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NAME OF SUPERVISOR/*NOM DU DIRECTEUR DE THÈSE* Dr. Thomas M. Nelson

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DATED/*DATÉ* May 9, 1975 SIGNED/*SIGNÉ* Paul Charles Vasold

PERMANENT ADDRESS/*RÉSIDENCE FIXÉ* 608 Patterson Ave.
Bay City, MI 48706

THE UNIVERSITY OF ALBERTA

SHAPE-SLANT INVARIANCE AS A MEASURE OF ENVIRONMENTAL INFORMATION

By

Paul Charles Vasold

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
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FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Shape-Slant Invariance as a Measure of Environmental Information" submitted by Paul Charles Vasold in partial fulfilment of the requirements for the degree of Master of Science.

T.M. Nelson
Supervisor

Paul Swartz

Date April 29, 1969

ABSTRACT

Research was performed to empirically fix the shape-slant invariant component manifested in response to a fixed range of stimulus transformations and to discover the invariant relations within the process of perceiving shape and slant. The shape-slant response functions were compared to functions describing impingement and inclination of targets in terms of Euclidean geometry (cosine functions) by measurement of area between respective functions to discover the degree of information lost by visual transformation of various target configurations. Theoretical aspects of physical and psychological invariance were discussed in special reference to a hypothesis that physical and psychological invariance are distinct.

Sixty-four male subjects observed targets of a special class described as 'circles' and 'ellipses' varied three ways in respect to frontal plane minor/major axis ratio (5 x 5, 4 x 5, 2 x 5), three ways in respect to target surface condition (outline, plain surface, textured surface), two ways in respect to background (unstructured, structured), and four ways in respect to target inclination from the frontal plane (0°, 22.5°, 45°, 67.5°). Shape response was measured from drawings, while slant response was measured from tilt-board settings.

Basic analysis of the results by comparison of stimulus and response values in terms of impingement/shape and inclination/slant, respectively, show shape (response) values to be similar to impingement (stimulus) values, but slant values to differ from inclination values. The differences between slant and inclination increased with decreases in target axis ratios, but were constant when comparing shape and impingement. The data

precluded discussion in terms of an "error" hypothesis.

Points fixing shape-slant response functions for target surface-background-axis ratio conditions demonstrated unique psychological invariance, with functions varying with target-field conditions used. Specifically, the results show, first, a constant surround condition will produce a shape-slant invariant relation for a given target surface condition; second, transformation of target surface will transform the shape-slant function; third, a constant target surface condition will produce a shape-slant invariant function for a given surround; and fourth, transformation of the surround will transform the shape-slant function. The reliability of the data was established.

An empirical measure of environmental information was established for the conditions used by comparison of the psychological invariant functions and the Euclidean geometric functions, revealing the outline condition presented the greatest information loss (greatest area between physical and psychological functions), with textured surface, plain surface, and background conditions presenting less information loss, respectively.

The psychological invariance functions were discussed in terms of distortion of an edge given with two dimension targets 90° from the frontal plane. Two variables were considered: proportion of visible area and symmetry of visible area around the line of rotation.

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Paul C. Vasold.

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Introduction

Within the ordinary language system, a category of physical stimuli refered to as 'form' has had various "names" (proper nouns) associated with it which designate numbers of the category. However, as in the case of naming surface color, where names are assigned to only several hundred of the approximately 7 1/2 million discriminately different samples, few of the endless possibilities of 'form' as members of the category actually receive distinguishing titles. For example, within the special range of two dimensional stimuli of focal interest here, one form is assigned the name "circle" if certain properties are realized, while a whole group of distinguishably different forms are lumped together under the heading "ellipse" if other properties are realized.

Using measurement, the convention has been to call two dimensional stimuli "circle" when the measuring device employed gives the same values from center to outer edge at all positions when located in the same plane as the figure. In the case where measurements made under identifical conditions describe the formula $x^2/a^2 + y^2/b^2 = 1$, for example[1], the form is given the title "ellipse."

