Taken together, the results of Experiment 1.2 indicate that the radial-tangential effect is functionally related to the speed of limb movements in the horizontal plane. Specifically, the apparently longer radial movements are executed at slower speeds compared with those for the apparently shorter tangential movements. These results are in line with earlier suggestions (Brown, 1846/1964; Reid, 1954) and confirm previous haptic studies involving both passive (Wapner et al., 1967) and active (Ono, 1969) limb movements.

2.4 Experiment 1.3: Time, velocity and acceleration characteristics of radial and tangential movements.

The findings of Experiment 1.2 imply that for the haptic L figure with components of equal length, the apparently longer radial extent is associated with a slower movement executed for a longer time. Thus, both differences in time and velocity cues are associated with the illusion of extent. Current physiological data suggest that control systems for displacement, speed, and the force of movement are intricately linked (Brooks & Stoney, 1971). This further implies that the force and, in the case where the mass of the limb is constant, the acceleration components of radial and tangential movements may also contribute to the illusion. Accordingly, Experiment 1.3 was conducted, using the haptic L figure, to obtain additional information on the time, velocity, as well as acceleration characteristics of radial and tangential movements.

Method

Apparatus. The apparatus consisted of a 45 x 45 x 1 cm black Masonite board on which were secured two No. 11 gauge polished steel rods, each measuring 36 cm in length. The rods were secured 3.0 cm from the surface of the board and arranged in the form of an L figure with the joining ends meeting at right angles. This point of junction* was cut and machined so that the ends abutted onto each other leaving no gap and the upper surfaces of the rods flush. Adjacent to each component of the L

* The terms "dichosection" and "intersection" have also been used by past investigators in relation to the L and T figures, and these terms will be used synonymously.

a 30-cm black plastic ruler, calibrated in mm in gold lettering, was fixed and aligned in parallel. The flat surfaces of the rulers were just below the upper parts of the rods. A gap of 1.0 cm separated the longitudinal edge of each ruler from the respective rod. A brass slider, 1.0 cm diameter in cross section and 1.2 cm long, was attached to each rod so that it could be slid and secured along any desired position on the rod. The inner face of the slider delimited the prescribed extent for the moving index finger. The rods and attached sliders were painted a matt black.

Subjects. There were 20 unpaid volunteer subjects; 12 males and 8 females. Their age range was 18-22 years, with a mean age of 20 years.

Procedure. The procedure was similar to that employed in Experiment 1.2, except here the L figure was employed. The experimental arrangements are as those shown in the lower half of Figure 2.1. The stimulus figure was presented in the Horizontal-Front condition, such that one component of the figure was radial and the other tangential. Both components of the L were set equal at 10 cm. The subject was instructed to move his index finger along the L figure at a moderate speed, after which he was required to indicate whether the radial or tangential component felt longer (in length). For each recording, the subject traversed each component of the L twice, beginning and ending at the junction. The starting movement direction was counterbalanced across subjects. Only one photographic record was obtained from each subject. From the finished print, the relative duration of movement along successive 1-cm portions of the figure could be determined by counting the number of light dots (each of 1/10 sec duration) outlined beside respective portions of the rulers. The gold-lettered calibrations of the rulers could be seen clearly through the reflected light of the stroboscope.

Results and discussion

Of the 20 subjects, 19 subjects indicated that the radial extent felt longer (in length) while one subject judged the tangential component to be longer. This difference in responses is significant ($p < .001$) by the binomial test. The duration of movement and respective standard deviations across successive locations of the L figure are shown in Table 2.2. These data on movement time were analysed in accordance with a 2 x 10 (Movement Direction x Location) repeated measures design. Significant differences were found between movement directions, $F(1,361) = 13.011$, $p < .001$, between locations, $F(9,361) = 236.065$,

Table 2.2

Mean Movement Duration (sec) and Standard Deviation across Successive Locations of the L Figure in Experiment 1.3

Movement Extent		Successive Locations (cm) from junction of L Figure 1	2	3	4	5	6	7	8	9	10	Total
Radial	Duration	1.245	.340	.255	.235	.215	.230	.245	.230	.245	.560	3.765
	SD	.325	.142	.160	.113	.126	.117	.099	.080	.114	.181	1.038
Tangential	Duration	1.145	.280	.225	.200	.185	.210	.195	.230	.255	.420	3.345
	SD	.367	.128	.085	.072	.093	.085	.099	.092	.082	.100	.752

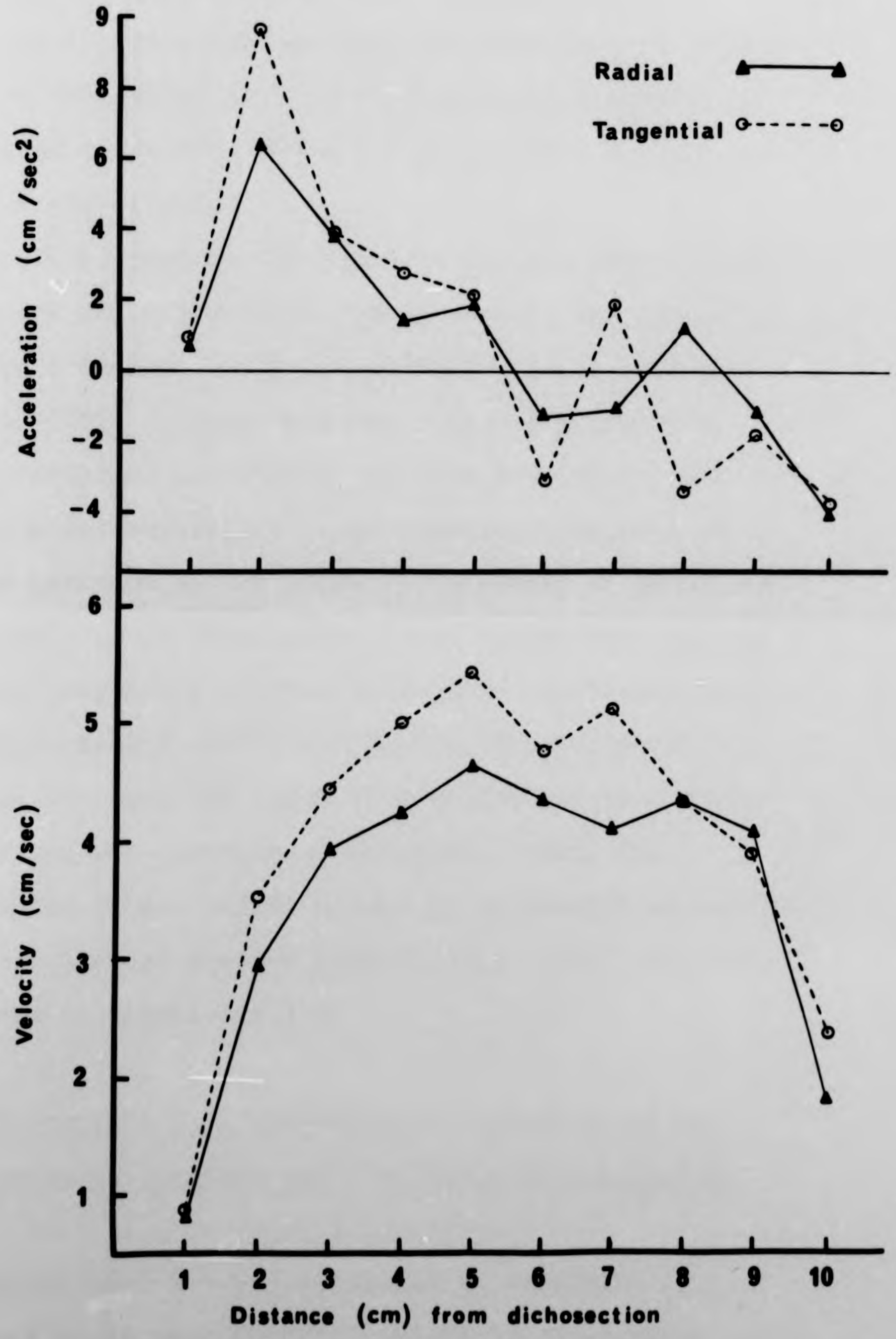
$p < .001$, and for the interaction between movement directions and location, $F(9,361) = 5.318$, $p < .001$. These results indicate that movement along the radial component of the figure takes a longer time to execute compared with the tangential, and that the patterns of movement time across the two extents are different.* From these data, further information was derived concerning the velocity and acceleration characteristics of the movements as a function of the distance from the junction of the L figure. These results are shown in Figure 2.5. As the analysis of the data on movement durations already indicated, the velocity of the tangential movement is clearly greater compared with that for the radial. However, no clear interpretation can be made of the data on the differences between the acceleration characteristics of radial and tangential movements.

From these results, it seems unlikely that acceleration cues, in the present context, can directly contribute to the illusion of extent. This analysis is in accordance with previous observations of the illusion of extent under conditions that precluded the

* In an unpublished supplementary experiment involving a further 14 subjects, it was found that the difference in radial and tangential movement times remained unchanged with repeated measurements over trials.

FIGURE 2.5

Velocity and acceleration characteristics of radial and tangential movements, from Experiment 1.3, as a function of the distance from the dichosection of the L figure.


Radial
Tangential
Acceleration (cm / sec2)
9
8
6
4
2
0
-2
-4
Velocity (cm/sec)
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10
Distance (cm) from dichosection

operation of acceleration cues. Specifically, the illusion is still present when real movement is either passive (Wapner et al., 1967) or absent altogether in cutaneous perception (Helson & King, 1931; Jones, 1956; Wieland, 1960).

With respect to the observed relationship between both time and velocity to judged extent, the physiological (Brooks & Stoney, 1971) and psychological literature (Keele, 1968) suggest that the interrelationship of these variables is complex and does not lend itself to a single interpretation. The specific relationship may be governed by the points of emphasis of particular experiments. In this regard, Reid (1954) has observed from introspective reports that under conditions that give rise to the haptic L illusion, the subjects attempt to keep the speed of movement constant while estimating the duration of movement. Thus, the apparently longer radial extent is presumably preempted by a judgment of greater elapsed time. This issue is examined in Experiment 1.4.

2.5 Experiment 1.4: Relationship between apparent movement duration and the haptic HV-L illusion.

Experiment 1.4 was conducted to determine if subjects could make accurate judgments of movement durations under conditions that produced the haptic L illusion. If the illusion of extent were governed by the discrimination of differential movement times along radial and tangential directions, it could be expected that the perception of movement durations would be veridical.

Method

Apparatus. The stimulus L figure employed was essentially the same as that described in Experiment 1.3. Two digital timers (Forth Instruments, Edinburgh) were also employed to record the actual duration of limb movements.

Subjects. There were 12 unpaid volunteer subjects: 2 males and 10 females. Their age range was 17-20 years, with a mean age of 19 years.

Procedure. The general experimental conditions of testing were similar to those described in Experiment 1.3, except here the subject was required to judge the relative duration of movement along the radial and tangential lengths while attempting to keep the velocity of limb movement constant along both lengths. For each trial, the experimenter operated a microswitch to synchronise with the observed movement along the radial and tangential component so that the actual durations of these movements were recorded separately by the two digital timers.

By changing the relative length of the components of the L figure along with judgments of duration, a point of subjective equality (PSE) for the length of the two extents could also be derived. This was accomplished by using the double-staircase technique (Wetherill, 1963; Wetherill & Levitt, 1965). Each staircase started with the tangential length (standard) equal to the 20-cm radial component (variable) and was replaced by a shorter or longer variable according to the subject's judgment of relative duration. Thus, a "longer" response (in time) for the variable resulted in its decrease in one step size (in length) for the next trial in the same staircase series. Steps of 1.0 cm were used until six reversals of judgment from "longer duration" to "shorter duration" (or vice versa) occurred. The mean of the six variable lengths that resulted in a reversal of judgment constituted the PSE.

Results and discussion

In accordance with Experiments 1.2 and 1.3, the mean movement time of 10.468 sec (SD = 6.625 sec) obtained for the radial component is significantly longer, $t(11) = 4.120$, $p < .005$, than that of 9.105 sec (SD = 5.955 sec) for the tangential. To determine if subjects could in fact perceive a difference in the relative movement times for the two movement directions, the total number of judgments on relative duration from all subjects were categorised in the form of a 2 x 2 contingency table as shown in Table 2.3. These results indicate that the subject's judgments of relative duration were more often correct than not, $\chi^2(1) = 10.603$, $p < .01$. The corresponding phi coefficient between subjects' judgments of relative duration and the actual relative time is .252 ($p < .01$). To assess the role of the velocity of movement on apparent duration, velocity data were also derived and analysed in the same manner as the data on duration. If velocity is a primary factor in the resolution of both apparent length and duration, it can be expected that apparent duration is also related to velocity such that a judgment of longer time is associated with the slower velocity. However, this relationship was found to be insignificant, $\chi^2(1) = 3.372$, $p > .05$, with a corresponding phi coefficient of .145 ($p > .05$).

The mean PSE for the component lengths of the L figure was found to be 18.583 cm ($SD = 1.201$ cm), thus confirming the overestimation of the radial movement by 7.085%, $t(11) = 4.085$, $p < .005$. In summary, the results of Experiment 1.4 indicate that

Table 2.3

Frequency of Judgment of Relative Duration against Actual Relative Duration of Radial and Tangential Movements in Experiment 1.4

Actual relative duration	Judged relative duration		
	Radial longer	Tangential longer	Total
Tangential longer	11	18	29
Radial longer	89	38	127
Total	100	56	156

under conditions that give rise to the haptic L illusion, the relative movement times along radial and tangential directions, in the majority of instances, can be discriminated by the subjects. The data favour an interpretation of the illusion of extent in terms of the differential perception of movement duration rather than velocity.

2.6 General discussion of the results in Experimental Series I.

As noted by Davidon and Cheng (1964), tangential movements involve distinctly different patterns of muscle activation and motion at the joints compared with radial movements. It is now evident that these differences in the intrinsic properties of the actively moving limb are reflected in the duration and speed of movement. Specifically, apparently longer radial movements are executed slower and for a longer time compared with tangential movements of equal extent. Given such data, a greater elaboration of the differential actions of radial and tangential movements now seems warranted.

In the present study, a purely radial movement involves greater motion at the elbow joint compared with that at the shoulder. In contrast, a purely tangential movement mainly involves abduction and adduction at the shoulder joint with the elbow joint relatively immobile. However, it should be noted that in the earlier study by Day and Wong (1971), the illusion persisted regardless of whether the radial movement involved flexion at the elbow or only rotation at the shoulder joint when the movement was executed with the arm outstretched. This argues against an explanation of the illusion solely in terms of the relative sensitivities of the joints or in terms of the differences afforded by proximal and distal musculature in the density of their spindle innervation and muscle type (Howard & Templeton, 1966; Matthews, 1972). The possibility that spindle discharges may influence the perception of joint angle and the induction of constant errors of movement (Goodwin, McCloskey & Matthews, 1972a, 1972b; Granit, 1972) is recognised, but the present data are not readily amenable to an interpretation in these terms. It thus seems more appropriate in the following discussion to consider the illusion in terms of the relevant cues that are inherent to the dynamic phase of the movement itself.

With rotational movements of the shoulder joint, the resistance offered by the limb to acceleration depends not only upon the mass but also upon its distribution about the shoulder axis, that is, upon the moment of inertia. The closer the mass is to the axis, the easier it is to turn. Since radial movements are executed with the limb more distal from the shoulder axis compared with tangential movements, the moment of inertia is accordingly greater along radial directions. With a smaller moment of inertia, a limb moving tangentially can be expected to accelerate faster and to maintain a greater velocity throughout the extent of movement.* The obtained velocity and duration components of the movement are clearly differentiated in accord with this analysis, but the differences in acceleration characteristics are not as clearly defined.

The obtained relationship between an apparently <u>shorter</u> haptic length with a <u>greater</u> velocity of movement does not appear to be in accord with the

* In a supplementary experiment, when the tangential component was placed <u>maximally</u> distal from the subject at full arm's length (with 180° rotation of the L figure), it was judged <u>longer</u> by 1.69% ($p > .05$) and 6.02% ($p < .005$) in the horizontal-front and horizontal-side condition, respectively. For both conditions (with 14 subjects each) the mean tangential movement velocity was also <u>less</u>, but not by a significant degree ($p > .05$), compared with that for the radial movement. As these data are only suggestive, the explanation offered in terms of moments of inertia should not be taken without qualification.

physiological evidence that indicates that movements of greater velocity result in the most kinaesthetic stimulation (Gibbs, 1954, 1961; Matthews, 1964; Ruch, Patton, Woodbury, & Towes, 1961). However, if elapsed time of movement is taken as the relevant determinant, then the relationship is accountable in terms of a greater "counting" of existing stimulus elements (Treisman, 1963) for movements of greater duration to give rise to judgments of longer length. This interpretation is endorsed by the finding that the differential time cues are indeed perceptible to the subject. In these terms, it should be noted that the illusion of extent is a further documentation of the interdependence in judgments in space-time relations in line with the tau (Helson & King, 1931) and tau-movement (Ono, 1969) effects found in the studies of psychological relativity.

This being so, the effect is not obviously related to the visual HV-L illusion either in its mode of operation or through a common principle of relational stimulation. On this account, the suggestion (Cheng, 1968) that both the visual and haptic HV-L illusions are governed by similar perceptual field effects can be rejected.

Before concluding this chapter, it seems desirable to consider, in the next section, the status of current explanations of the visual HV-L illusion, bearing in mind the implications of the haptic studies already presented.

2.7 An evaluation of current explanations of the visual HV-L illusion.

Apart from the visual field hypothesis, a number of explanations for the visual HV-L illusion have also been advanced (see: Robinson, 1972; Woodworth & Schlosberg, 1954; Zusne, 1970; for a listing). Wundt (1897) proposed one of the earliest explanations, in terms of the feedback derived from eye movement. This explanation asserts that greater effort is required to execute vertical eye movements than horizontal ones, and in some unspecified manner, this greater effort is translated into apparent length. Hicks and Rivers (1908) and more recently, Schiffman and Thompson (1974) were able to discredit the importance of eye movements by showing that the illusion was still present in tachistoscopic exposures where the presentation was too brief (e.g. 50 msec) for eye movements to occur.

Related to the eye movement explanation is the more subtle "centration" explanation put forward by

Piaget (1969). Over (1968) provides a succinct evaluation of this approach. According to the centration theory, attentional processes underlying illusions are closely related to peripheral inspection processes. Using photographic techniques, Piaget and Bang (1961a, 1961b) found that all parts of a figure do not receive equal densities of fixations during inspection. When shown a vertical and a horizontal line of equal length, subjects tended to fixate the top of the vertical line but the middle of the horizontal line. If inspection consists of movement from one fixation point to the other, the vertical line would receive the greater amount of direct attention during inspection. For this reason, it is claimed (Piaget, 1969) that the vertical line appears longer than a horizontal line of equal extent.

Teuber (1960) suggested that the objections raised earlier against eye movement explanations of illusions also apply to the centration theory. As noted by Over (1968), however, this criticism is not valid in that the centration theory states that errors are induced by localized attention and diminished by widespread attention, whereas eye movement explanations imply that illusions are minimal in the absence of eye movement and maximal with free inspection. Also Piaget (1969) has recognized the possibility that attention may involve central rather than peripheral processes. (This issue is taken up in greater detail in later sections). The close relationship normally existing between attention and regard makes it convenient to study attention through measures of fixation, but use of this method does not necessarily involve acceptance of the position that attention is a peripheral process. Nonetheless, significant objections remain with respect to the centration explanation. For instance, no specification is given of the particular stimulus features of the L figure that control attentional preferences. It would appear that attentional processes are thus defined in terms of their consequences rather than the initiating stimulus conditions. Without prior (and independent) specification of the error inducing features of the stimulus, the centration approach is unsatisfactory in that the claim can always be made that eye movements and attention differ whenever the expected pattern of fixations is not found (Over, 1968; Robinson, 1972). Thus, unless centration is defined by specific features of the stimulus conditions, independently of eye fixation patterns, the theory has little heuristic value. Further evaluation of Piaget's approach is deferred to later sections.

Another explanation of the illusion is based on the assumption that a line drawing may suggest surfaces and planes in depth or that the apparent length of a line is affected by the perspective read into the figure (e.g. Gregory, 1963, 1966; Tausch, 1954). Thus, a short vertical line in a drawing may represent a relatively long horizontal line extending away from the observer. According to this contention, the HV-L illusion is explained by assuming that the vertical component lies nearly parallel to the line of regard and represents a forshortened line, i.e. a line receding into the distance. In contrast, the horizontal segment is perceived as a line normal to the line of regard. If the images of the two components are equal, then, according to the operation of size constancy mechanisms, the apparently more distant vertical line appears longer.

Researchers interested in cross-cultural differences in the perception of the HV-L illusion (e.g. Segall, Campbell & Herskovits, 1963, 1966) have argued that the extent to which the vertical line is taken to represent a forshortening of a receding horizontal line is dependent upon habits of inference which subjects have learnt through interaction with the environment; and therefore, that the environment plays a role in determining the extent of the illusion. Apart from the poor empirical support (see; Deregowski, 1967; Gregor & Mcpherson, 1965; Jahoda, 1966; Morgan, 1959; Mundy-Castle & Nelson, 1962) for such an "ecological" hypothesis, the argument against it can be made in the same terms as the present argument against the perspective theory (see: Over, 1968, for further reservations about the ecological hypothesis).

Although misapplied constancy scaling explanations (or "perspective" theories), have been reasonably successful in explaining a variety of illusions of length (see: Day, 1972; Gregory, 1963), the available data suggest that they cannot account for all the illusory distortion in the HV-L figure (Girgus & Coren, 1975). Specifically, if misapplied constancy is the determining factor, then the positive illusion elicited by the upright L should reverse in direction (i.e. become negative to indicate overestimation of the horizontal component) when the figure is rotated 180° and presented to the subject as an inverted-L (┌ or ┐). That both the L and inverted-L figures produce positive illusions is clear from the experimental data (e.g. Avery & Day, 1969; Dawson, Young, & Choi, 1973; Thompson & Schiffman, 1974; Wober, 1972; Wursten, 1947). In view of the established body of evidence, the recent report of Schiffman and Thompson (1975) that the inverted-L produces a negative illusion of about 3%, is puzzling, especially when such data appear contradictory to their earlier report (Thompson & Schiffman, 1974).

In any case, variation in the magnitude of the HV-L effect with changes in the relative position of the elements on the retina, can be directly accounted for in terms of the dioptrics of the eye, without recourse to an explanation based on inferred features (e.g. depth cues) of the stimulus (Pearce & Matin, 1969; Pearce & Taylor, 1962; Valentine, 1912). Specifically, it has been suggested that the flattening of the peripheral zones of the refracting surfaces of the eye may be involved in the variation of the illusion with retinal position, especially when vertical eccentricity is involved (Pearce & Matin, 1969). In addition to such distortions due to the inadequacies of the optical system, the so-called "anisotropy" of visual space along the vertical and horizontal directions is known since the time of the Gestalt psychologists (Koffka, 1935) who made it one of the explanatory principles to account for visual phenomena, including the HV-L illusion. Recently, Avery and Day (1969) have argued that this anisotropy of perceived space, of which the HV-L illusion is one instance, is probably a function of retinal directions rather than directions relative to the elliptical visual field as suggested by Kunnapas (see;

section 1.2). This presupposes that in man, the organization of retinal cells may go even as far as to produce biases in favour of certain spatial directions. At the present time, there is insufficient data to resolve this issue. However, in view of the perceptual frame effect obtained with the tactile HV-L figure (Wong, Ho, & Ho, 1974), a reasonable tack is to assume that both retinal characteristics as well as a visual frame effect contribute to the visual illusion, with possibly a subsidiary influence from constancy scaling mechanisms. As has been suggested for so many other illusion figures (Coren, 1970; Coren & Girgus, 1973; Girgus, Coren, & Horowitz, 1973) the visual HV-L effect is probably also multiply caused. The strength of this conclusion is no less diminished by the findings of Experimental Series I, where it was shown that quite different mechanisms, specific to the haptic modality, can give rise to illusion effects analogous but unrelated, to the visual HV-L illusion.

2.8 Summary of findings in Experimental Series I.

Experimental Series I was conducted to determine if the constant errors in the haptic judgment of length could be related directly to specific stimulus features of the moving limb. Experiment 1.1 showed that apparent haptic length is longest when the limb movement is purely radial and shortest when purely tangential. Experiment 1.2 showed that for the haptic L figure with components of equal length, the apparently longer radial extent is associated with a slower movement executed for a longer time. Taken together with the findings of Experiments 1.3 and 1.4, the results suggest that the haptic illusion with the L figure is determined by the perception of the difference in movement duration rather than movement velocity or acceleration. As this effect is specific to properties of the moving limb, it is obviously unrelated to the analogous illusion obtained with the visual L figure.

CHAPTER 3: EXPERIMENTAL SERIES II: A DEVELOPMENTAL STUDY OF THE HAPTIC HORIZONTAL-VERTICAL ILLUSION WITH THE L FIGURE.

3.1 Introduction to Experimental Series II.

A substantial volume of work has been done on variations in the magnitude of the geometrical optical illusions as a function of age (see: Piaget, 1969; Vurpillot, 1963; Walters, 1942; Wohlwill, 1960; for reviews). In general, there is a clear trend of a decrease of visual illusion from early childhood to adulthood. The visual HV-L illusion, however, is a notable exception to this rule. Both Wursten (1947), and Hanley and Zerbolio (1965) have found that this illusion increases from early childhood and reaches a maximum at 9-10 years, followed by a gradual decline to adulthood. This trend is also suggested by the more limited study of Fraisse and Vautrey (1956).
A more recent study by Dawson, Young and Choi (1973), indicates that the illusion decreases sharply from 3 to 6.75 years, and then increases from age 6.75 to 12, to be followed by the expected slight decline to adulthood.

As noted by Pollack (1969), distinctly different mechanisms appear to underlie the ontogenetic trends of different classes of visual illusions. Thus, the decreasing illusory effect of some visual illusions (Type I) with increasing chronological age is believed to be produced by receptor aging. On the other hand, the growing magnitude of visual illusion (Type II) with increasing age is thought to be related to cognitive functioning.

Pollack's argument (see; Sjostrom & Pollack, 1971) about Type I effects is based on the decreasing sensitivity of the visual receptors which occurs with increasing chronological age. This loss of sensitivity has been measured in terms of both the amount of light reaching the retina (Weale, 1961a) and the absolute threshold to light stimulation (Luria, 1960; Robertson, & Yudkin, 1944; Stevens, 1948; Weale, 1961b). Weale (1963) states that the aging process is produced by physiological factors such as the yellowing of the crystalline lens and decreasing diameter size of the pupils.

Corresponding to the general loss of sensitivity of the receptors, Pollack (1969) feels that there is a decline in sensitivity to the variables which underlie the configuration of Type I phenomena, causing the illusory effect of the figures to decrease. In support of this view, investigations of Type I

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Corresponding to the general loss of sensitivity of the receptors, Pollack (1969) feels that there is a decline in sensitivity to the variables which underlie the configuration of Type I phenomena, causing the illusory effect of the figures to decrease. In support of this view, investigations of Type I illusions have revealed that the magnitude of the illusory effect is enhanced with increases in the brightness difference between the inducing parts of the figures and their backgrounds (Oyama, 1961; Weintraub, Wilson, Green, & Palmquist, 1969). Furthermore, Pollack (1963) claimed that sensitivity to brightness contrast declines as age increases from 8 to 12 years. The increasing contour detectability thresholds were also found (Pollack, 1963) to be negatively correlated with magnitude of a Type I effect such as the Mueller-Lyer illusion.

It seems unlikely that curvilinear developmental trends of the type found for the visual HV-L illusion, can be due to age changes in the physiology of the visual receptor system of the type suggested by Pollack (1969). In any case, the HV-L figure does not contain features that can give rise to brightness differences in the first place.

Although the most plausible explanations for the visual HV-L illusion are those that ascribe the effect to structural and retinal characteristics of the eye (sections 1.2 and 2.7), it is conceivable that variation in its magnitude across ages may be governed by the information processing strategies peculiar to subjects at different age levels. In the latter regard, Piaget's centration theory (section 2.7) is perhaps the only explanation capable of accounting for both the general decrease in the magnitude of geometric illusions with age as well as for the occasional exceptions (e.g. the HV-L illusion) to this rule.

As described earlier (section 2.7), according to the centration theory, parts of an illusion figure which receive the greatest density of fixations are overestimated in size, relative to parts which receive fewest fixations. Thus, the smaller illusion found for adults compared with children is attributed to a more even and wider scanning (i.e. "decentration") of the total stimulus figure during inspection so as to incur less relative error.

Although no explicit reference is made to haptic inspection of illusion figures, Piaget (1969) has indicated that young children adopt a more passive haptic, as well as visual, approach to the inspection of stimuli. In this regard, similar age differences in illusion magnitudes may be expected across the two modalities. Thus, with the HV-L effect, the analogous illusions across vision and active touch, afforded by structural and physiological features of the eye and limb respectively, operate across all age levels. However, the magnitude of the illusions can be expected to vary in accordance with the differences in the patterns of information sampling as reflected in eye fixations and relative movement times. In order to supplement the available developmental data on the visual HV-L effect, Experimental Series II was undertaken to establish both the developmental trend and corresponding limb movement times on the haptic HV-L illusion.

3.2 Experiment 2.1: The developmental trend of the haptic HV-L illusion.

The aim of Experiment 2.1 was to determine the trend of the haptic HV-L illusion across subjects of different age levels.

Method

Subjects. For this and Experiment 2.2, adult subjects consisted of students enrolled in introductory courses in Psychology at the University of Waikato. The data from children were collected from subjects attending a number of metropolitan schools in Hamilton, New Zealand.

Seven groups of 20 subjects each were used. Each group consisted of 10 females and 10 males. Groups I, II, III, IV, V and VI consisted of children with respective mean ages (in years) of 6.6 (range 6.1-

6.9), 7.7 (range 7.2-7.9), 9.5 (range 9.0-9.9), 11.7 (range 11.1-11.9), 12.5 (range 12.0-12.9) and 13.6 (range 13.0-13.9). Group VII consisted of University students with a mean age of 20.4 (range 17.5-27.2). The choice of these age levels was based on data from a pilot study.* In line with Over's (1967) study, preliminary testing indicated that children below the age of six could not understand instructions to make haptic judgments.

Apparatus. The apparatus was the same as that used in Experiment 1.3 (see section 2.4).

Procedure. Each subject wore blindfold goggles and was seated in front of a low table. For the children in Groups I, II, and III, each child was tested in preliminary trials with a 15 cm and 20 cm rod, to ascertain that he could in fact make haptic discriminations of length. The apparatus was placed horizontally in front of the subject so that the standard rod (set at 10 cm) extended away from him along the sagittal plane, while the variable rod was fronto-parallel. Thus, movements along the standard were radial, and along the variable tangential.

Before each judgment, the experimenter guided the subject's index finger of his right hand, along

* Conducted by Joan Simpson from the Hamilton (N.Z.) Child Health Clinic.

the path to be followed; two complete movements along one rod followed by two along the other, beginning each time at the point of intersection of the two. In order to minimize the bias against the more diffident subjects, each subject was specifically instructed that he could request up to two repetitions of such pairs of movements, made actively before making a response, although he was encouraged to make a judgment on the first pair of active movements. The finger was not lifted from the rods until a judgment of relative length was made. The initial direction of movement was alternated between the radial standard and tangential variable. After each pair of movements, the subject was instructed to indicate whether the first or second rod felt longer.

The double-staircase technique was used throughout to establish the point of subjective equality (PSE). Each staircase started with the tangential rod (variable) equal to the 10-cm radial rod (standard) and was replaced by a shorter or longer variable according to the subject's judgment. Steps of 1.0 cm were used until four reversals of judgment from longer to shorter (or *vice versa*) occurred. Only four reversals were obtained since the younger children, with short interest spans, were liable to give unreliable responses if the experimental trials lasted longer.

Results

The PSEs were derived from the mean of the four lengths resulting in a reversal. The difference between this mean and 10 cm served as an index of the illusion and was stated as a percentage. The mean PSE, the standard deviation, and percentage of illusion for each group are shown in Table 3.1.

For all age groups, the radial extent was judged longer than the tangential ($p < .01$) as indicated by directional t tests for single means (Hays, 1973). Trend analyses for unequal intervals (Kirk, 1968), performed on the data across age groups, indicated that only the quadratic trend was significant, $F(1,133) = 5.132$, $p < .05$, and this accounted for 57.96% of the variance between groups. As shown in Figure 3.1 (bottom curve), the developmental function is curvilinear, decreasing from six year-olds to seven year-olds, and then increasing from seven year-olds to a peak among 11 year-olds, followed by a decline to adulthood.

The general features of this curve resemble those obtained by Dawson, Young and Choi (1973) for the visual HV-L figure. The data are also in substantial agreement with those obtained in the pilot study by

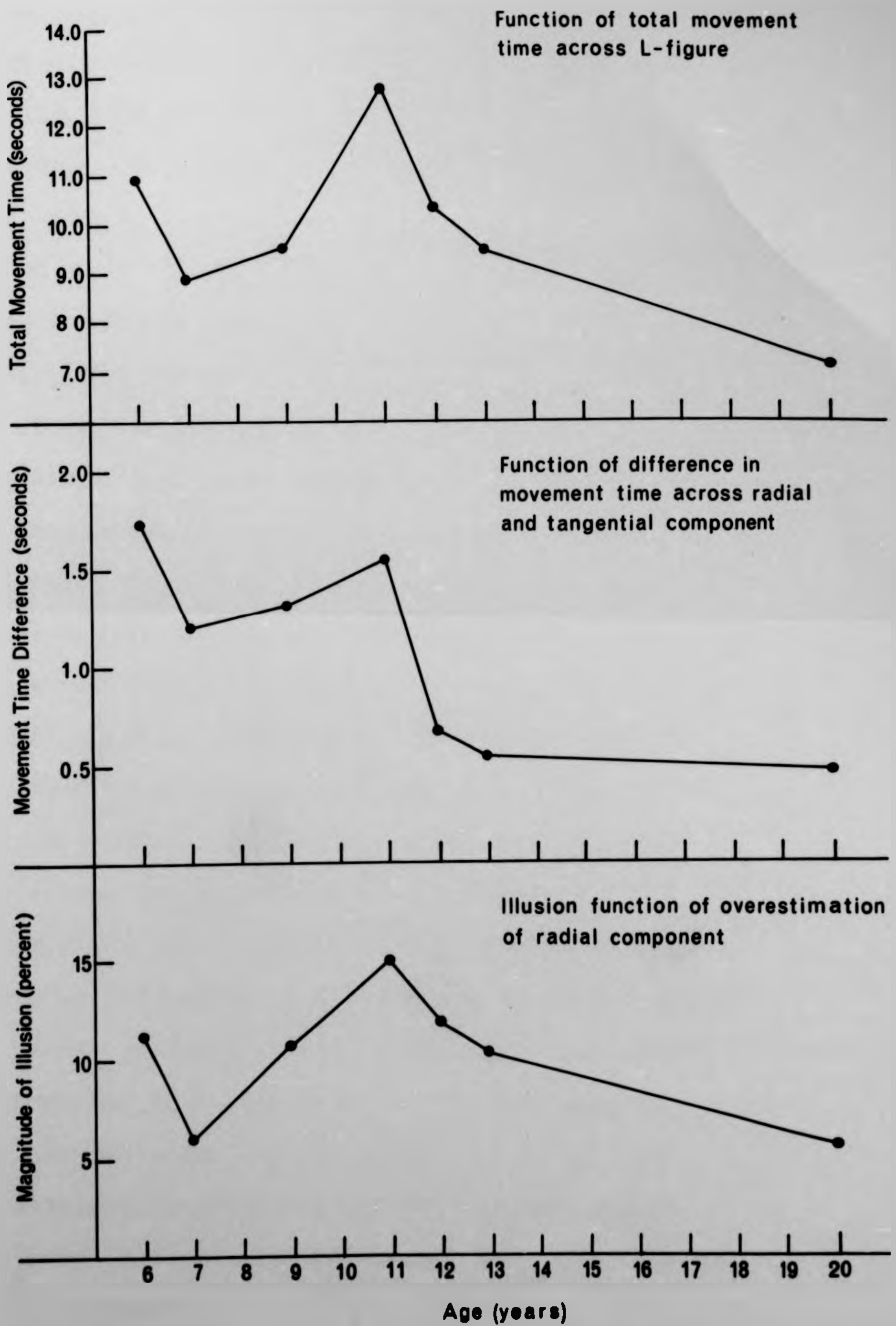
TABLE 3.1

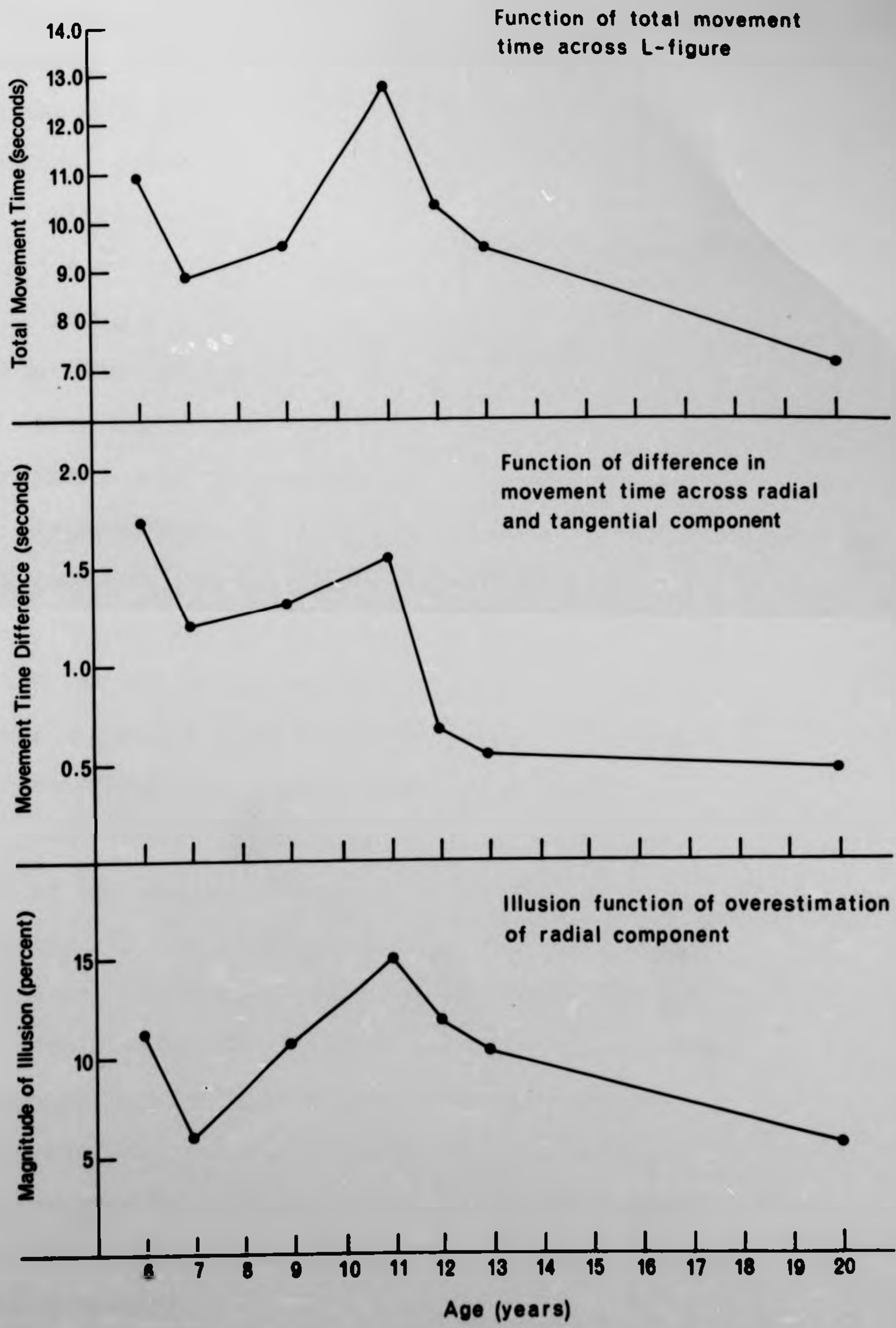
Mean PSEs (points of subjective equality, in cm) of the Tangential Variable with the Radial 10-cm Standard, Standard Deviations, and Percentage of Illusions for Groups I to VII in Experiment 2.1

Statistic	Group (Mean age in years)						
	I(6.6)	II(7.7)	III(9.5)	IV(11.7)	V(12.5)	VI(13.6)	VII(20.4)
PSE	11.22	10.70	11.16	11.50	11.38	11.07	10.62
SD	1.98	1.08	1.31	1.21	1.01	0.73	0.52
% illusion	12.25	7.00	11.62	15.00	13.87	10.75	6.25

FIGURE 3.1

Illusion magnitude (Experiment 2.1) and movement time scores (Experiment 2.2) as a function of age.