Such measurements ultimately define the "real" (Thouless, 1931) or "distal" (Brunswick, 1956) object and are expressed as simple ratios. A circle is designated by the value 1.00 as all axes are equal. Ellipses are designated by values varying between 1.00 and 0.00 depending upon the relation of the length of the minor and major axes. Much has been made of "real" object measures conceptually, but nevertheless they seem to have doubtful status as explanatory concepts (Koffka, 1935).

Two dimensional stimuli may also be described in other ways using plane geometry. Within perception, three metric variables have been evident. These are (A) measurements of the frontal plane projection or impingement of the stimulus, earlier called retinal image or stimulus object by Thouless (1931) and "proximal" stimulus by Brunswick (1956); (B) inclination from the frontal plane; and (C) cosine functions, which are invariants abstracting the general relationship of frontal plane projection to orientation.

With solid geometry, the cosine represents cross-sections of solid forms as well. Hence, two dimensional stimuli may be defined as solids with flat surfaces represented by various cross-sections, ie. circles and ellipses as cross-sections of right circular cylinders or cones.[2]

The above specifications each represent measurements on physical scales. Physical stimuli are also comprised of other photic variables which have not been given precise metric treatment. Commonly included are those conditions described as outline or edge, surface, texture, foreground and background.

The notion of invariance is difficult. It is usually conveyed using visual devices or metaphors. For example, the mathematician presents the concept at an "intuitive" level by asking one to appreciate that when a rubber dollar bill is stretched or twisted in any way, printed elements on the bill undergo orderly changes in relationship. The particular relationship being determined by the physical distortion produced.

The concept of invariance became scientifically significant when geocentric theory began to give way to more universal physical conceptions. According to Bohm (1965) and von Fieandt (1966), conceptualization of the general characteristics of movement was only possible because Galileo was able to describe movement as a permutation of velocity, making no reference to objects which might be involved in movement.

Abstract treatment of change consists mathematically of describing relations between measurements (Bohm, 1965). It is probably inaccurate to conceive of physical invariance simply as relations between phenomena, as von Fieandt (1966) suggests. Instead, the physical facts of space consists of relationships between observed phenomena and instruments (Bohm, 1965, p. 51).

The notion of invariance as theorization about sets of measurements has some importance for the present problem. For purposes of theory, we require basically no more of instruments than that they produce measurements, representative of the whole range of phenomena under consideration and are variable.[3]

In perception, the human in fulfilling explicit experimental directions provides phenomena which when scaled constitutes the measuring instrument. This is analogous to a thermometer as an instrument: change in volume of the mercury is the phenomena and graduations on the tube the scaling device. In the case of the human however, altering directions or mode of response creates a new instrument and necessarily different values or indexes even though the same individual human is employed. Theoretically, the particular measuring instrument used may or may not make a difference in the form of the invariance. There is generally no way of knowing before experimentation whether a difference will occur or how this difference will occur. This is determined on an empirical basis. Thus, one finds Stevens (1951) describing invariance on the basis of scale types in psychophysical work, the particular type of scale depending upon the rate at which the relation of impingement to response changes. Definition of the functional relation does not depend upon qualitative or intuitive considerations such as whether magnitude estimation, hand grip, line length, circle size, loudness, or brightness is the index used. They are found to be of one type or another on an empirical basis. So, as a matter of fact, he distinguishes two general types of psychophysical invariance, those described by metathetic and prothetic scales.

Psychologists concerned with shape-slant invariance have often wanted to go beyond these requirements. This unfortunately amounts, in some cases, to the assumption that some "true" type of measurement for qualitative dimensions of shape exists. Epstein & Park (1963, 1964) for example offer extraneous criticisms of the use of drawing as an indicant of shape, ignoring empirical considerations (Thouless, 1931) (Nelson & Bartley, 1964) in doing so.

Returning to matters more closely allied to the experimental problem, let me take the case of special stimuli used in the experiment to be reported to exemplify invariance. As said, invariance is described when a set of measures are coordinated in a form stating functional dependence through a group of transformations. Taking the case of the circle and two examples of ellipses, relations of the metric variables of impingement and inclination defining these physical stimuli may be intuitively grasped through use of ordered tabular values or at a visual level using a graphic technique. Table 1 gives the relational values arrived at through appropriate measurement. Inclination is represented in degrees from the frontal plane while impingement is given as the minor/major axis ratio of the frontal plane projection using a linear measure, i.e. centimeters. Both aspects contribute one set of measures to form the relation for each example of target form. These same values are presented graphically in Figure 1. The curves show invariance visually, representing Euclidean cosine functions which may be taken as mathematical expressions of invariance. The graph and functions describe transitional or dynamic objects as well, as previously noted, as various cross-sections of a solid.