Function of total movement time across L-figure
Total Movement Time (seconds)
14.0
13.0
12.0
11.0
10.0
9.0
8 0
7.0
Function of difference in movement time across radial and tangential component
Movement Time Difference (seconds)
2.0
1.5
1.0
0.5
Illusion function of overestimation of radial component
Magnitude of Illusion (percent)
15
10
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Age (years)



Function of total movement time across L-figure
Total Movement Time (seconds)
14.0
13.0
12.0
11.0
10.0
9.0
8 0
7.0
Function of difference in movement time across radial and tangential component
Movement Time Difference (seconds)
2.0
1.5
1.0
0.5
Illusion function of overestimation of radial component
Magnitude of Illusion (percent)
15
10
5
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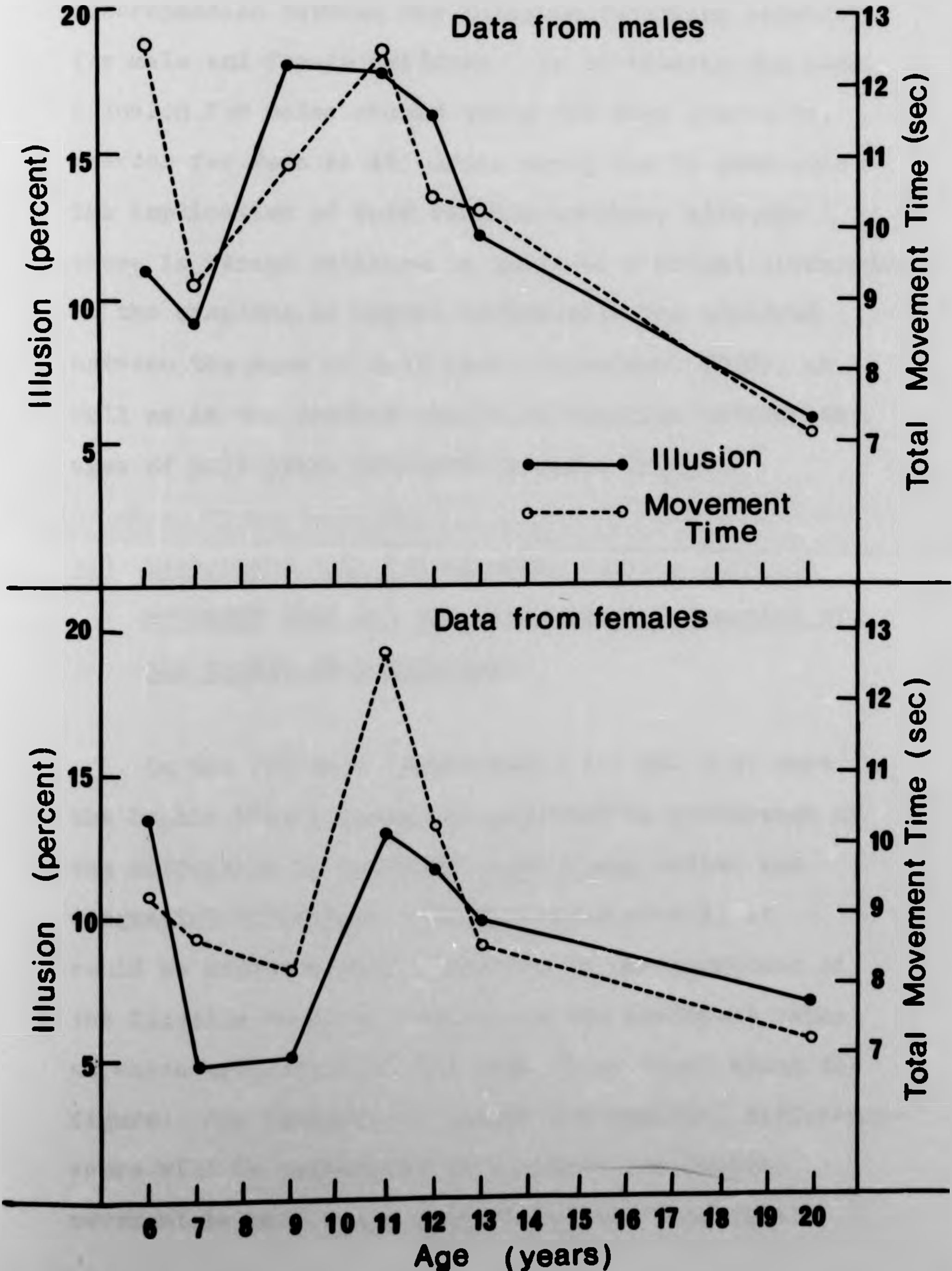
Age (years)

Simpson (unpublished report), although in that preliminary study, the peak illusion was obtained among the 9-10 year-olds, rather than among 11 year-olds. Other discrepancies should also be noted. First, although both the haptic function obtained here and the visual trend obtained by Dawson, Young and Choi (1973) are essentially sigmoid in shape, the deflection points of the visual data occur among the six and 12 year-olds, whereas for the haptic data, they occur among the seven and 11 year-olds, respectively.

Second, the visual trends obtained by earlier authors (Hanley & Zerbolio, 1965; Wursten, 1947) do not show the deflection among the very young children, i.e. the functions were a more flattened inverted-U rather than sigmoid. Thus, as noted by Robinson (1972), one should be cautious about the precise nature of the changes within early childhood, as psychophysical observations of this kind with small children are obviously difficult, and any trend ought to be better established before attempts can be made to incorporate them into theory. In this regard, the present data for the six year-olds as well as those obtained by previous authors with the visual figure from children six and below, should be treated with reservations.

FIGURE 3.2

Illusion magnitude (Experiment 2.1) and movement time scores (Experiment 2.2) as a function of sex and age.


Data from males
Illusion (percent)
Total Movement Time (sec)
Illusion
Movement Time
Data from females
Illusion (percent)
Total Movement Time (sec)
6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Age (years)

Finally, as shown in Figure 3.2, there are minor discrepancies between the illusion functions obtained for male and female children. In particular, the peak illusion for males occurs among the nine year-olds, whereas for females it occurs among the 11 year-olds. The implication of this remains unclear, although there is recent evidence to indicate a sexual difference in the sampling of haptic information for children between the ages of 6-12 years (Witelson, 1976), as well as in the drawing skills of children between the ages of 5-14 years (Richards & Ross, 1967).

3.3 Experiment 2.2: Relationship between scanning movement time and the developmental function of the haptic HV-L illusion.

On the evidence (Experiments 1.3 and 1.4) that the haptic HV-L illusion is governed by perception of the difference in movement times along radial and tangential directions ("difference-scores"), it could be expected that variation in the magnitude of the illusion would be related to the different rates at which subjects move the limb (i.e. scan) along the figure. For instance, a larger (or smaller) difference-score will be registered if a slower (or faster) movement is made along both radial and tangential directions. In other words, the size of the difference-score is governed by the total movement time ("total-scores") along the L figure. In this way, it is conceivable that the magnitude of the illusion would be related to the respective total-scores obtained by subjects at different age levels.

Experiment 2.2 was conducted to obtain information on the scanning movement times from subjects, across the same age levels as those of Experiment 2.1. Such data could then be used in conjunction with those of Experiment 2.1, to determine the relationship between the movement times and the magnitude of the respective illusions across different age levels.

Method

Subjects. Six groups of 20 subjects each were used. None of the subjects had previously taken part in Experiment 2.1. Each group consisted of 10 females and 10 males. Groups I, II, III, IV, V and VI consisted of children with respective mean ages (in years) of 6.5 (range 6.2-6.9), 7.6 (range 7.1-7.9), 9.6 (range 9.2-9.9), 11.5 (range 11.0-11.9), 12.5 (range 12.2-12.9) and 13.7 (range 13.0-13.9). A seventh group, consisting of data from Experiment 1.3 (section 2.4) using adult subjects with a mean age of 20.2 (range 18.1-22.8), was also included for analysis.

Apparatus. The apparatus, and photographic equipment employed to record the movement times, were the same as those used in Experiment 1.3 (see section 2.4).

Procedure. The procedure was the same as that described for Experiment 1.3 (see section 2.4).

Results

The mean movement times (with respective standard deviations) along the radial and tangential components of the L figure, across the seven groups, are shown in Table 3.2. Across age groups, movement times were consistently greater along the radial extent compared with those for the tangential, $F(1,133) = 111.18$, $p < .0005$. These results are in accord with those reported for Experiments 1.2 and 1.3 (sections 2.3 and 2.4). From the data in Table 3.2, both total-scores and difference-scores were derived, and the functions of these across age levels, are shown in Figure 3.1 (top and middle graphs) together with the trend of the illusion obtained in Experiment 2.1 (bottom graph). The data from males and females are shown separately in Figure 3.2. Trend analyses, for unequal intervals, were carried out on the combined data from both sexes and revealed the following results.

TABLE 3.2

Mean Times (sec) and Standard Deviations of radial and tangential movements along the L figure, across age groups, in Experiment 2.2

Movement		Group (Mean Age in Years)						
Extent		I(6.5)	II(7.6)	III(9.6)	IV(11.5)	V(12.5)	VI(13.7)	VII(20.2)
Radial	Duration	6.29	5.09	5.44	7.10	5.50	4.99	3.80
	SD	2.81	1.03	1.77	2.39	2.17	1.65	1.04
Tangential	Duration	4.63	3.88	4.13	5.56	4.83	4.45	3.35
	SD	1.61	1.30	1.39	1.93	1.78	1.49	0.75

For the total-scores: the linear, $F(1,133) = 9.703$, $p < .0005$; quadratic, $F(1,133) = 10.612$, $p < .005$; and cubic, $F(1,133) = 4.876$, $p < .0005$, trends were all significant, and accounted for 31.77%, 34.75%, and 15.96% of the variance between groups, respectively.

For the difference-scores: only the linear trend, $F(1,133) = 12.657$, $p < .0005$, was significant, and this accounted for 62.85% of the variance between groups. There was no significant departure from the linear trend, $F(5.133) = 1.495$, $p > .05$.

From the statistical data and the profiles of the three functions shown in Figure 3.1, it would appear that the developmental trend of the haptic HV-L illusion resembles that obtained from the total-scores more than it does that for difference-scores. This is further indicated by the values of Kendall's Rank Correlation (*tau*), calculated between age levels and the respective total-scores and difference-scores. The relationship between the magnitude of illusion and respective total-scores across age groups is given by: *tau* = .904, $p = .0014$, while the corresponding relationship for the difference-scores is: *tau* = .714, $p = .015$. Variation in magnitude of the haptic HV-L illusion has thus been shown to be related to the rate at which subjects of different ages move the limb, in scanning the stimulus L figure.

3.4 General discussion of Experiments 2.1 and 2.2.

The developmental trend of the haptic HV-L illusion was found to be curvilinear, with a decrease in the illusion from 6.6 to 7.7 years, and increasing from 7.7 years to a peak at 11.7 years, to be followed by a decline to adulthood. It should be noted, however, that the decrease in illusion from the six year-olds to the seven year-olds is only suggestive, as only the quadratic component of the trend is significant. Barring the discrepancies already noted earlier, this developmental trend for the haptic figure, broadly resembles that reported previously for the visual figure (Dawson, Young & Choi, 1973; Hanley & Zerbolio, 1965; Wursten, 1947) except for the data from children of six years and below, which appear equivocal.

With the haptic figure, it would appear that variation in the magnitude of the illusion across age levels is closely associated with the rate at which subjects of a particular age group typically move the limb in scanning the figure. Thus, subjects from age levels who took more time in scanning the stimulus figure, produced larger illusions, and *vice versa*. For each group, the apparently longer (in length) radial component of the L was also invariably executed slower compared with the tangential component of equal extent.

In Piaget's (1969) terms, the child at five or six years has not developed a stable system of spatial coordinates, and is thus relatively immune to the effects of spatial orientation or direction, in the judgment of length. "As co-ordinates and objective references develop and assist the structuring of directions, estimations of lengths are more and more troubled by considerations of direction,..... from 9 or 10 years, directions have become structured, or are on, the way to becoming so, and the progressive exercise of dimensional transports when changes in orientation are involved once more reduces the errors" (1969, pp. 171-172). Also, the decrease in errors from 9-10 years to adulthood derive not only from the modification of perceptual activity but also from the maturation of intelligence itself.

In this way, the magnitude of illusion at a particular age level, will be governed by the level of development of the subject's ability to structure spatial coordinatés. Conceivably, such cognitive processes will affect the information sampling activity of the eye or limb during inspection of the stimulus figure. It would appear that in vision, this influence is manifest in the patterns of eye fixations (Piaget & Bang, 1961a, 1961b), and in active touch, in the rate of limb movement.

According to Fraisse and Vautrey (1956) the increase in visual illusion from six to 10 years only occurs under conditions of unlimited viewing, but does not occur under tachistoscopic perception. Presumably, under the latter condition, the brief exposures had eliminated the contribution from differential eye fixations.

It is clear from the present results that the haptic illusion occurs at all age levels, as would be expected of an effect that is intrinsic to the action of radial and tangential movements (as described in section 2.6). However, the observed variation in the magnitude of the illusion with age is held to be determined by secondary perceptual activities that vary in accordance with the scheme outlined by Piaget. Specifically, it is suggested that in the haptic mode, the child of about seven years is able to judge length unhampered by considerations of spatial direction just as the adult of 20 years, as shown by the faster rate of limb movement. However, for the young child, the facility comes from a lack of a structured spatial framework, whereas for the adult, it derives from the presence of a stable system of spatial coordinates acquired through maturity and experience. From age seven to a peak age of about 10 or 11 years, the increasing awareness of spatial directions hampers the discrimination of length, and this is reflected in the progressively longer total movement times, resulting in relatively larger illusion effects. The decrease of illusion magnitude from 10-11 years to adulthood can be similarly explained, in terms of the smaller total time required for judgments, on account of the subject's increasing ability to judge length, unhampered by the influence of spatial direction.

A further comment seems warranted with respect to the relatively large haptic illusion obtained by the six year-olds. Notwithstanding the earlier remarks on the unreliability of the data produced by children in this age group, it is possible that the magnitude of the illusion at age six reflects the operation of an independent factor. For instance, children of age six are slower in the execution of motor skills compared with older children (Connolly & Brown,1968), and may thus incur a larger illusion, quite independently of the effect of spatial directions. It was maintained early in the thesis (section 1.1) that most illusion effects appear to be multiply caused. It may be concluded that the present developmental data on the haptic figure serve to endorse this position.

3.5 Summary of findings in Experimental Series II.

Experiments 2.1 and 2.2 employed subjects across the ages of 6, 7, 9, 11, 12, 13 and 20 years. Across these age groups, the developmental function of the haptic HV-L illusion was found to be curvilinear, decreasing from the six year-olds to seven year-olds, and then increasing from seven year-olds to a peak among 11 year-olds, followed by a decline to adulthood. It was concluded that the general features of this function resemble those obtained in past studies using the visual HV-L figure.

The results also showed that variation in the magnitude of the haptic illusion across age levels was closely associated with the rate at which subjects of a particular age group typically move the limb in scanning the figure. Thus, subjects from age levels who took more time in scanning the stimulus figure, produced larger illusions, and vice versa. It was concluded that the rate of scanning movements at a particular age level was probably governed by the level of development of the subject's ability to structure spatial coordinates.

CHAPTER 4: EXPERIMENTAL SERIES III: HAPTIC AND VISUAL STUDIES OF THE HORIZONTAL-VERTICAL ILLUSION WITH THE T FIGURE.

4.1 The visual horizontal-vertical illusion with the T figure.

As already noted in section 1.2 in Chapter 1, the visual HV-T illusion is governed by different parameters than those of the illusion with the L figure. This section examines this issue in greater detail.

A number of studies have shown that the spatial arrangement of the components of the T figure is an important determinant of the magnitude of the illusion. Kunnapas (1955a) who studied this extensively, showed that when the inverted T figure is presented with the dividing line ("stem") vertical with reference to the upright subject, the illusion is greater compared with that for a sideward presentation (⊢) of the figure with the divided line ("bar") vertical. He also showed that the point at which the stem (vertical in the T or inverted T, and horizontal in the sideward T) meets the bar was an important variable. With all three figures, the overestimation of the stem is maximal when it meets at the centre of the bar, and this illusion decreases when the stem is placed increasingly toward one end of the bar (to form an "L" in the extreme). From such data, it was inferred that the HV illusion is composed of both an effect of the dividing line and of verticality (HV-L illusion), with the former effect being normally greater. The two illusions summate in the T and inverted T but oppose one another in the side T.

Suto (1959, reported by Oyama, 1960) using the inverted T figure, was able to separate the two effects by asking subjects to compare each component with a plain horizontal line. The bar was judged shorter by 4% and the stem longer by 14%, the latter illusion presumably being produced by the two effects combined. Also, when the components (each of 3 cm) of the T are separated by a gap of 5 cm, the magnitude of the illusion is halved (Fraisse & Vautrey, 1956). Again, presumably the residual illusion is due to verticality alone, with the dividing-line factor being eliminated through the separation.

Piaget and Morf (1956, reported in Piaget, 1969), working independently, also obtained quantitative data that are in substantial agreement to those of Kunnapas (1955a); viz. the dividing line is overestimated with a maximum of error when it divides the other into two equal segments and that there exist two illusion-producing factors which can either reinforce or oppose each other depending on the spatial orientation of the figure. Such results have also been confirmed by more recent studies (Cormack & Cormack, 1974; Tedford & Tudor, 1969). The illusion can also be obtained under tachistoscopic presentation (Fraisse & Vautrey, 1956; Piaget, Bang, & Matalon, 1958), even at an exposure as brief as 40 msec, a duration well below the minimum latency for eye movements (Haber & Nathanson, 1969; Wheeless, Boynton, & Cohen, 1966). Further evaluation of the illusion is deferred to later sections.

4.2 The haptic horizontal-vertical illusion with the T figure.

Using blind subjects, both Revesz (1934) and Hatwell (1960) have provided data to support the occurrence of the HV-T illusion in active touch. Revesz (1934) also obtained an illusion tactually, with a relief model of the figure pressed onto the skin surface. Subsequent to these two studies, studies with sighted but blindfolded subjects have also consistently found a haptic illusion in line with a maximum of error when it divides the other into two equal segments and that there exist two illusion-producing factors which can either reinforce or oppose each other depending on the spatial orientation of the figure. Such results have also been confirmed by more recent studies (Cormack & Cormack, 1974; Tedford & Tudor, 1969). The illusion can also be obtained under tachistoscopic presentation (Fraisse & Vautrey, 1956; Piaget, Bang, & Matalon, 1958), even at an exposure as brief as 40 msec, a duration well below the minimum latency for eye movements (Haber & Nathanson, 1969; Wheeless, Boynton, & Cohen, 1966). Further evaluation of the illusion is deferred to later sections.

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Since the above studies have obtained illusions with presentation of the T figures in both the vertical and horizontal planes it would appear that the effect operates independently of the role of radial and tangential movements, the former being present only with movements in the horizontal plane (see section 1.4). Two recent studies have been conducted on this issue. Using both the haptic L and inverted T figures, presented in the vertical plane, Day and Avery (1970) failed to obtain an illusion for the L but a substantial illusion of 16.5% for the inverted T. This finding was confirmed in a more detailed study by Deregowski and Ellis (1972) who again found an insignificant effect with the L but a large illusion of 23.53% with the inverted T, in the vertical plane. When the figures were presented in the horizontal plane so that one component of the L and the stem of the inverted T were associated with radial movements and the other components tangential, the radial extent of the L and the stem of the inverted T were judged longer by 12.4% and 22.5%, respectively. This result indicates that the dividing-line factor in the horizontal plane is 10.1% greater than the illusion associated with the over-estimation of radial movements alone.

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Thus, while the haptic HV-L illusion is only present in the horizontal plane, the HV-T illusion is substantially large when the figure is presented to the subject in either the vertical or horizontal plane. However, with presentation in the horizontal plane, the magnitude of the illusion is influenced by the radial-tangential factor just as the visual illusion is affected by the factor of verticality with orientation of the stimulus within a plane. The next section evaluates the illusion in the general context of form perception. Following which, a statement of the general aim of the present series of experiments is given.

4.3 Form perception, significant features of the T figure and selective attention.

The visual illusion with the T figure still occurs when the lines are replaced by two narrow rectangles to form a symmetrical T pattern with extended area (e.g. Julesz, 1971, p. 227). It follows that the same mechanisms normally involved in the perception of form also operate here to produce the illusion.

As the neurophysiological evidence has accumulated (e.g. Hubel & Weisel, 1962, 1965, 1968; Jung, 1961; Maturana, Lettvin, McCulloch, & Pitts, 1960;

Mountcastle, 1957), the visual cortex is now seen to be a highly specialized structure designed to select and emphasize the main features of optical inputs that are relevant in the perception of shapes and figures, viz. contours and their elements (lines, angles, etc.). However, as Hubel and Weisel themselves have stressed, these elementary feature detectors go only a little way toward explaining the complex processes of perception. Take, for instance, the simple and cogent example provided by Rock (1970). If an afterimage of a square is formed with head upright and then "viewed" with the eyes closed and the head tilted 45°, it appears to be a diamond. Why should this be true if the <u>same</u> feature detectors are responding ? Rock suggests that perhaps the orientation-specific detectors only provide certain stimulus information e.g. that one orientation is the same as or different from another, but the percept is really governed by the cognitive referents given to parts of the form by the observer, e.g. with respect to what constitutes the top or bottom of the form, etc. Thus, feature detectors are necessary to provide the basic information as a starting point for perception, but by no means should such information be thought of as the neural correlates of percepts. Ganz (1971) has also argued that even a simple discrimination between an upright and inverted triangle requires some additional and more flexible mechanism, which he calls "selective attention", that actively suppresses the dominant reaction of feature detectors.

Other limitations of an anaysis of perceptual processes based solely on feature detectors, have been discussed elsewhere (Pribram, 1971; Rock, 1975; Sommerhoff, 1974). It seems reasonable to assume, at least from introspection, that the human brain forms internal models or "cognitive maps" of external realities (Sommerhoff, 1974), and that the input systems are organized so that neural signals become coordinated with some sort of psychological "imaging" process (Pribram, 1971). In this way, "the mechanisms of visual imagination are continuous with those of visual perception — a fact which strongly implies that all perceiving is a constructive process..... The relationship between cognitive "activity", as here conceived, and motor action is that much the same sort of integrated construction is necessary in both cases. Both are "schematic", in Bartlett's (1932) sense; both synthesize novel and temporary objects — percepts or movements — under more or less specific constraints..... Perceiving a letter and writing one are synthetic activities of the same kind" (Neisser, 1967, pp. 95, 97).

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It also seems obvious that to extract information about shape from the retinal image of a stimulus, the perceptual system must focus on the geometrical relationships among the parts of the image of the figure (Rock, 1975). Ordinarily, the contours of the extended retinal image of a figure delineate these relative locations but the contours should be thought of as markers of location rather than as essential factors in form perception. Essential information about relative location can be conveyed without the presence of an extended retinal image as in tracking a moving point or viewing a piecemeal presentation (i.e. sequential, aperture-viewing) of the form (Girgus, 1973; Hochberg, 1968; Rock, 1975).

Information provided through haptic and tactile stimulation is of necessity also piecemeal and sequential (Gibson, 1962, 1966). Such information, which is serially ordered and in temporal succession, must then be integrated to give rise to the phenomenal impression of form. In addition, the perceiver can construct, or reconstruct such representations even in the absence of stimulus information. This implies that both attentive and imaging processes are also involved (Neisser, 1967, 1972). A similar view has been voiced by Rock (1975, p. 328), "A cognitive process very much like description must occur based to a large extent on the information about relative location of the parts of the figure but including other features as well..... It is very much influenced by salient features of a figure such as symmetry. It requires attention, and if a figure is very complex such description will not do justice to all its nuances."

It may thus be instructive to evaluate the illusion process in terms of the salient features of the T figure and the role of attention in the generation of the percept. That symmetry is an important feature of a form is well documented (see: Berlyne, 1971; Bradshaw, Bradley, & Patterson, 1976; Zusne, 1970), and this feature typically biases the organization of scanning eye movements or overt fixations to one half of the symmetrical form (Locher & Nodine, 1973; Noton & Stark, 1971; Stratton, 1906; Thomas, 1963). There is also evidence that the centre of gravity of a form is where attention is maximally deployed in the extraction of perceptual information (Kaufman & Richards, 1969; Richards & Kaufman, 1969).

As the bisector of the T both defines the one-fold symmetry (Yaglom, 1962; Zusne, 1970) as well as containing the centre of gravity of the figure, it is accordingly selectively attended to at the expense of the bisected component. Symmetry extraction of simple forms, especially that about the left-right axis, can occur with exposures as brief as 40 msec (Corballis & Roldan, 1975). It seems appropriate at this stage to digress somewhat to give a brief outline of the concept of symmetry in relation to simple forms like the T figure. This outline is adapted from Zusne (1970).

Geometrically, a figure is symmetric if it remains unchanged after a symmetry operation has been performed on it (e.g. Yaglom, 1962). The two principal symmetry operations that are relevant here are rotation and reflection. A form may be "richer" or "poorer" in symmetry depending on how many types of symmetry operations may be performed on it without affecting it. With a single two-dimensional form, the transformation may affect or fail to affect: (1) its amount of measured information, or (2) the way in which this information is distributed along its contours. Reflection may take place along any number of axes. Some shapes, when a mirror is placed vertically to the plane in which they lie, will remain unchanged in only one position of the mirror, i.e. they will be symmetric only about one axis. The letter A, T or inverted T are examples of such one-fold symmetry. The letter B or sideward T (⊢), on the other hand, remains unchanged only if reflected in simple forms, especially that about the left-right axis, can occur with exposures as brief as 40 msec (Corballis & Roldan, 1975). It seems appropriate at this stage to digress somewhat to give a brief outline of the concept of symmetry in relation to simple forms like the T figure. This outline is adapted from Zusne (1970).

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In terms of rotation, the letters S, H, I, O and X possess two-fold symmetry because they appear the same after a 180° rotation. In this regard, an equal-arm cross "+" displays four-fold symmetry since it is not altered by four different rotations, whereas a circle remains symmetric regardless of orientation of the axis about which it is reflected, thus representing the richest kind of symmetry. Although a figure is either symmetric or asymmetric regardless of how many symmetry operations may be performed on it, symmetry nevertheless is a continuous variable in the sense that there are degrees of symmetry and hence it is measurable on a continuum. A symmetric form whose two halves are congruent after reflection, repeats exactly the same information that is contained in either half. In this sense, it is a redundant form or, more exactly it contains redundant information (Zusne, 1970).

Selective attention on the T figure can take the form of a greater focus on the bisector or alternatively the focus may be along the whole extent of the bisector, but only half of the bisected component.

Either contingency would result in the bisector being overestimated in length. The fact that the visual form of the illusion diminishes and consequently disappears, when the dividing line is shifted from the midpoint to one end of the divided line (Kunnapas, 1955a; Piaget & Morf, 1956), can then be explained in terms of the progressive violation of the one-fold symmetry of the figure. The five experiments reported below were conducted to substantiate the claim that the illusion process is governed by attentional mechanisms in the extraction of features and construction of the perceptual image.

4.4 Experiment 3.1: Variation in magnitude of the haptic HV-T illusion with changes in location of the dividing line.

Experiment 3.1 was conducted initially to confirm that for the haptic figure, the location of the dividing line along the divided line is an important determinant of the magnitude of the illusion, as indicated by observations (Kunnapas, 1955a; Piaget & Morf, 1956) on the visual form of the figure.

Method

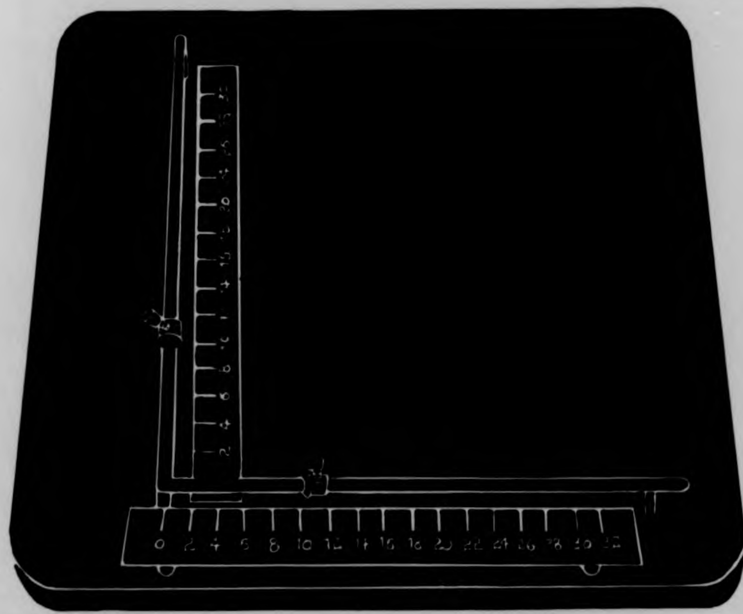
Subjects. There were 80 volunteer subjects, 48 females and 32 males. Their ages ranged from 17 to 28 years with a mean age of 20.

Apparatus. The two stimulus figures employed are illustrated in Figure 4.1. The top figure illustrating the "L" was the same as that employed for Experiment 1.3 (section 2.4). As both figures were similarly constructed, the reader is referred to section 2.4 for further details. These two stimulus figures were used to form the five different stimulus conditions as illustrated in Table 4.1. For stimulus figures 2 and 4, the adjustable brass sliders were set such that the intersection of the rods was located 2.5 cm from the left (from the subject's viewpoint) and right end of the divided rod, respectively. Stimulus figures 1 and 5 were L and reversed-L figures respectively, while stimulus figure 3 was a symmetrical inverted T.

Procedure. The 80 subjects were randomly assigned to the five stimulus conditions with 16 subjects each. The stimulus figure was placed horizontally in front of the blindfolded subject such that movement along one component (in the sagittal plane) was radial, and along the other (in the frontoparallel plane), tangential. The divided component was tangential and this served as the standard extent (10 cm) throughout the five stimulus conditions.

FIGURE 4.1

The two stimulus figures employed in Experiment 3.1



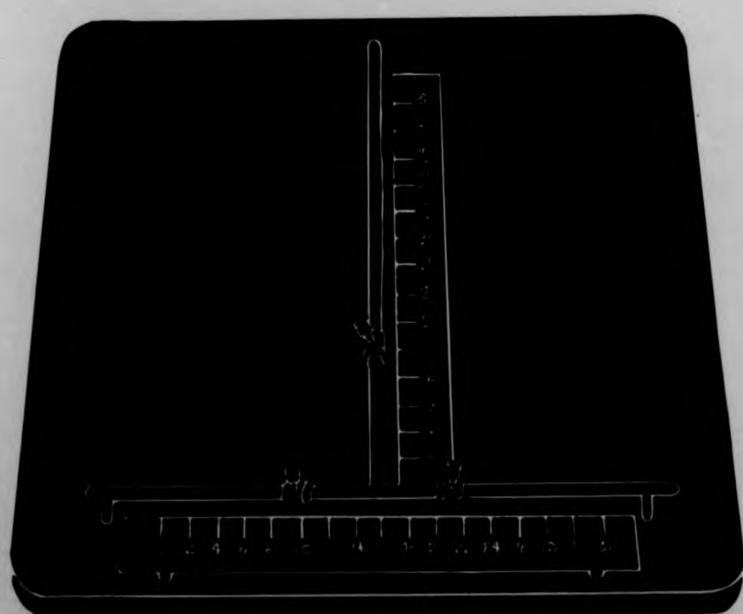
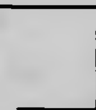


TABLE 4.1

Mean PSEs (Points of subjective equality) in cm of the dividing line with 10-cm divided line (standard), Standard Deviations, and Percentage of Illusions for the five stimulus figures in Experiment 3.1

	Stimulus figures				
	1	2	3	4	5
Statistic					
PSE	9.385	8.166	7.760	8.739	9.510
SD	0.516	0.805	0.934	0.852	0.560
% illusion	6.15	18.34	22.40	12.61	4.90

Note: The 10-cm standard was the tangential component.

Each subject was given two practice trials to familiarise him with movement along the stimulus figure, before the experimental trials. The procedure was essentially the same as that described for Experiment 2.1 (section 3.2). With stimulus figures 2, 3, and 4, the movement was made successively from the tip of the dividing line, to the intersection, to one end of the divided line, back to the intersection, and then to the other end of the divided line. This order was also reversed and the procedure counterbalanced across subjects. It is clear from the literature that consistent haptic illusions are obtained in spite of differences in the patterns of scanning limb movements afforded by differences in figure dimensions and psychophysical procedures (Day & Avery, 1970; Deregowski & Ellis, 1972; Over, 1966, 1967; Tedford & Tudor, 1969). This implies that the pattern of limb movements per se is not a relevant consideration. Nevertheless, it should be noted that the experiment (as well as others to be reported) involved the same pattern of scanning movements for the figure across the T figures, so that the pattern of limb movement was in fact under experimental control.

The double staircase technique was used throughout to determine the point of subjective equality (PSE).

Each staircase started with the radial (variable) component equal in length to the 10-cm tangential extent (standard),and was replaced by a shorter or longer variable according to the subject's judgment. Initially, coarse steps of 10 mm were used until six reversals of judgment from longer to shorter (or vice versa) occurred. The mean of these six reversals was then used as the starting position for the fine series of judgments in which steps of 5 mm were used until a further six reversals of judgment from longer to shorter (or vice versa) were obtained.