Notice in the case of each form that one of the impingement values, given through the ratio conception, describe the "real" object of Thouless (1931) and the "proximal" object of Brunswick (1956). Points marked A, B, and C are thus a statement of the 'real' forms called circle, 4 x 5 ellipse, and 2 x 5 ellipse respectively.

To this point I have been concerned with formal notions of invariance without much reference to perceptual theory, that is as to what it is that is being measured. Let us turn now to a consideration of the role invariance plays in such matters.

Within psychological theories of perception, concern with invariance has been represented in several forms, although not all deal specifically with shape and slant. As indicated, Stevens (1951), dealing with the

TABLE 1

IMPINGEMENT/INCLINATION RELATIONSHIPS

(for three target forms)

CIRCLE		4 x 5 ELLIPSE		2 x 5 ELLIPSE	
1.000	0	0.800	0	0.400	0
0.996	5	0.797	5	0.398	5
0.985	10	0.788	10	0.394	10
0.966	15	0.773	15	0.386	15
0.939	20	0.751	20	0.376	20
0.924	22.5	0.739	22.5	0.370	22.5
0.906	25	0.725	25	0.362	25
0.866	30	0.693	30	0.346	30
0.819	35	0.655	35	0.328	35
0.766	40	0.613	40	0.306	40
0.707	45	0.566	43	0.283	45
0.643	50	0.514	50	0.257	50
0.574	55	0.459	55	0.230	55
0.500	60	0.400	60	0.200	60
0.423	65	0.338	65	0.169	65
0.383	67.5	0.306	67.5	0.153	67.5
0.342	70	0.274	70	0.137	70
0.259	75	0.207	75	0.104	75
0.174	80	0.139	80	0.070	80
0.087	85	0.070	85	0.035	85
0.000	90	0.000	90	0.000	90

TABLE 1. The relationship between values of impingement and inclination giving the cosine functions for the circle 4 x 5 ellipse, and 2 x 5 ellipse. Impingement values are given on the left in each set of columns and expressed as ratios of minor to major axes. Inclination values are given on the right and expressed as degrees from the frontal plane.

Figure 1. Physical or cosine functions describing inclination and impingement for a circle (I), a 4 x 5 ellipse (II), and a 2 x 5 ellipse (III). Points marked A, B, and C describe the 'real' objects of Thouless (1931) and the distal objects of Brunswick (1956) named circle, 4 x 5 ellipse, and 2 x 5 ellipse, respectively.