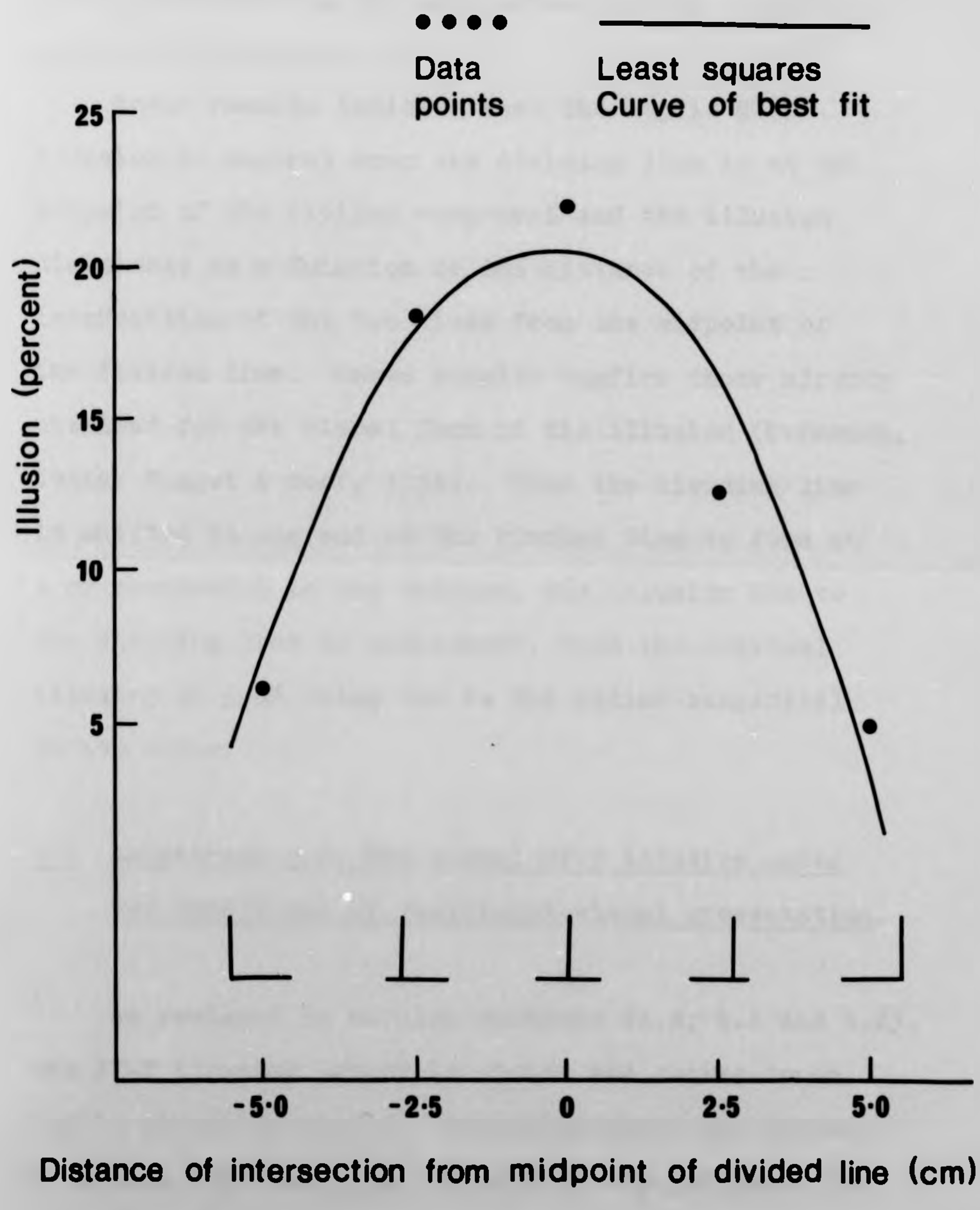
Results and Discussion

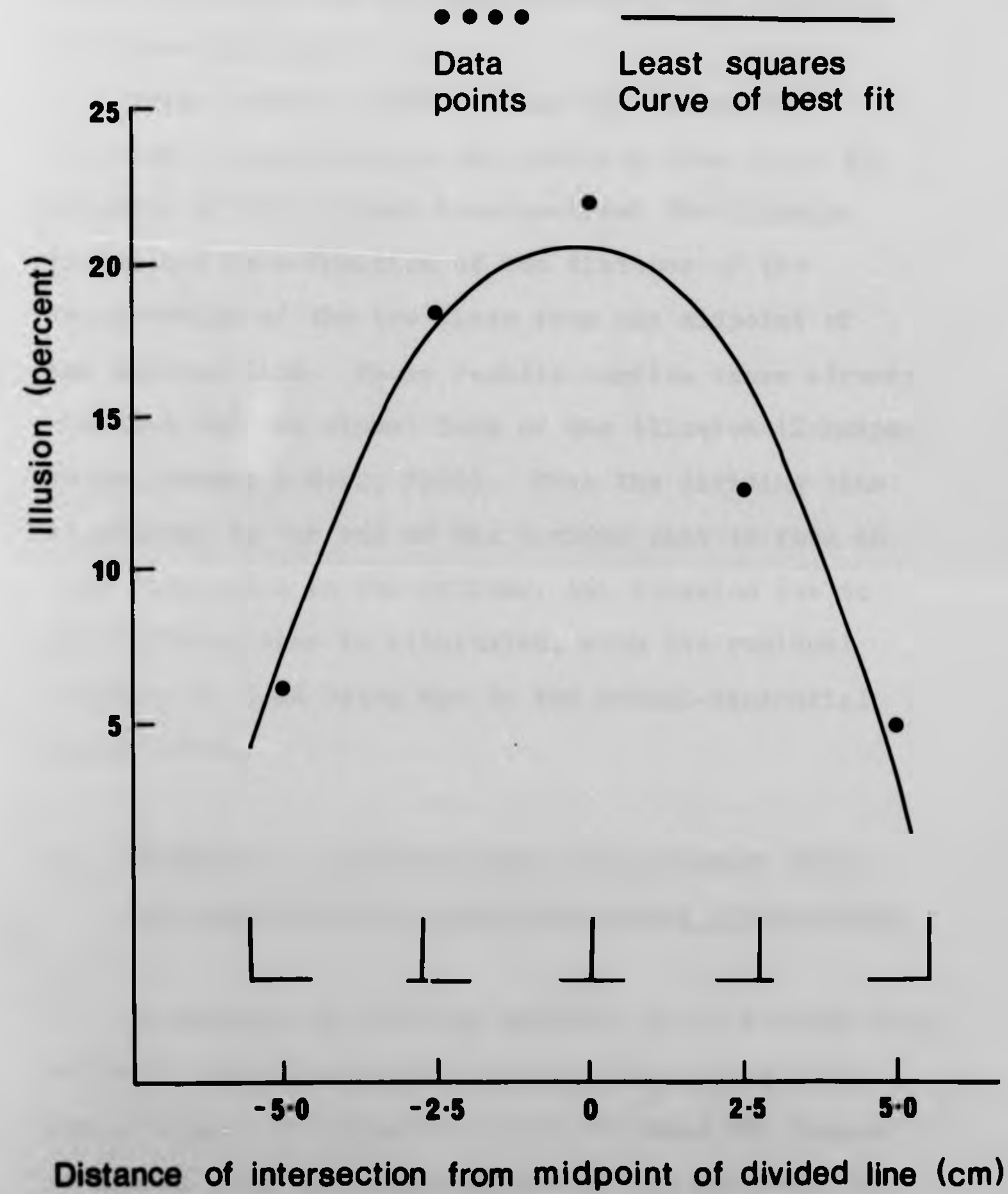
The PSEs were derived from the mean of the six lengths obtained from the reversals in the fine series. The difference between this mean and 10 cm (the standard length) was used as an index of the illusion and expressed as a percentage. The mean PSE for each condition, the standard deviation, and the percentage of illusion are shown in Table 4.1.

Differences among mean PSEs across the stimulus figures were found to be significant, $F(4,75) = 16.242$, $p < .0005$. The least squares curve of best fit for the parabolic trend of the illusion across the stimulus conditions was found to be: $X = 20.544 - 0.823Y - 3.832Y^2$. This curve, together with the data

FIGURE 4.2

Magnitude of illusion as a function of the location of the dividing line along the divided component in Experiment 3.1.


Data points
Least squares Curve of best fit
Illusion (percent)
25
20
15
10
5
-5·0
-2·5
0
2·5
5·0
Distance of intersection from midpoint of divided line (cm)



Data points
Least squares Curve of best fit
Illusion (percent)
25
20
15
10
5
-5·0
-2·5
0
2·5
5·0
Distance of intersection from midpoint of divided line (cm)

points derived from the mean percentage of illusion, are shown in Figure 4.2.

These results indicate that the haptic HV-T illusion is maximal when the dividing line is at the midpoint of the divided component and the illusion diminishes as a function of the distance of the intersection of the two lines from the midpoint of the divided line. These results confirm those already obtained for the visual form of the illusion (Kunnapas, 1955a; Piaget & Morf, 1956). When the dividing line is shifted to one end of the divided line to form an L or reversed-L in the extreme, the illusion due to the dividing line is eliminated, with the residual illusion of 5-6% being due to the radial-tangential factor alone.

4.5 Experiment 3.2: The visual HV-T illusion under two conditions of restricted-visual presentation.

As reviewed in earlier sections (1.3, 4.1 and 4.2), the HV-T illusion occurs in vision and active touch, but is absent in tactile perception where the figure is traced onto the volar surface of the forearm. In contrast to active touch, limb movements are not involved in tactile perception. But clearly, neither eye nor limb movements are necessary for the occurrence of the illusion as indicated by studies that have employed tachistoscopic (Fraisse & Vautrey, 1956; Piaget, Bang, & Matalon, 1958) and tactual (Revesz, 1934) presentation of the stimulus.

With visual and tactual presentation, the relative locations of the figure are given together by the contours of the retinal and tactual image. Selective attention can thus operate upon presentation of the stimulus. In contrast, with piecemeal presentation where the form has to be constructed from temporally successive impressions, it is likely that selective attention will be circumscribed by the manner in which the successive impressions are registered. Tactile perception is merely receptive, placing both the production and regulation of movement impressions with an external agency. Volitional shifts in attention are thus limited, since attention deployment is forced to conform to an externally imposed set of stimulus impressions. In contrast, the scanning movements in active touch are self-produced and self-regulated. Here,,selective attention can operate, unhampered by the successive impressions imposed by an external agency. It seems also likely that where the perceiver himself has to gather information from the stimulus figure as in active touch, attention demand will be greater compared with tactile perception where he can rely on the experimenter to provide him with such information.

If the T figure is presented piecemeal for visual inspection so that only a small part is visible through an aperture at any one moment, the appearance of the partial views would conform to the piecemeal registration of haptic or tactile information. Two contingencies can be superimposed over such restricted-visual presentation. In a subject-directed condition, the subject's manual control of a light stylus determines the exposure of the partial views. In an experimenter-directed condition, movements of the light stylus are solely controlled by the experimenter. In this way, the partial views obtained through the subject-directed and experimenter-directed condition conform to the piecemeal registration of active haptic and tactile information, respectively. Accordingly, an illusion would be expected under the subject-directed condition but not for the experimenter-directed condition. This prediction was tested in Experiment 3.2.

Method

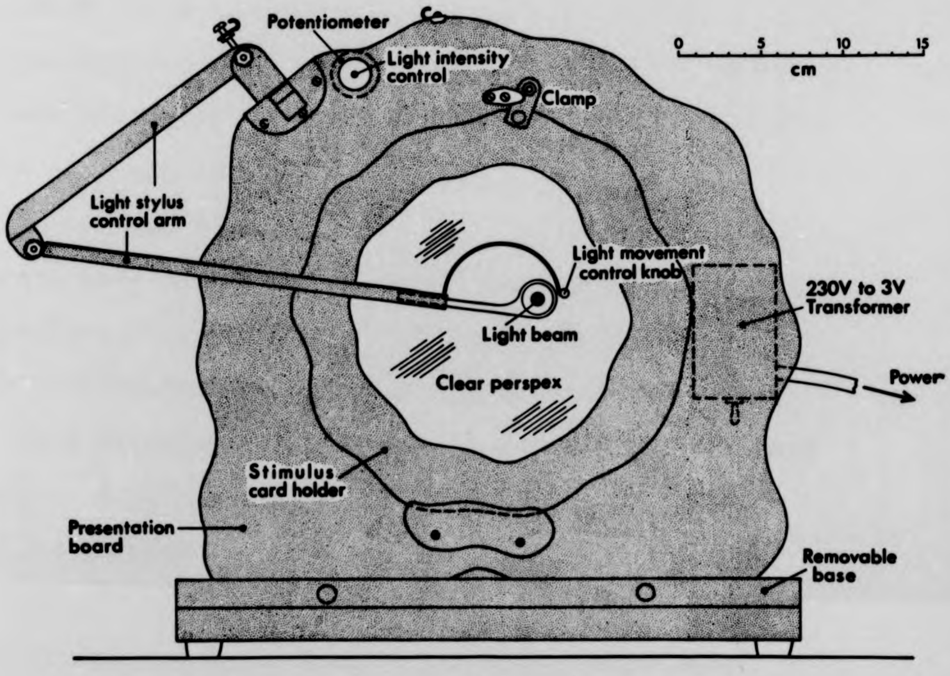
Subjects. There were 48 unpaid volunteer subjects, 23 males and 25 females. Their ages ranged from 17-27 years, with a mean age of 20.

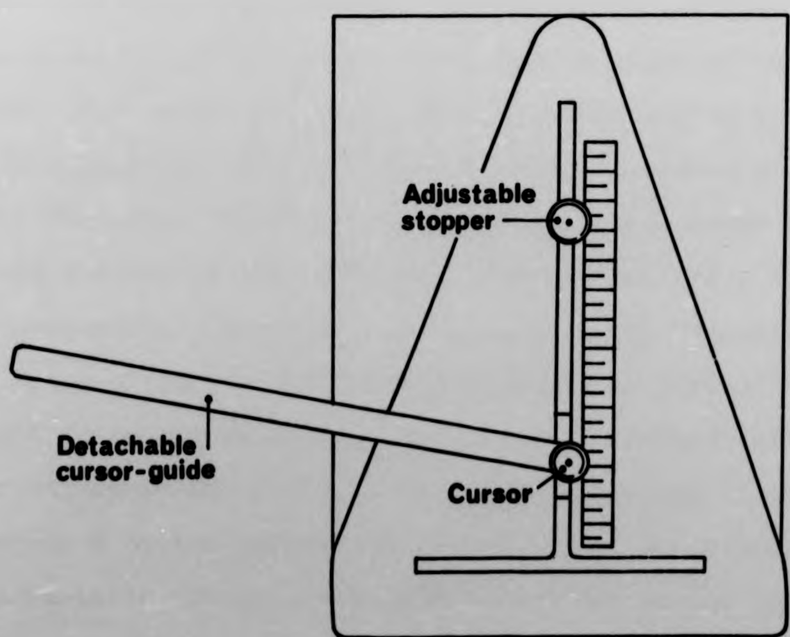
Apparatus and design. The restricted-visual apparatus employed is shown in the top row of Figure 4.3. This is a front view of the apparatus and additional details are provided with the figure. The apparatus was originally designed to present the stimulus figure in the vertical plane so that the illusion with the T figure would not be compounded with the constant error due to radial and tangential movements. However, from preliminary observations in a pilot study, it was evident that the differential load exerted on the stylus by gravity (with movement in the vertical plane) featured as a perceptible cue in the judgments of some subjects. This observation, taken in conjunction with the demonstrated influence of the load of the stylus in the haptic perception of contours (Weber & Dallenbach, 1929), suggested that the presentation of the apparatus in the horizontal plane would perhaps result in better stimulus control. The apparatus was accordingly modified for use in the horizontal plane, with the consequent deployment of the L figure to act as a control against which the systematic effects of radial and tangential movements could be evaluated.

The stimulus figures were finely drawn with black Indian ink onto white drawing cards. Two sets of cards were used. One composed of drawings of T figures with the bisected line (standard) kept constant at 9.0 cm and the bisector (variable) increasing or decreasing in

FIGURE 4.3

Top figure shows front view of restricted-visual apparatus employed in Experiment 3.2. The light-holder is joined to an aluminium tubing (partially drawn in dotted lines) situated behind the presentation board and connected to the top control arm at the "elbow", so that movement of the light beam is coordinate with movement of the control knob. Bottom figure shows the apparatus for presenting the inverted-T figure in Experiment 3.3.


Potentiometer
Light intensity control
Clamp
0 5 10 15
cm
Light stylus control arm
Light movement control knob
230V to 3V Transformer
Light beam
Clear perspex
Power
Stimulus card holder
Presentation board
Removable base


Adjustable stopper
Detachable cursor-guide
Cursor

3-mm steps to give a total of 15 stimulus cards. The drawings for the L figure were similarly prepared with one component (standard) of the L drawn a constant 9.0 cm long and the other component (variable) varying in 3-mm steps. In drawing the stimulus figures, care was taken to ensure that no line indentation was produced on the under sides of the cards so that these remained uniformly blank to view.

Fig. 4.3

Each stimulus card was placed over the transparent "Perspex" sheet of the apparatus "face down" so that the line drawing of the figure could not be seen when the back of the card was in the subject's view. When the light stylus was turned on, a light beam could be directed from below the stimulus card to illuminate any portion of the card such that parts of the figure illuminated would appear clearly in the light of the beam. The area illuminated was approximately circular, with a diameter of 5 mm. The irregular outlines of both the card holder and presentation board served to limit the use of the peripheral visual field as a cue to perceptual judgments. The apparatus was presented in front of the subject directly below his line of sight in the horizontal plane such that movement of the stylus by the subject was radial along one component of the figure and tangential on the other. The variable extent of the inverted-T and of the

L figure constituted the radial components. The experimental design was that of a 2 x 2 (Figure Type x Directive Condition) factorial with randomised groups, with 12 subjects assigned to each group.

Procedure. The double-staircase technique was employed to establish the point of subjective equality (PSE). Each staircase started with the figure with component extents at equality (9.0 cm). The figure was replaced by one with the variable (radial) either longer or shorter than the standard (tangential) according to the subject's judgment. Steps of 3 mm were used until six reversals of judgment from longer to shorter (or vice versa) occurred. The starting position along either component extent was counter-balanced across subjects.

Each subject was specifically instructed that he could request up to three repetitions of the same trial if he was unsure, although he was encouraged to make a judgment on the first presentation. The 24 subjects in the subject-directed condition moved the light stylus by grasping the control knob between the right index finger and thumb, either along the assigned L or inverted-T figures. For the 24 subjects in the experimenter-directed condition movements of the light stylus were controlled by the experimenter.

Results

The PSEs were derived from the mean of the six lengths that resulted in a reversal of judgment. The difference between this mean and 9.0 cm (the standard length) was used as an index of the illusion and expressed as a percentage. The mean PSE and standard deviation for each stimulus condition, are shown in Table 4.2. The magnitude of illusion obtained across the four stimulus conditions is shown in Figure 4.4.

Using t tests for single means (Hays, 1973), no significant effects were found with the L figure under both the experimenter-directed (t = 0.90, df = 11, $p > .05$) and subject-directed (t = 1.46, df = 11, $p > .05$) conditions. The illusion with the inverted-T figure under the experimenter-directed condition was also not significant (t = 1.51, df = 11, $p > .05$). However, for the subject-directed condition, a significant effect with the inverted-T figure was obtained (t = 5.24, df = 11, $p < .01$). Furthermore, this illusion is significantly greater than that obtained for the inverted-T figure under the experimenter-directed condition (t = 3.21, df = 22, $p < .005$).

Overall, the results confirm that the visual HV-T illusion occurs only when the subject himself manually directs the registration of the partial views and not when the exposures of these are governed by an external agency. Such data conform to those obtained in past

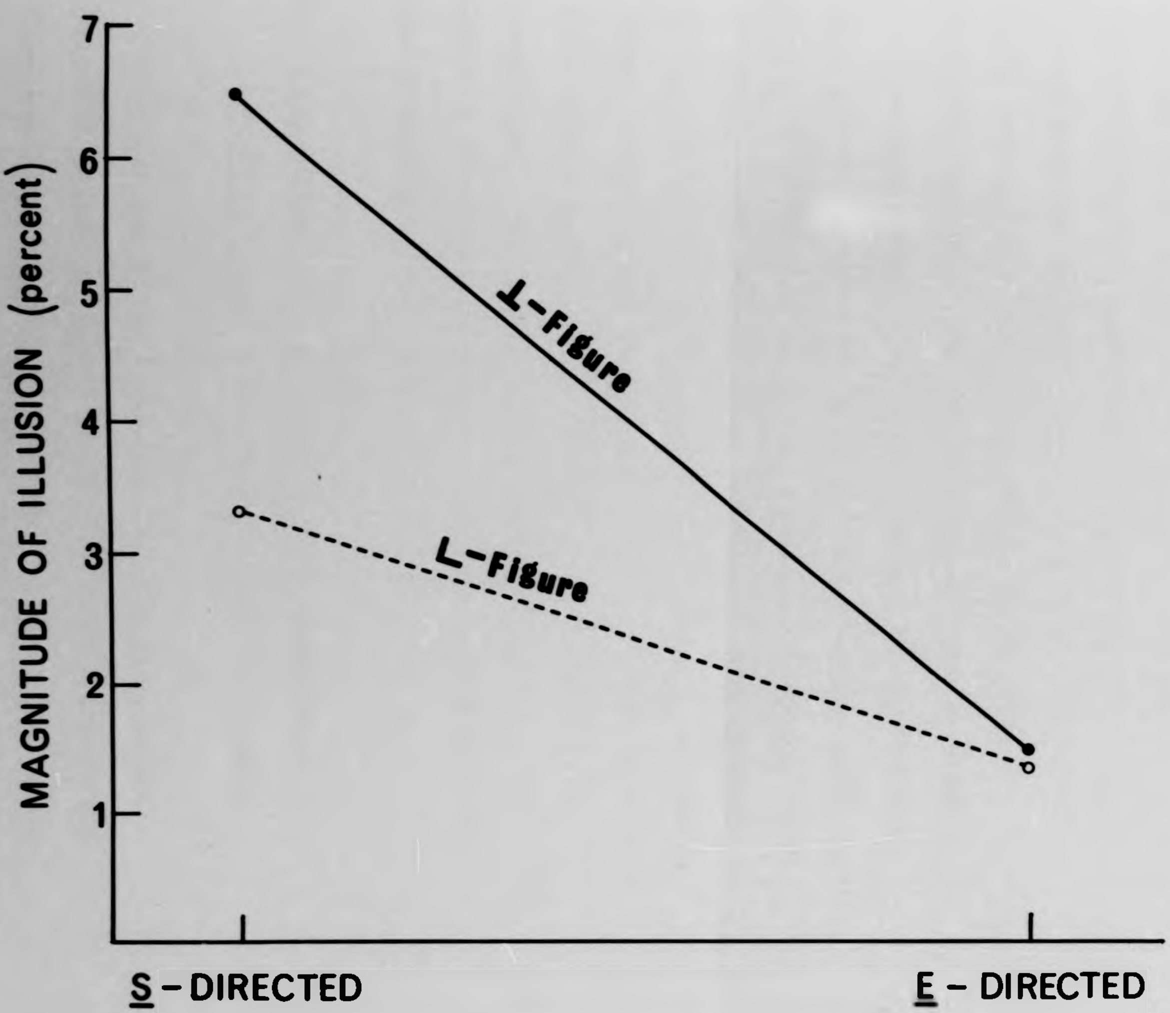
TABLE 4.2

Mean PSEs (Points of subjective equality) of the variable (radial) with 9.0 cm standard (tangential) and standard deviations for two movement conditions with the inverted-T and L figures in Experiment 3.2.

Movement condition	Statistic	inverted-T figure	L figure
Experimenter-directed	PSE (cm)	8.869	8.875
	SD (cm)	0.300	0.458
Subject-directed	PSE (cm)	8.419	8.700
	SD (cm)	0.384	0.681

FIGURE 4.4

Percentage of illusion as a function of subject-directed and experimenter-directed restricted viewing of the figures in Experiment 3.2.


MAGNITUDE OF ILLUSION (percent)
7
6
5
4
3
2
1
⊥-Figure
L-Figure
S - DIRECTED
E - DIRECTED

studies which indicate that the illusion occurs when the figure is scanned by the subject himself as in active touch and not when the registration of information is merely passive, as in tactile perception. These results are consistent with the proposal that attentional mechanisms govern the illusion and that these can operate only when the perceptual act is self-directed and thus requires attentional control.

However, the statistical analyses also indicate that the differences found among the stimulus conditions were not great. It is likely that the piecemeal input of visual information was unfamiliar to the subjects, so that they had difficulty in interpreting successive views, resulting in relatively small illusion effects where these existed. Accordingly, Experiment 3.3, involving a different approach, was undertaken to examine further the role of attention in relation to the illusion.

4.6 Experiment 3.3: The haptic HV-T illusion in relation to active and passive limb movements.

If selective attention is contingent on self-directed action of the limbs during haptic inspection, then the illusion can be expected to be abolished or diminished when limb movements during haptic inspection are rendered passive. This prediction was tested in Experiment 3.3.

Method

Subjects. There were 24 unpaid volunteer subjects, 12 males and 12 females. Their ages ranged from 17-26 years, with a mean age of 20. None of the subjects had taken part in Experiment 3.1.

Apparatus and design. The apparatus employed is illustrated in the bottom half of Figure 4.3. The inverted-T figure was represented along grooves cut into a plastic board. The bisected component (standard) was fixed at 10 cm long, while the bisector varied in length as determined by the adjustable stopper. A plastic rule, graduated in mm and affixed in parallel along the bisector, was used for calibration.

The inverted-T figure was presented in the horizontal plane so that the bisector was radial and the bisected component tangential. To assess the independent effects due to the radial-tangential factor alone, the figure was rotated 90° clockwise (sideward-T figure) and presented to the same subject with the bisected component radial and the bisector tangential. The sideward-T, in this instance, would serve as a more effective control than the L figure, since the nuances of the movement per se as dictated by the design of the apparatus are obviously different across the L and T figures. The stimulus figures were scanned with either passive or active limb movements. The design of the experiment was thus a 2 x 2 (Figure Orientation x Movement Condition) factorial with repeated measures on the figure orientation factor. Twelve subjects were randomly assigned to each movement condition with the order of presentation of figure orientation counterbalanced across subjects.

Procedure. As the experimental conditions only required haptic judgments, all subjects were blindfolded beforehand. For the passive movement (PM) condition, the tip of the index finger of the subject's preferred hand was placed lightly onto the cursor (shaped to fit the finger tip) so that no undue force was exerted throughout the course of movement. The subject was then told that his task was to judge the relative length of the components of the figure through the passive movement of the finger along the dimensions of the stimulus figure. The passive movement was effected by the experimenter moving the cursor-guide (attached at one end to the cursor) along the prescribed dimensions.

In the active movement (AM) condition, the movement was made by the subject himself pushing the cursor along the grooved figure with the tip of the index finger of his preferred hand. The cursor-guide was removed for this condition. In both PM and AM conditions, the subject's finger remained on the cursor until movement along the full dimensions of the figure was completed.

For both conditions, the psychophysical procedure and derivation of PSEs were essentially similar to those employed in Experiment 3.1 (section 4.4). The coarse and fine steps employed in the staircase series were 6 mm and 3 mm, respectively.

Results

The means, PSEs and respective standard deviations for the two movement conditions are shown in Table 4.3. An analysis of variance indicated that the main effects of movement condition ($F_{(1,22)} = 5.046$, $p < .05$), and figure orientation ($F_{(1,22)} = 36.295$, $p < .01$) were significant, but their interaction was not ($F_{(1,22)} = 2.002$, $p > .05$). All illusion effects were significant ($p < .005$) as indicated by t tests for single means, except that obtained for the PM condition with the sideward-T figure ($p > .05$). The difference between the effects with the inverted-T and sideward-T figures was significant within the passive ($t_{(11)} = 4.38$, $p < .005$) as well as the active movement condition ($t_{(11)} = 4.28$, $p < .005$.

TABLE 4.3

Mean PSEs (Points of subjective equality) in cm of the bisector with 10-cm bisected line (standard), Standard Deviations, and Percentage of Illusions for the four stimulus conditions in Experiment 3.3.

Movement condition	Statistic	Inverted-T figure	Sideward-T figure
	PSE	8.708	9.541
Passive	SD	0.718	0.905
	% illusion	12.92	4.58
	PSE	7.763	9.082
Active	SD	1.143	0.694
	% illusion	22.36	9.18

Note: For the inverted- and sideward-T, the 10-cm standard was tangential and radial, respectively.

The data clearly indicate that the haptic illusion can be obtained with either active or passive limb movements, with the illusion involving active movements being consistently larger. Such results are in accord with the selective attention hypothesis if it is assumed that the active haptic condition provides a greater scope for the operation of selective attention compared with the passive haptic condition, and that the tactile condition totally precludes the operation of selective attention. This assumption seems reasonable,,since the attention demand of the three conditions can be seen to vary in terms of the level of self-directed activity, viz. in the order of active limb movement, passive limb movement, and no limb movement. This analysis is taken further in Experiment 3.4, in the next section.

4.7 Experiment 3.4: The haptic HV-T illusion in a line-drawing task.

Drawing a symmetrical T figure while blindfolded would seem to demand greater attention than would be necessary in actively scanning a relief model of the figure. In the latter, movement is constrained by the contours of the figure. Also, the subject is not required to make a decision regarding where to terminate the movements, since the dimensions of the figure are predetermined by the experimenter. In a line-drawing task however, movements are unconstrained with the subject having to construct the figure himself, and he is thus required to make a decision either in advance or during the course of the movement as to where the endpoints of the movement would be.

Thus, a more active process of encoding information about length is required in the line-drawing task compared with constrained presentation. The increased attention demanded for such active encoding should elevate the role of selective attention. Accordingly, a large illusion can be expected when the blindfold subject is required to construct the T figure in a line-drawing task. This prediction was tested in Experiment 3.4.

Method

Subjects. There were 12 unpaid volunteer subjects, 5 males and 7 females. Their ages ranged from 17-28 years, with a mean age of 20. None of the subjects had taken part in previous experiments in this series.

Apparatus, design and procedure. Using a pencil, the subject was required to draw both the inverted- and sideward-T figure on pieces of unlined paper. He was instructed to draw the component lines as straight and as equal in length as possible,,and with the point of bisection at the midpoint of the bisected line. The experimenter showed him how to do this. The subject was told that he could draw the figure of any dimensions within the limits imposed by the foolscap sheet of paper. The subject was blindfolded prior to the experimental trials.

The same subject drew both the inverted and sideward form of the figure, with the order of presentation of each form counterbalanced across subjects. Each figure drawing was attempted 10 times by each subject. The pencil was not lifted off the paper until the total figure was completed. In line with Experiment 3.3 (section 4.6), the bisected line was taken as standard. The starting position along either the bisector or bisected component was counterbalanced across subjects.

Results

The mean length (over 10 trials) of the drawn bisector and bisected lines was calculated for each subject for both the inverted-T and sideward-T figures. The difference between the mean of the bisector and bisected line (standard) was taken as an index of the illusion and expressed as a percentage. The means, standard deviations and percentage of illusions, are shown in Table 4.4.

Both the inverted-T and sideward-T illusion effects were significant, $t(11) = 6.847$, $p < .005$, and $t(11) = 5.116$, $p < .005$, respectively. However, the difference between the illusions was not significant, $t(11) = 0.645$, $p > .05$. These results suggest that under line-drawing conditions, the independent illusion due to the overestimation of radial movements was not operative. To examine this further, 12 more subjects (four males and eight females) with a mean age of 20 years, were instructed to draw the L figure and also the figure displaced 90° (inverted-L figure). No significant effects were obtained with both the L ($t_{(11)} = 0.224$, $p > .05$) and the inverted-L figure ($t_{(11)} = 0.623$, $p > .05$). For the L figure, the respective mean lengths (cm) for the radial and tangential components were 2.435 (SD = 0.850) and 2.449 (SD = 0.946); and correspondingly for the inverted-L figure, 2.401 (SD = 0.810) and 2.329 (SD = 0.945). This finding confirms the suggestion that in the present line-drawing task, no overestimation of radial movement occurs. The full implication of this remains unclear, but an explanation is suggested in conjunction with the evaluation of the main findings in the general discussion.

The main results indicate that a relatively large haptic HV-T illusion of about 35% occurs under

TABLE 4.4

Mean lengths (cm) of bisector and bisected line (standard), Standard Deviations, and Percentage of Illusions for two stimulus conditions in Experiment 3.4.

Figure	Inverted-T		Sideward-T	
Component extent	Bisector	Bisected	Bisector	Bisected
Mean	2.784	4.115	2.533	4.034
SD	1.236	1.667	1.425	1.841
% illusion	32.345 (SD = 11.708)		37.208 (SD = 18.887)	

line-drawing conditions.

4.8 General discussion of Experiments 3.1, 3.2, 3.3 and 3.4.

The results of Experiments 3.2, 3.3 and 3.4 indicate that under conditions of restricted-visual and haptic presentation of the HV-T figure, the strength of the illusion is greatly affected by the level of self-directed activity involved in the registration of the stimulus. Thus, the visual illusion occurs only if the piecemeal exposure of the figure is directed by the subject himself, and is absent when exposure of the partial views is solely controlled by the experimenter (Experiment 3.2). With haptic presentation, the illusion obtained is greater when the scanning limb movements are active and self-directed rather than passive and experimenter-directed (Experiment 3.3). Also, when the blindfold subject is required to make freehand drawings of the figure, a relatively large illusion is obtained (Experiment 3.4).

Taken together with the data obtained earlier for tactile perception (Wong, Ho, & Ho, 1974), the results suggest that the presence of self-directed activity greatly affects the size of the illusion when information about the figure is obtained piecemeal. Such results are in accord with the hypothesis that selective attention governs the illusion, if it is accepted that the level of self-directed activity is a measure of the attention demanded of the subject in the perceptual task. Thus, the illusion is greater under the drawing and active haptic conditions since such conditions demand greater attention from the subject compared with the passive haptic and tactile conditions.

It is also assumed that salient features such as the one-fold symmetry of the figure govern the process of selective attention. Both the visual (Kunnapas, 1955; Piaget & Morf, 1956) and haptic form (Experiment 3.1) of the illusion diminish and subsequently disappear when the dividing line is shifted from the midpoint to one end of the divided line. Such results can be explained in terms of the progressive violation of the one-fold symmetry of the figure. Specifically, the dividing line becomes less salient and thus receives less attention when it is shifted away from the midpoint of the divided line.

Further evaluation of the results can now be made in relation to what is known about the illusion obtained with full vision. Under haptic and restricted-visual conditions, the time course for the piecemeal registration of the stimulus is necessarily of the order of seconds. With full-visual presentation, however, the HV-T illusion can take place within 50 msec of exposure time (Piaget, Matalon, & Bang, 1961). One should note further that the maximum visual illusion (e.g. as much as 43%), or the so-called "temporal maximum illusion" (Piaget, 1969) for the HV-T figure, usually occurs at longer exposure times of between 100-200 msec* (Fraisse & Vautrey, 1956; Piaget, Matalon, & Bang, 1961).

Since the minimum time for saccadic eye movements is in the order of about 250 msec (see: Dick, 1974; Haber & Hershenson, 1973), the temporal maximum illusion would appear to take place during the fixation time between saccades. It is precisely under such impoverished conditions of visual presentation, and in the absence of information derived from saccades, that salient features and thus selective attention would play a maximal role in the resolution of the percept. This accounts for the maximum illusion occurring within the minimum latency time for eye

* Using 20 adult subjects and the double-staircase procedure the author has found the temporal maximum illusion at 150 msec, a value in accord with the findings of Piaget and Fraisse.

movements. At greater exposure times, the illusion is diminished on account of the availability of information derived from eye movements.

An analogous interpretation can be made of the data obtained under haptic conditions. The maximum haptic illusion (about 35%) under unconstrained line-drawing conditions can be compared to that of the maximum visual temporal illusion in that the former occurs when proprioceptive feedback is minimum. Just as eye movements provide the additional information in vision, haptic feedback is provided by movement along the structural outlines of the stimulus T figure. Such feedback is available where a relief model of the T figure is employed, so that the illusions thus obtained using active and passive limb movements are accordingly smaller, viz. about 15% and 7% respectively. In the same manner, the absence of a radial-tangential effect with the L figure under line-drawing conditions (Experiment 3.4) may be due to a lack of clearly defined proprioceptive cues upon which the timing of the movement responses could operate (see section 2.6) to give rise to the haptic L illusion.

4.9 Experiment 3.5: The HV-T illusion under walking conditions.

To date, all the studies on the haptic HV-T illusion have been confined to relatively small arm movements executed within the physiological limits of the moving limb. If the illusion is governed by central attentional mechanisms, it should operate independently of the type of reafferent activity that governs the sampling of spatial information, provided that such activity is directed by the subject himself. For instance, instead of scanning the T figure with the arm and fingers, the same illusion can be expected if the blindfold subject is made to sample spatial information by walking across distances delineated in the form of a T configuration on flat ground.

Although the pattern of walking movements required is essentially different to the action of scanning with the arm and fingers, selective attention should operate similarly in the encoding of extent information, regardless of whether such information is derived through the action of limb movements or through locomotion about the larger spatial environment. Experiment 3.5 was conducted to see if an "ambulatory" HV-T illusion could be obtained under walking conditions.

Method

Subjects. There were 32 unpaid volunteer subjects, 14 males and 18 females. Their ages ranged from 17-30 years with a mean age of 20.

Apparatus and design. The subjects were randomly allocated to two groups of 16 subjects each. One group was required to walk blindfolded along a symmetrical "T-maze" while the other along an "L-maze". The L-maze group served as a control for possible confounding effects due to the "error of the standard" (Wursten, 1947). In studies with the visual T and L figures, Gardner and Long (1960a, 1960b) showed that the magnitude of illusion varied as a function of which component was used as a standard. Independent of the effects of bisection and verticality, the standard itself was also overestimated, and this constant error was attributed to the relative time involved in centring attention upon standard and comparison lines, i.e. to centration effects (Piaget, 1969; Wursten, 1947). However, more recent studies suggest that this so-called error of the standard is dependent on the psychophysical procedures employed, and does not occur when a double-staircase technique is used (Avery, 1970; Teightsoonian, 1972). Nevertheless, these findings pertain to visual studies where the scope of operation of relative time errors is limited to the short latencies of visual judgments. On the other hand, centration effects could conceivably occur when the response latencies are relatively long, as would be the case with judgments of walking distances.

Thus, the inclusion of a control group using the L-maze seemed warranted. A systematic error obtained with the L-maze could only be attributed to centration effects since both the effect of verticality and that due to radial and tangential arm movements were not relevant under walking conditions.

The T and L mazes were set up in a large teaching laboratory by arranging a number of low wooden benches appropriately. The width of the walking paths, as delineated by the edges of the benches, measured 65 cm. The blindfolded subject walked along these paths, guided by his fingertips in contact with the wooden edges on both sides. The bisected path of the T measured 600 cm and this component served as the standard throughout. The standard path of the L measured 568 cm, the limit being imposed by the available laboratory space. The length of the variable path for both mazes was measured inclusive of the width of the path at the intersection. This length was varied by changing the position of a terminal wooden bar placed across the path of the walking subject.

Procedure. The subject was blindfolded prior to entering the laboratory. He was allowed one practice trial before the actual experimental trials. After walking twice over the entire distance of the maze, beginning and terminating at the same spot, a judgment was required of the relative distance of the two component paths. The starting position was alternated from one end of the variable to one end of the standard, across subjects. The instructions stressed that the subject should walk at his preferred pace without attempting to count the number of steps taken.

The double-staircase technique (Wetherill, 1963; Wetherill & Levitt, 1965) was employed to establish the point of subjective equality (PSE). Each staircase started with component paths of the maze at equal distance (600 cm for the T and 520 cm for the L). Initially, coarse steps of 60 cm were used until four reversals of judgment occurred. The mean of these four reversals was taken as the starting position for the fine series in which steps of 30 cm were used until a further four reversals of judgment from longer to shorter (or vice versa) were obtained.

Results and discussion

The PSEs were derived from the mean of the four distances obtained from the reversals in the fine series. The difference between this mean and the standard (600 cm for the T-maze and 520 cm for the L-maze) was used as an index of the illusion and expressed as a percentage. A positive illusion indicates that the variable was judged longer, whereas a negative illusion indicates that the standard was judged longer. The means, PSEs and respective standard deviations for both experimental and control conditions are shown in Table 4.5.

Using *t*-tests (two-tailed) for single means (Hays, 1973), both the positive illusion (5.33%) for the T-maze and negative illusion (-3.85%) for the L-maze were found to be significant, $t(15) = 2.308$, $p < .05$; and $t(15) = 2.191$, $p < .05$; respectively.

The negative illusion obtained by the L-maze can be taken as a measure of the error of the standard as governed by centration effects. As these effects operated against the overestimation of the bisector in the T-maze, the positive HV-T illusion of 5.33% thus obtained is a conservative estimate of the actual strength of the illusion. In view of the negative illusion of -3.85% found for the L-maze, the true magnitude of the ambulatory HV-T illusion should be about 9%. This study has thus shown that a substantial illusion occurs under walking conditions, as predicted by the selective attention model of the illusion (see; section 4.3). A further evaluation of this model in relation to other explanations, is given in the next section.

TABLE 4.5

Mean PSEs (Points of subjective equality) in cm, standard deviations, and percentage of illusions for the T and L mazes in Experiment 3.5

Statistic	T-Maze	L-Maze
PSE	568.00	540.00
SD	55.47	36.52
% illusion	5.33	-3.85

Note: The standard of the T (bisected path) and that for the L maze is respectively 600 cm and 520 cm. The positive and negative illusions indicate an under- and over-estimation of the standard, respectively.