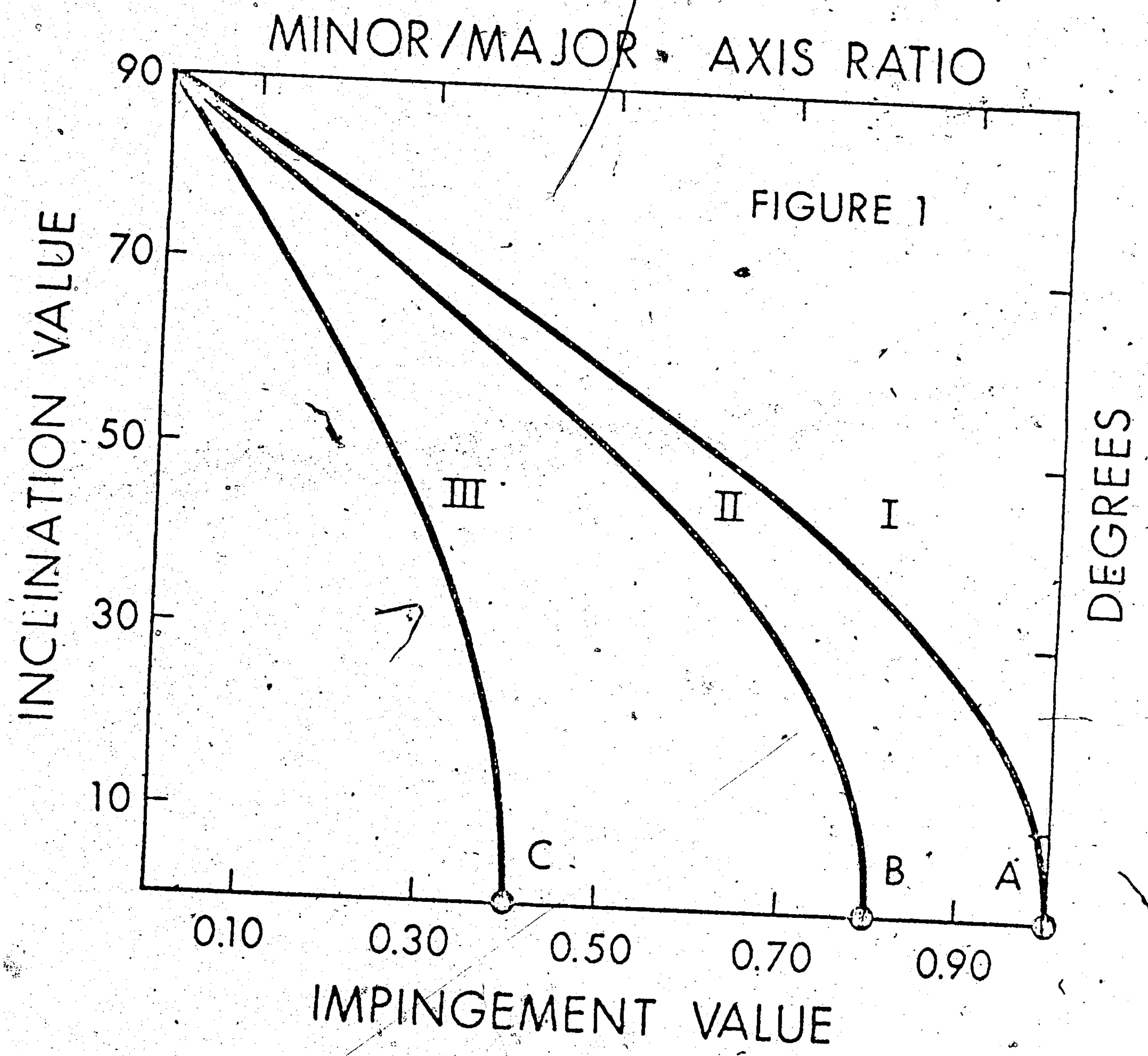


FIGURE 1

MINOR/MAJOR AXIS RATIO
INCLINATION VALUE
DEGREES
90
70
50
30
10
IMPINGEMENT VALUE
0.10
0.30
0.50
0.70
0.90
I
II
III
A
B
C

syntactical aspect of response data has been much impressed with the arbitrary dimension of theoretical description. Accordingly he defines measurement as the "assignment of numerals to things so as to represent facts and conventions about them." From this position, one would consider invariance as a formal dimension of theorization, ie. as separate from but not necessarily independent of natural events (Nelson & Bartley, 1961).

In contrast, another major group has traditionally considered invariance a property represented in perception. What this position stands for is not so clear as invariance per se was not often discussed. The movement probably began with the German tradition of Experimental Phenomenology as a concern with process in contrast to content. Geothe was certainly an early figure (Amer. Sci. 1952). But, within psychology the notion can be traced to Brentano's rather cryptic statement[4] that "mind consists of acts that are phenomena characterized by their ... inherent objectivity, that is ... these acts have ... intentional inexistenc an object that inexists intentionally within every act" (Interpretation from Herrnstein & Boring, 1965). Brentano apparently would have considered invariance as the 'act' within which an object 'inexists.' Invariance and object are psychic phenomena which are to be distinguished from physical phenomena.

This distinction is made in several points (Brentano, 1874). First, psychic phenomena are ideas and phenomena based on ideas which appear to the observer without physical extension. Second, psychic content has a relationship to an external or physical object only through 'intentional inexistence', ie. only through that which the mind suggests the external object to be. To put it another way, acts exclusively belong to inner perception and they are interpreted through other acts. Third, all external existence, whether actual or intentionally determined, is derived from psychic content, which is perceived as unitary in contrast to external existence (physical phenomena) which may come as parts of a single phenomena. It is from this basis that others began to make assumptions concerning invariance and its probable physical correlates.