4.10 A comparative evaluation of the selective attention model for the HV-T illusion.

Apart from Piaget (1969), it appears that no other investigator has specifically developed an explanation for the HV-T illusion. The mathematical formula provided by Kunnapas (1955a) merely describes the empirical function of the illusion and offers no insight into the underlying psychological basis for the effect. Neither does it seem helpful to merely assert without elaboration, that the illusion is due to the effect of bisection.

A number of investigators, instead of using the HV-L figure, have inappropriately employed the HV-T figure in visual studies designed in the context of the apparent-distance or perspective theory (see sections 1.2 and 2.7). In any case, haptic studies of the HV-T illusion using congenitally blind subjects (Hatwell, 1960; Revesz, 1934), as well as the findings of the present series of experiments, clearly render any exclusively visual theory, like the perspective theory, irrelevant. Recently, Ginsburg (e.g. Ginsburg, 1971; Ginsburg, Carl, Kabrisky, Hall, & Gill, 1972) suggests that his "spatial filter" model of visual form perception is also applicable to a description of some optical illusions, including the HV-T effect.

4.10 A comparative evaluation of the selective attention model for the HV-T illusion.

Apart from Piaget (1969), it appears that no other investigator has specifically developed an explanation for the HV-T illusion. The mathematical formula provided by Kunnapas (1955a) merely describes the empirical function of the illusion and offers no insight into the underlying psychological basis for the effect. Neither does it seem helpful to merely assert without elaboration, that the illusion is due to the effect of bisection.

A number of investigators, instead of using the HV-L figure, have inappropriately employed the HV-T figure in visual studies designed in the context of the apparent-distance or perspective theory (see sections 1.2 and 2.7). In any case, haptic studies of the HV-T illusion using congenitally blind subjects (Hatwell, 1960; Revesz, 1934), as well as the findings of the present series of experiments, clearly render any exclusively visual theory, like the perspective theory, irrelevant. Recently, Ginsburg (e.g. Ginsburg, 1971; Ginsburg, Carl, Kabrisky, Hall, & Gill, 1972) suggests that his "spatial filter" model of visual form perception is also applicable to a description of some optical illusions, including the HV-T effect.

It does not seem relevant to elaborate on Ginsburg's general approach here. His allusion (Ginsburg, 1971) to the HV-T effect does not appear to go beyond a demonstration of how the inverted-T figure may be distorted through a transformation by computer simulation. This is done according to a model based on spatial frequency analysis of two-dimensional patterns.

At first sight, the centration explanation of Piaget (1969) resembles the present selective attention hypothesis in so far as both approaches attribute the illusion to central attentional mechanisms. However, it will be shown below that selective attention as conceived here, differs significantly from Piaget's notion of centration. It is not appropriate to speak further about Piaget's general centration theory (or so-called "law of relative centration") beyond what has already been said earlier (section 2.7). Adequate outlines of Piaget's theory can be found elsewhere (e.g. Flavell, 1963; Robinson, 1972; Vurpillot, 1959; Zusne, 1970).

It would appear (see: Zusne, 1970), that the overestimation of size elements due to centration can depend on a number of factors, regardless of the observer's age: (a) the overestimation of stimulus elements that are being fixated, i.e. upon which the observer's attention centres; (b) intensity of the attentional process; (c) duration of the fixation period; (d) the sequence in which stimulus elements are fixated, the last one in the sequence being overestimated, i.e., the classical time error; and (e) clarity of perception, which is determined by such factors as the visual angle, level of illumination, etc.

An optimum combination of some or all of these factors would presumably lead to a centring of perception and results in the overestimation of the stimulus elements involved. Thus, a combination of factors described in (a), (c) or (d) could conceivably account for the error of the standard described earlier (section 4.9). However, with respect to the HV-T figure, Piaget (1969 pp. 12-14) does not give any good reason as to why the features of the inverted-T should give rise to differential centration effects in the first place. From his treatment of the illusion figure as an effect due to the "error of semi-rectangles" (pp. 8-12), Piaget argues that the figure gives rise to the percept of two incomplete rectangles, which share a common longer side as defined by the bisector. Piaget further claims that from experimentation, if two lines differ "markedly" in length, then the difference will be overestimated, but if they differ only "slightly", then the difference will be underestimated. The illusion arises since a judgment of relative length is made between the markedly longer bisector and the two perceptually disparate shorter segments of the bisected line. However, the precise manner in which the perceptual system can accomplish such discriminations is left unexplained (Robinson, 1972). Further, if the figure does give rise to a percept of two semi-rectangles, then the subject would have to match the length of the single bisector with the combined length of the two perceptually distinct segments of the bisected line. The results of a recent study by Krueger (1970) have a direct bearing on this point.

Krueger (1970) found that when a subject is required to adjust the length of one line to match the combined length of two other lines, he generally makes the variable line much longer than the actual combined length of the two lines. The results are consistent whether one of the two lines is 50%, 65% or 75% of the total combined length. In other words, if apparent lengths are additive, then two lines appear to have a greater total length than the single line they would form if physically joined. Such results appear contradictory to those explanations of the illusion, such as that of the effect of the semi-rectangle, that imply the perceptual segmentation and additivity of lines.

In contrast, the present explanation maintains that selective attention is operative for the very reason that perception of the figure entails a description of the global configuration of the form, and that certain features, such as symmetry, are salient in such a description. The illusion occurs for the reason that selective attention governs the synthesis of the percept so that a gestalt "T" form is perceived, rather than two perceptually disparate lines. Thus, selective attention is seen here as intrinsic to the synthesis of apparent form, whereas centration from Piaget's description, appears to relate to factors involved in the focus of attention at stimulus elements of the form. While it is conceded that centration effects may influence the magnitude of the illusion, they cannot be the basis for its occurrence.

It may be noted in concluding this section, that the current concept of the role of selective attention seems to be in accord with the mainstream of accepted theory on selective attention, in relation to the stages of perceptual analysis (see; Kahneman, 1973). Thus, it is assumed that early in the perceptual act, there exists a stage which Kahneman calls, unit formation which performs some of the functions that Neisser (1967) attributes to pre-attentive mechanisms. Such mechanisms constrain the subsequent allocation of attention, and it is at this initial stage that the gestalt laws of grouping, e.g. similarity, proximity, etc. (and including symmetry extraction for present purposes), operate. Attention enters at the next stage, where some of the units isolated earlier receive greater figural emphasis than others. The perceptual act is thus conceived as a series of processes involving attentional mechanisms, which can be applied alike to different modalities and to units over time and space. The illusion can thus be attributed to the process of symmetry extraction at the stage of unit formation and the subsequent selective attention at the later stage of figural emphasis.

4.11 Summary of findings in Experimental Series III.

Experiment 3.1 confirmed that for the haptic T figure, the location of the dividing line along the divided line is an important determinant of the magnitude of the illusion. The illusion is maximal when the dividing line is at the midpoint of the divided component and diminishes progressively as the dividing line is shifted from the midpoint to one end of the divided line. These results are similar to those found in past studies using the visual form of the figure.

In Experiment 3.2, the T figure was presented piecemeal for visual inspection so that only a small part was visible through an aperture at any one moment. The appearance of the partial views would thus conform to the piecemeal registration of haptic or tactile information. An illusion was found only when the piecemeal exposure of the figure was directed by the subject himself, but not when exposure of the partial views was solely controlled by the experimenter.

In Experiment 3.3, the haptic HV-T illusion was found to be greater when the scanning limb movements were active and self-directed rather than passive and experimenter-directed. Also, in Experiment 3.4, a relatively large illusion was obtained when the blindfold subject was required to make freehand drawings of the T figure. Taken together with the previous finding that the illusion is absent in tactile perception, the results were taken to support the hypothesis that the illusions in vision and touch are governed by a central selective attention process. Thus, the illusion is greater under the drawing and active haptic conditions since such conditions demand dividing line is shifted from the midpoint to one end of the divided line. These results are similar to those found in past studies using the visual form of the figure.

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It was further argued that selective attention should operate similarly in locomotive space if the subject were required to sample spatial information by walking across distances delineated in the form of a T configuration on flat ground. Experiment 3.5 showed that an HV-T illusion, analogous to that found in vision and touch, does indeed occur in locomotive space.

CHAPTER 5: GENERAL CONCLUSIONS.

More than 40 years ago, Revesz (1934), using both blindfolded and blind observers, obtained visual, active-haptic, and passive-haptic judgments of 29 geometrical illusions and found similar visual and haptic illusions for most figures. Such findings are of considerable theoretical import. For if the same explanation is to cover vision and touch perception, then it is clear that the explanation must be couched in terms of processes that can share a common expression across the two modalities.

However, the precise meaning of the haptic data may not be always obvious. For instance, it is possible that the processes underlying haptic and visual illusions may be similar in principle but quite different in operation (Over, 1966). It is even conceivable that the similarity may be only coincidental. There is thus a need to determine, for the visual and haptic analogue of the illusions, the specific stimulus-features being compared and the level of operation of the processes involved in the comparison. The present studies of the so-called horizontal-vertical illusion serve to emphasize this point.

The haptic illusion with the L figure was shown to be specific to the dynamic properties of the moving limb. As such, it is obviously not related to the analogous illusion in vision. On the other hand, the similarity in the developmental trends of the illusion across the two modalities can only be reasonably explained in terms of developmental processes that give rise to similar kinds of relational responding, in the judgment of haptic and visual length.

With the T figure, it would appear that the similar visual and haptic illusions stem from a common illusion process, probably brought about by selective attention that governs the formation of the perceptual image. These studies also emphasize the necessity to give careful attention to the specific stimulus-features that govern the registration of illusion figures, as these in themselves can profoundly affect the illusion process. Thus, whether the figure is presented in toto or piecemeal over time, or whether the information is obtained actively or passively, can greatly affect the outcome. Further, the finding that a similar T illusion can be obtained under walking conditions would suggest that perhaps representations in haptic and locomotive space are similar, although very little is known on this score (Brambring, 1976). The extension of studies of illusions of extent to locomotive space is thus a potentially fruitful, but hitherto, neglected enterprise.

Three further comments ought to be made in conclusion. First, the available literature on haptic illusions is decidedly meagre, considering that the proliferation of explanations and studies of the visual illusions has kept pace with the mainstream of perceptual research. This is an unfortunate state of affairs, since the validity of purely visual explanations may be seriously questioned, if the illusions concerned can be shown subsequently to behave in the same way in haptic space.

Second, some theorists assert that even an apparently simple illusion may be multiply caused. The present findings serve to endorse this position. Therefore, attempts at <u>general</u> explanations that encompass many illusions, may be shortsighted.

Finally, the point has sometimes been made (e.g. Gregory, 1963) that an illusion obtained through touch perception may require some cross-modal transfer (e.g. involving visual imagery) such that touch information is dealt with centrally just as if it were visual in origin (see Frisby & Davies, 1971). Apart from overlooking the fact that congenitally blind subjects can also experience similar illusions, the suggestion of visual encoding is unnecessary, if one takes the view that space perception depends on a fusion of sensory modalities, with vision as one channel in a reciprocal system, rather than as a necessary reference point. Central motor mechanisms are thus viewed as akin to sensory systems, in that imagery processes must also occur in the translation of movements into plans for action and *vice-versa* (Herrick, 1956; Jones, 1972b; Neisser, 1967; Pribram, 1971; Sherrington, 1951). Given the unity of perception and motor action, one should thus *expect* rather than be surprised by the finding that similar illusions exist in visual, haptic and locomotive space.

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APPENDICES

APPENDIX 1.1

SUPPORTING PAPER I

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INFLUENCE OF SHAPE OF RECEPTOR ORGAN ON THE HORIZONTAL–VERTICAL ILLUSION IN PASSIVE TOUCH [1]

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In four experiments involving 156 *S*s, stimulus templates were traced onto the volar surface of *S*'s forearm. Experiment I showed that rotation of a T figure over 180° resulted in an illusion function, with a reversal of the effect at 90°. A similar function was obtained in Experiment II with an L figure, indicating the absence of a bisection effect. The component line along the shorter lateral axis was judged longer than that aligned with the longitudinal axis of the forearm. Experiments III and IV indicated that the effect was independent of the degree of stimulation on the skin and that an inscribed circle was similarly affected and perceived as a lateral ellipse. It was concluded that the horizontal-vertical illusion in passive touch is a function of the orientation of the figure with reference to the elongated frame of the receptor organ and is independent of the effect in vision and active touch.

Similar distortions have been found for the horizontal–vertical (HV) illusion with an inverted T figure under visual and active haptic conditions (Day & Avery, 1970; Deregowski & Ellis, 1972; Over, 1966; Revesz, 1934). However, studies with the figure under passive haptic conditions have produced conflicting data (Fry, 1967; Fry & Craven, 1972; Revesz, 1934). The early work of Revesz indicated that the bisected line of the figure was judged *shorter* than the bisector, though to a lesser degree than was similarly found for vision and active touch. In contrast, Fry's more recent studies indicate that the bisected line is judged *longer* by about 9%–19% among children and adults. The experiments reported here were designed to confirm the earlier findings of Fry and Craven and to test the hypothesis that the elliptical skin surface provided by the forearm and the palm determines the tactile HV illusion in a manner analogous to the role played by the elliptical visual field (Künnapas, 1955, 1957) in the visual form of the HV illusion.

Although Revesz (1934), Fry (1967), and Fry and Craven (1972) conducted their studies under passive haptic conditions, their procedures were essentially different. While Revesz required *S* to press his fingers onto the figure, Fry and Craven (1972) traced the figure through a template onto the palm of *S*'s preferred hand. As noted by Over (1968), tactual presentation whereby the total figure is impressed onto *S*'s skin has disadvantages in that rapid adaptation of the skin renders judgments difficult. This problem is also manifest in the method employed by Revesz and undermines the validity of data thus collected. Apart from circumventing the problem of rapid adaptation of the skin, the Fry and Craven study has one notable feature. The variable "vertical" line was traced on the proximal-distal axis of *S*'s supine palm, while the standard "horizontal" line was traced at right angles to the variable line and located along the lateral axis of the palm near the wrist. The stimulus figure was thus imposed onto the natural elongated frame of the outstretched hand such that the bisector and bisected line were along the longitudinal and lateral axis, respectively. The overestimation of the bisected line is accountable in terms of this elongated frame of the extended hand if one assumes that the greater the proportion of the frame covered by the stimulus, the greater the

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apparent length. This explanation is similar in principle to Künnapas's (1955, 1957) visual frame hypothesis, which attributes the overestimation of the vertical component of the HV illusion to its alignment with the shorter component of the natural elliptical orbit of the eye.

Experiment I

If the primary determinant of the HV illusion in passive touch is the orientation of the component lines relative to the elongated boundary of the receptor surface, it would be expected that variation in the orientation of the figure would correspondingly effect changes in the illusion. Specifically, the bisector of the T figure when inscribed onto the longitudinal axis of the volar surface of the supine forearm should be judged *shorter* (defined here as *positive* illusion) than the objectively equal bisected line inscribed along the lateral axis of the forearm. It would be expected that rotation of the figure through 180° would produce an illusion function with positive maxima at 0° and 180° with the bisector longitudinal, and a negative maximum illusion at 90° with the bisector lateral.

Method

Apparatus. Stenciled T figures were cut using symmetrical pieces of hard translucent Perspex each measuring 63.5 × 63.5 × 1.5 mm. The width of the stencil lines of the T was kept uniform at 2.5 mm. By using an aluminum rod 152.4 mm. long and 1.6 mm. cross section, a template of the figure could be traced onto the volar surface of the forearm. The length of the bisected stencil line was kept constant at 38.1 mm., while the bisector varied from 19 mm. to 58 mm. in 3-mm. gaps, to give a total of 13 stimulus templates. The bisector was measured inclusive of the width of the bisected line.

Subjects. There were 60 unpaid volunteer *S*s, 25 males and 35 females. Their ages ranged 17–26 yr., with a mean age of 19 yr.

Procedure. The *S*s wore blindfold goggles and were seated with their supine forearms extended ipsilaterally and rested horizontally on a table directly in front of them. The template was traced onto the volar surface of the forearm on a site just distal of the juncture with the upper arm. The *E* traced the stenciled figure onto *S*'s skin, without lifting the stylus off the template, until the T was completed. The starting position from either line was counterbalanced across *S*s. After each trace, *S* was instructed to indicate whether the first or second line was felt as longer. Previous work (Day & Wong, 1971) and preliminary observations indicated that a proportion of the *S*s would directly request multiple presentations of the stimulus before attempting a response. In order to minimize the bias against the more diffident *S*, each *S* was specifically instructed that he could request up to two repetitions of the same stimulus template before making a response, although he was encouraged to make a judgment on the first presentation. The stimulus was repeated only upon a specific request from *S*.

The double-staircase technique (Wetherill, 1963; Wetherill & Levitt, 1965) was used throughout to establish the point of subjective equality (PSE). Each staircase started with the bisector (variable) equal to the 38.1-mm. bisected line (standard) and was replaced by a shorter or longer variable according to *S*'s judgment. Steps of 3 mm. were used until six reversals of judgment from longer to shorter (or vice versa) occurred. After the sixth reversal, the procedure was repeated on *S*'s other arm until six more reversals were obtained.

The 60 *S*s were assigned to five groups of 12 *S*s each. Each group was tested under only one of the figure orientations at 0°, 45°, 90°, 135°, or 180°. These orientations are depicted in Figure 1. The longitudinal axis of the forearm was initially determined and marked lightly with indicator dots. The orientation of the stimulus figure was then determined with reference to the longitudinal axis and marker lines on the templates calibrated according to the five stimulus conditions. A pilot study with 12 *S*s using the palm as the stimulus surface and the T figure at 0° produced a significant positive illusion of 13.72%, $t(11) = 3.080$, $p < .01$. This confirmed the findings of Fry and Craven (1972), who employed figures of similar dimensions and homologous sites on the palm. Preliminary observations also indicated that *S*s differed markedly in terms of topographic eccentricities of the palm. This feature would enhance the difficulty of obtaining a uniform template across the different figure orientations. Accordingly, the forearm, with its relatively even receptor surface and a greater polarity of outline shape, was picked as the logical receptor site.

Results

The PSEs were derived from the mean of the 12 lengths obtained from both arms. The difference between this mean and 38.1 mm. (the standard length) was used as an index of the illusion and expressed as a percentage. The mean PSE for each condition, the standard deviation, and the percentage of illusion are shown in Table 1.

Differences among mean PSEs across orientations were found to be significant, $F(4, 55) = 4.869$, $p < .01$. Duncan's new

TABLE 1

MEAN PSEs (IN MM.) OF BISECTOR WITH 38.1-MM. BISECTED LINE (STANDARD), STANDARD DEVIATIONS, AND PERCENTAGE OF ILLUSIONS FOR THE FIVE ORIENTATIONS OF THE T FIGURE IN EXPERIMENT I

Statistic	T figure orientation				
	0°	45°	90°	135°	180°
PSE	41.504	38.755	36.779	37.693	40.767
SD	2.463	.050	.431	.279	.889
% illusion	8.933	1.666	−3.465	−1.066	7.000

Note. Abbreviation: PSE = point of subjective equality.

multiple-range test indicated that the only significant comparisons ($p < .05$) were those between orientations at 0° vs. 90°, 90° vs. 180°, and 0° vs. 135°. A trend analysis (Kirk, 1968) across orientations indicated no significant linear trend, F (1, 55) = 1.215, $p > .05$; a significant quadratic trend, F (1, 55) = 18.393, $p < .0005$; and no significant departure from quadratic trend, F (3, 55) = .3616, $p > .05$. The least squares curve of best fit was found to be: $X = -3.4342 - 0.6500 Y + 2.9071 Y^2$. This curve, together with the data points derived for the mean percentage of illusion, are shown in Figure 1. The summary data indicate that as the T figure is rotated through 180°, the direction of the illusion is reversed at 90°.

These results, taken in conjunction with those in the pilot study, indicate that the function of the illusion with the T figure is dependent on its orientation with respect to the boundary of the receptor surface.

EXPERIMENT II

Recent studies (Day & Avery, 1970; Day & Wong, 1971; Deregowski & Ellis, 1972) indicate that under active haptic conditions, the HV illusion with the L figure is only present in the horizontal plane, whereas the inverted T figure invokes a substantial illusion when presented to *S* in either the vertical or horizontal plane. In accord with such observations, these authors have suggested that the active haptic illusion with the L figure is functionally related to the components of radial and tangential exploratory arm movements described earlier by Davidon and Cheng (1964), while the effect of the inverted T figure is ascribed to the bisection effect similarly found in the visual figure (Finger & Spelt, 1947; Künnapas, 1955). A further question relates to whether the bisection of the lines contributes in any degree to the illusion in passive touch. If the effect is solely determined by the shape of the receptor surface, it would be expected that the L figure, when rotated to the same degree, would elicit an illusion function similar to that obtained for the T figure in Experiment I. This prediction is tested in Experiment II.

Method

Apparatus. The same materials and range of stimulus values were used as those in Experiment I, except stenciled L figures were employed. One line (A) of the L was kept constant at 38.1 mm., while the other line (B) varied from 19 mm. to 58 mm in 3-mm. gaps, to give a total of 13 stimulus templates.

Subjects. There were 60 unpaid volunteer *S*s, 34 males and 26 females. Their ages ranged 17–28 yr., with a mean age of 19 yr. None of the *S*s had participated in Experiment I.

Procedure. The psychophysical procedure, method of testing, derivation of PSEs, and statistical treatment were the same as for Experiment I. Line B (variable) was inscribed along the longitudinal axis for orientations at 0° and 180°, and along the lateral axis at 90°.

Results

The mean PSE for each condition, the standard deviation, and the percentage of illusion are shown in Table 2. Differences among mean PSEs across orientations were found to be significant, F (4, 55) = 3.496, $p < .05$. Duncan's new multiple range test indicated that the only significant

TABLE 2

MEAN PSEs (IN MM.) OF VARIABLE (LINE B) WITH 38.1-MM. STANDARD (LINE A), STANDARD DEVIATIONS, AND PERCENTAGE OF ILLUSIONS FOR THE FIVE ORIENTATIONS OF THE L FIGURE IN EXPERIMENT II

Statistic	L figure orientation				
	0°	45°	90°	135°	180°
PSE	40.563	38.760	36.779	39.598	41.273
SD	1.981	4.216	3.048	2.387	3.886
% illusion	6.466	1.733	−3.466	3.933	8.333

Note. Abbreviation: PSE = point of subjective equality.

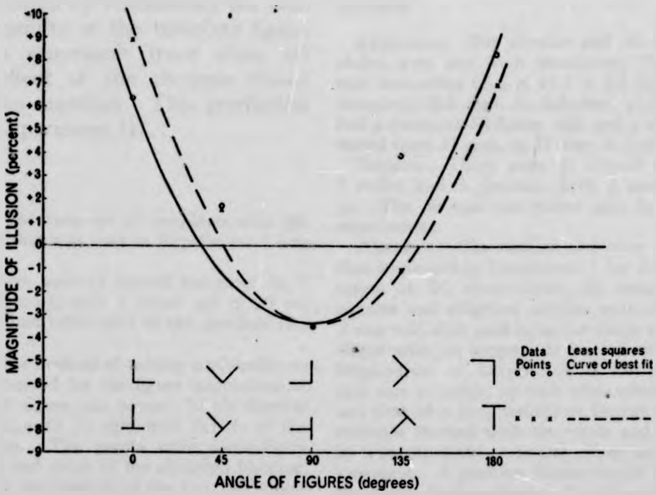

FIGURE 1. Percentage of illusion as a function of figure orientation from 0° (judged component lateral) through 90° (judged component longitudinal) to 180° (judged component lateral).

comparisons ($p < .05$) were those between orientations at 0° vs. 90°, and 90° vs. 180°. A trend analysis across orientations indicated no significant linear trend, F (1, 55) = .590, $p > .05$, a significant quadratic trend, F (1, 55) = 11.409, $p < .01$, and no significant departure from quadratic trend, F (3, 55) = .865, $p > .05$. The least squares curve of best fit was found to be: $X = -3.4000 + .5500\,Y + 2.7500\,Y^2$. This curve, together with the data points derived for the mean percentage of illusions, is shown in Figure 1. The data, together with those obtained in Experiment I, were further analyzed in terms of a 2 × 5 (Figure × Orientation) factorial design. The analysis revealed no significant difference between mean PSEs obtained across the L and T figures, F (1, 110) = .216, $p > .05$, a significant difference among mean PSEs across orientations, F (4, 110) = 7.770, $p < .001$, and no significant interaction effects between figure type and orientation, F (4, 110) = .624, $p > .05$.

A pertinent question could be raised regarding whether *S*s could in fact discriminate between the T and L figures. Accordingly, an additional eight *S*s, six females and two males, were each presented with both the standard T and L stimulus figures, orientated at 0°, on the volar surface of the forearm. Each stimulus figure was presented twice, once on each forearm. The order of the four stimulus presentations was randomized. After each stimulus was presented, *S* was required to indicate whether the stimulus was that of an L or inverted T. The results indicated that all *S*s could discriminate between the L and T figures on each of the four presentation trials, without exception.

The results, taken in conjunction with those obtained in Experiment I, indicate that the bisection of the lines does not play a role in the HV illusion under passive haptic conditions. Furthermore, essentially the same illusion function can be obtained with either the L or T figures when the figure is rotated with reference to the boundary of the receptor surface of the forearm.

EXPERIMENT III

If the distorting effect of the receptor frame is a general one, it should operate irrespective of the method of presenting the stimulus figure. Specifically, if the T figure is presented by stimulating the skin at strategic points of the template figure instead of a movement trace along all parts, the effect of the receptor frame should still be manifest. This prediction is tested in Experiment III.

Method

Apparatus. The same set of templates with the stencil T figure that was used in Experiment I was employed.

Subjects. There were 12 unpaid volunteer *S*s, 7 males and 5 females, with a mean age of 19 yr. None of the *S*s had taken part in the previous two experiments.

Procedure. The method of testing was similar to that in Experiment I for the figure orientation at 0°, except the T figure was defined by six discrete points impressed onto *S*'s skin with the tip of the aluminum stylus. The points were successively localized at the end point of the stenciled bisector, its midpoint, the intersection of the line, one end of the bisected line, the intersection, and the other end of the bisected line. A T figure was thus defined by the six discrete point stimuli. The order of presenting the points was alternated between the bisector and bisected stencil lines, across *S*s.

Results

The mean PSE was found to be 40.259 mm. ($SD = 3.352$) to give a positive illusion of 5.66%, $t\ (11) = 2.205$, $p < .05$. This directional t test is achieved with an estimated *power* of .8011. For the corresponding illusion (8.93%) found in Experiment I with the T figure at 0°, a directional t test, $t\ (11) = 4.745$, $p < .01$, is obtained with an estimated *power* of at least .98 when α is set at .05. Thus, it has been shown that the illusion with the T figure operates irrespective of the manner of presenting the stimulus template onto the forearm.

Experiment IV

The generality of the receptor frame effect should also extend to distortions of *shapes*, as with its demonstrated influence on the apparent *sizes* of lines. Thus, a circle traced onto the volar surface of the forearm should feel like an ellipse with the longer axis aligned with the lateral axis of the arm. This prediction was tested in Experiment IV.

Method

Apparatus. One circular and six elliptical templates were cut from translucent Perspex pieces, each measuring 63.5 × 63.5 × 1.5 mm. The circle measured 50.8 mm. in diameter, while the ellipses had a constant 50.8-mm. axis and a short axis that varied from 47 mm. to 32 mm. in 3-mm. steps.

Subjects. There were 12 unpaid volunteer *S*s, 7 males and 5 females, with a mean age of 29 yr. The *S*s had not taken part in the previous experiments.

Procedure. The method of testing was similar to that employed in Experiment I for the figure orientation at 0°, except that the templates defined circular and elliptical outlines onto *S*'s skin. The *S* was told that each stimulus shape was that of an ellipse with its longer axis located either along the longitudinal or lateral axis of the forearm. His task was to judge, on each trial, whether the shape was that of a longitudinal or lateral ellipse. Each staircase started with the circle and was replaced by a longitudinal or lateral ellipse according to *S*'s judgment. A positive illusion would be obtained if the mean PSE indicated that the circle was perceived as a lateral ellipse.

Results

The PSEs were derived from the 12 reversals obtained from both arms. Each PSE was calculated from the difference between the variable axis and the 50.8-mm. constant. For reversals with a longitudinal ellipse, the difference was added to 50.8 mm., while for a lateral ellipse, the difference was subtracted from 50.8 mm. to give the PSE. The mean PSE was found to be 52.984 mm. ($SD = .355$), indicating that the circle was perceived as a lateral ellipse with a distortion of 4.300%, $t\ (11) = 2.461$, $p < .05$. The differences among the mean illusion percentages obtained for the T, L, "dotted" T, and circle templates at 0° orientation were found to be insignificant, $F\ (3, 44) = .9771$, $p > .05$. These results indicate that the effect of the shape of the forearm on the judgment of lines is similarly manifest in the judgment of the shape of a stimulus circle.

Discussion

The HV illusion in passive touch was found to be about 6%–9% on the volar surface of the forearm irrespective of whether the T or L figure was used as stimulus. A rotation of the inscribed T and L figures in Experiments I and II through 180° on the forearm produced similar illusion functions with a reversal of the effect at 90°. The stimulus dimension aligned with the shorter lateral axis of the forearm was judged larger relative to parts inscribed on the longitudinal axis. The effect is independent of the degree of local stimulation of the skin surface as shown in Experiment III and can be generalized to account for a similar distortion in the judgment of shape (Experiment IV). The larger illusion of 13.72% obtained on the palm is comparable to that of about 15% obtained by Fry and Craven (1972). This larger value is more likely due to the greater spatial acuity of the palm compared with the forearm (Weinstein, 1968) than to the operation of additional effects.

The data support the view that the illusion is due to characteristics of the receptor organ rather than to phenomenal features of the stimulus. Nevertheless, the question remains as to whether a common relational principle can be invoked to account for the HV effect across conditions of visual, active haptic, and passive haptic stimulation.

As the bisection effect is absent in passive touch, the illusion with the T figure is specific to the operating characteristics of active touch and vision. With visual and active haptic inspection, attention can be focused selectively onto stimulus parts, and similar judgmental errors can be expected if a common pattern of inspection pertains to the two modalities. This issue remains open to an empirical test.

Contrary to the earlier claim of Künnapas (1955, 1957), the effect of the visual frame has been relegated to a minor role in its influence on the illusion with the L figure (Avery & Day, 1969; Houck, Mefferd, & Greenstein, 1972). As the effect in passive touch has been shown to be relatively large, its relation in principle to the visual frame effect may be only superficial.

Since the illusion in active touch has been assigned to the operating features of the moving limb (Cheng, 1968; Davidon & Cheng, 1964; Day & Wong, 1971; Deregowski & Ellis, 1972), it is obviously not associated with the effects ascribed to the illusion under passive haptic conditions. It can be concluded, therefore, that the HV illusion in passive touch operates independently of the illusion in vision and active touch.

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APPENDIX 1.2

SUPPORTING PAPER II

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A FURTHER EXAMINATION OF THE DEVELOPMENTAL TREND OF THE TACTILE HORIZONTAL-VERTICAL ILLUSION*[1]

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In a recent developmental study of the horizontal-vertical (HV) illusion in passive touch, Fry and Craven found substantial (about 9-19%) illusion effects among children and adults when a T figure was traced onto *S*'s outstretched palm.[2] The bisected line along the lateral axis of the palm was judged longer than the bisector along the longitudinal axis. However, no significant developmental changes were observed among *S*s of different age groups. Wong, Ho, and Ho[3] have since demonstrated, using adult *S*s, that a similar but smaller (about 6-9%) illusion could be obtained on the volar surface of the forearm irrespective of whether the T or an L figure was used as stimulus. The purpose of the present study was to reassess the developmental trend of the tactile HV illusion with the L figure as stimulus and the volar surface of the forearm as receptor site.

Details of the apparatus and psychophysical procedures employed have already been reported elsewhere.[3] The standard (1½ inch) and variable component of the figure was inscribed, respectively, onto the lateral and longitudinal axis of the forearm. Four groups of 20 *S*s each were obtained from a local coeducational school. Each group consisted of 10 males and 10 females with respective mean ages of 7.7 (seven years and seven months), 8.7, 9.8, and 10.6. A fifth group, consisting of data from the previous study obtained under the same conditions,[3] using 12 adult *S*s (seven males and five females) with a mean age of 20.9, was also included for analysis.

The points of subjective equality (in inches) obtained for the 7-, 8-, 9-, 10- and 20-year-old *S*s were, respectively, 1.530 (*SD* = .113), 1.582 (*SD* = .115), 1.583 (*SD* = .146), 1.590 (*SD* = .114), and 1.597 (*SD* = .078).

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[2] Fry, C. L., & Craven, R. B. A developmental examination of visual and of active and passive tactual horizontal-vertical illusions. *J. Genet. Psychol.*, 1972, 121, 127-132.

[3] Wong, T. S., Ho, R., & Ho, J. Influence of the shape of the receptor organ on the horizontal-vertical illusion in passive touch. *J. Exper. Psychol.*, 1974, 103, 414-419.

Expressed as a percentage of the standard, the illusions for the above groups are, respectively, 2.00% [$t(19) = 1.091$, $p > .05$]; 5.50% [$t(19) = 3.073$, $p < .01$]; 5.59% [$t(19) = 2.453$, $p < .05$]; 6.03% [$t(19) = 3.502$, $p < .01$]; and 6.46% [$t(11) = 4.240$, $p < .01$]. Since no significant ($p > .05$) sex differences were obtained within groups, the data from both males and females were pooled in each group to provide an analysis of variance across groups [$F(4,87) = .854$, $p > .05$].

Except for the marginal data from the seven-year-olds, these results corroborate and extend those of previous studies in showing that the tactile HV illusion when presented either in its L or T version is found among both children and adults. As with the T figure, no developmental trend of the illusion in its L form is manifest. The results are consistent with the view[3] that the illusion in either its L or T form is determined by the elliptical skin surface provided by the forearm and palm such that the stimulus line aligned with the shorter lateral axis of the receptor surface is judged longer relative to the component inscribed on the longitudinal axis. The reference effect is operative from the age of eight and is maintained through to adulthood.

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APPENDIX 2: MAJOR STATISTICAL ANALYSES FOR EXPERIMENTAL SERIES I.

EXPERIMENT 1.1

Horizontal-Front Condition.

Source:	SS	df	MS	F
Between orientation (O)	259.3358	6	43.2227	4.9151
Between length (L)	8355.2285	3	2785.0762	316.7019
O x L	94.1474	18	5.2305	0.5948
Total between conditions	8708.7117	27		
Between subjects	4237.8964	13		
Subjects x conditions (error)	3086.6957	351	8.7940	
Total	16033.3038	391		

Horizontal-Side Condition.

Source:	SS	df	MS	F
Between orientation (O)	175.2864	6	29.2144	3.5676
Between length (L)	9158.9160	3	3052.9720	372.8184
O x L	85.4064	18	4.7448	0.5795
Total between conditions	9419.6088	27		
Between subjects	6041.4004	13		
Subjects x conditions (error)	2874.2724	351	8.1889	
Total	18335.2816	391		

EXPERIMENT 1.1

Vertical-Front Condition.

Source:	SS	df	MS	F
Between orientation (O)	327.0058	6	54.5010	5.8993
Between length (L)	15408.6386	3	5136.2129	555.9515
O x L	1162.6792	18	64.5933	6.9917
Total between conditions	16898.3236	27		
Between subjects	7068.3623	13		
Subjects x conditions (error)	3242.7374	351	9.2386	
Total	27209.4233	391		

EXPERIMENT 1.2

Covariance Analyses with randomised blocks

(y = length scores, x = speed scores)

Horizontal-Front Condition.

Source:	yy	xy	xx	df	SS adj.	MS adj.
Rod orientation	5.524	3.435	2.633	4	2.807	0.701
Subjects	177.176	64.973	148.270	24		
Residual	35.247	13.824	30.606	95	29.003	0.305
Total	217.947	82.232	181.509	123		

Horizontal-Side Condition.

Source:	yy	xy	xx	df	SS adj.	MS adj.
Rod orientation	12.165	6.906	4.591	4	4.139	1.034
Subjects	225.343	86.921	136.667	24		
Residual	51.054	21.075	28.793	95	35.628	0.375
Total	288.562	114.902	170.051	123		

EXPERIMENT 1.3

2 x 10 (Movement Direction x Location) repeated measures design.

Source:	SS	df	MS	F
Between movement directions (A)	20.7025	1	20.702	13.0119
Between locations (B)	3380.2225	9	375.580	236.0654
A x B	73.5865	9	8.176	5.1389
Total Between conditions	3474.514	19		
Between blocks	266.847	19		
Blocks x conditions (error)	574.536	361	1.591	
Total	4315.897	399		

APPENDIX 3: MAJOR STATISTICAL ANALYSES FOR EXPERIMENTAL SERIES II.

EXPERIMENT 2.1

Trend analysis for unequal intervals: Illusion scores across seven age groups.

Source:	SS	df	MS	F
Between groups	12.9670	6	2.1611	1.4754
Linear trend	1.5167	1	1.5167	1.0355
Departure from linear trend	11.4503	5	2.2900	1.5634
Quadratic trend	7.5169	1	7.5169	5.1320
Cubic trend	4.7379	1	4.7379	3.2347
Within groups	194.8113	133	1.4647	
Total	207.7783	139		

EXPERIMENT 2.2

Trend analysis for unequal intervals: Total time-scores across seven age groups.

Source:	SS	df	MS	F
Between groups	19144.6144	6	3190.7690	5.0900
Linear trend	6082.7640	1	6082.7640	9.7034
Departure from linear trend	13061.8499	5	2612.3699	4.1673
Quadratic trend	6652.8875	1	6652.8875	10.6129
Cubic trend	3056.6754	1	3056.6754	4.8761
Within groups	83373.1881	133	626.8660	
Total	102517.8025	139		

Trend analysis for unequal intervals: Difference-time scores across seven age groups.

Source:	SS	df	MS	F
Between groups	3112.9715	6	518.8285	3.3559
Linear trend	1956.7567	1	1956.7567	12.6571
Departure from linear trend	1156.2145	5	231.2429	1.4957
Quadratic trend	7.7070	1	7.7070	0.0498
Cubic trend	288.9668	1	288.9668	1.8691
Within groups	20561.4500	133	154.5973	
Total	23674.4215	139		

APPENDIX 4: EXPERIMENT 3.3.

2 x 2 (Movement Condition x Figure Orientation) with repeated measures on the Figure Orientation factor.

Source:	SS	df	MS	F
Between movement condition	591.716	1	591.716	5.046
Between subjects within movement condition (error)	2579.634	22	117.256	
Between subjects	3171.350	23		
Between figure orientation	1389.008	1	1389.008	36.295
Figure orientation x movement condition	76.611	1	76.611	2.002
Pooled figure orientation x subjects (error)	841.938	22	38.270	
Figure orientation x subjects	918.549	23		
Total	5478.907	47		