Gestalt psychologists attempted invariant statements, but remained on a descriptive level without adequate scientific and empiric definition. Von Fieandt (1966) criticizes their considerations on the grounds of quantification in saying: "difficulty in finding appropriate quantitative definitions indicates the crude, abstract level of such constructs and the multiplicity of relational connections in the field of psychology."

However, Koffka (1935) succeeded in analyzing response invariance in detail to derive an understanding of shape perception. In doing so he used a direct translation. He apparently considered Euclidean geometry as adequate means of describing the perceptual processes taking place. Koffka says: (1935, p. 229) "if two equal retinal shapes give rise to two different perceived shapes, they will at the same time produce the impression that these two shapes are differently oriented."

A direct restatement of his hypothesis was made in 1945 by Stavrianos. She postulated that: "changes in the accuracy with which inclination is judged will be accompanied by changes in the accuracy of shape perception such that, when the inclination of an object is accurately perceived, its apparent shape will coincide with the actual shape; when inclination is underestimated...the apparent shape will deviate from the actual in the direction of the retinal shape; and when the inclination of the object is overestimated, the apparent shape will deviate from the actual in the direction of greater than object match or overconstancy."

Gibson (1965) and Beck & Gibson (1955) continue in the same traditi when they state that "the invariant component in a transformation carries information about an object " and "when an observer attends to invariance he perceives objects." Perceptual invariance is explained in the followin way: "a retinal projection of a given form determines a unique relation of apparent shape to apparent slant". Invariance is again considered to depend upon a counter-balancing of two types of perceptual error and manifested empirically as a direct relationship between error in perceived inclination (slant) and error in perceived frontal plane image projection (shape). This perceptual theory will be refered to as the 'error invariance hypothesis.'

The error invariance hypothesis has been used extensively in recent years, but has admittedly (Epstein & Park, 1963) not shown predictions to be entirely forthcoming. Koffka (1935) experienced difficulty interpreting experimental data then present and Stavrianos' (1945) direct test generally failed to satisfy predicted invariant relationships (Graham, 1951; Epstein & Park, 1963). Beck & Gibson (1955), in another report, state "that the hypothetical linkage between psychological shape and slant is not rigid. The results are analogous to those of Stavrianos." And, Clark (1953) and Clark, Smith, & Rabe (1955, 1956) studying the role of monocular retinal cues in the perception of slant, state: "With some individual exceptions, the results agreed with the invariance hypothesis (1955) but later (1956) "the data on the relation between slant and shape failed to accord with the invariance hypothesis." Also, Winnick & Rogoff (1965), Winnick & Rosen (1966), and Kraft & Winnick (1967) all acknowledge results providing only "limited" support to the error invariance hypothesis. Finally, Epstein & Park (1963), who reviewed most of the work involving what I have called the error invariance hypothesis concluded: "the invariance hypothesis rests on a precarious evidential base. Attempts to provide experimental confirmation of a precise relationship between apparent shape and slant have been unsuccessful. It would seem that the adequacy of the hypothesis depends on the possibility the various factors whose influence on shape constancy has been demonstrated, may be shown to affect perceived slant." This would suggest that the failure of the hypothesis may be due to improper accounting of certain operational variables. Little research has followed this direction.

Another suggestion concerning the apparent failure of the error invariance hypothesis has been given by Graham (1951). He feels the low level of confirmation is due to non-control of the surround about the stimuli, e.g. presence of "extraneous stimuli." However, Nelson (1953), Nelson & Bartley (1956), and Nelson, Bartley, & Bourassa (1961), using an outline target presented in a carefully controlled, undifferentiated field, give evidence that control of the surround only tends to reduce response variability but in other ways does not support predictions made by the error invariance hypothesis.

A third suggestion regarding the failure of the error invariance hypothesis indicates the problem may involve conceptual as well as operational difficulties. Measurement of the qualities of an object can refer only to details of that object and does not deal with the identification of the object by the observer (Nelson & Vasold, 1965). There appears to be actually two perceptual events taking place under the single name 'object constancy'. First, and most often used, treats object constancy as a graded perception, which most often implies and consequently involves measurement. That is, measurement of such things as visual angle, gradient density, area, etc. However, there is a second consideration that can be made and this involves constancy as identification, that is, the organism's ability to recognize objects despite varying conditions of encounter. Here constancy is an all-or-none situation, where the object is perceived as a single thing.

It would seem that if an object was mis-identified by an observer, measurement of details from response may also be different from those expectations considering the physical measurements. For example, if the traditional 'saber-tooth tiger' is at such a distance that it appears to be a house-cat and consequently identified as a house-cat, its weight, length, height, etc. may not be valued the same as those resulting from proper identification as a saber-tooth tiger. Similarly, Hastorf (1950) consistent with the transactional point of view he represented, attempted to interject an assumed object into constancy formulations. Haan & Bartley (1953) did the same thing.

In traditional discussions of the counter-balancing of errors leading to a statement of invariance, much concern has been shown for graded properties of the target accompanied by an assumption that the target was correctly identified. Data of Nelson (1953), Nelson & Bartley (1956), and Nelson, Bartley & Bourassa (1961) indicate, however, that a target may be apparently mis-identified and consequently yield a shape-slant invariance function different from that which would be predicted by Euclidean geometry. More specifically, shape-slant response data from an elliptical target showed apparent orientation to be much greater than was actually the case. Therefore, comparison of results from the mis-identified target to results predicted by Euclidean geometry could not be easily made and indeed, the two resulting curves may be considered as separate functions for the same target. Although mis-identification doubtless occured, this did not prove to be explanatory of the experimental outcome. The object described by shape and slant was not the assumed object unfortunately. Nelson (1953) asked his subjects what they were viewing and found very poor correspondence between shape-slant relations and the physical functions describing retinal projection and plane of orientation.

Let us now turn to another position on perceptual invariance. This position has been argued for by Nelson and others in 1953, 1956 and 1961. (Here, physical and perceptual invariants are considered uniquely distinct, each determined by its own unique set of values. The key question hinges upon, according to these men, the type of information given by the invariance function. If invariance is only to relate shape and slant perception to physical descriptions of objects then it is perhaps appropriate to employ the error invariance hypothesis. If, however, inquiry is more Galilean in spirit, the basic quest is discovery of the invariant relations within the process of perceiving shape and slant per se. Once these are ascertained the problem then becomes one of comparing psychological to physical invariance, and devising some manner for representing differences between functions. Taking this view, measures of difference between functions will give the degree of information lost by visual transformation.

Let us turn to a closer analysis of this problem. Physical invariance, Nelson suggests occured with a rigorous restriction of language within physics. That is, invariances are abstractions occuring within physical language systems. The common cosine function relating spatial position with respect to a frontal referent plane and frontal plane image projection is taken as an example of this purely physical or formal abstraction of spatial invariance. Physical invariances are then physical statements of the relationship between two physical characteristics of the object as provided, for example, by Euclidean geometry. This is seen to provide excellent statements of stimulation, but not of response.

On the other hand, perceptual invariances are considered as purely response characteristics. When defined as such, without reference to a physical space theory (i.e. Euclidean geometry) direct relation of shape and slant response data is taken as the statement of shape-slant invariance for that given condition. Perceptual invariance is again considered an experimental phenomena, distinct from the physical. In this way, Nelson is in close accord with Brentano (1874) and Husserl (1931). A similar theoretical position has been taken by Petermann (1932) who argues that in pure gestalt analysis "the theoretical interpretation of the data proceeds along lines of laying down functional dependencies, to which no ontological parallels are directly related."

Although very similar to the second position concerning invariance in psychology discussed above, Nelson's position differs from that of Brentano (1874), Husserl (1931), and Gibson (1950) in two major respects. First, definition of shape response and slant response is made within ratio and interval scales respectively, rather than within a pure phenomenal language. This was undertaken to eliminate one undesirable feature of pure phenomenal abstraction, namely the detachment of perception from physical abstractions of space. Nelson's approach allows one to relate perceptual invariance to physical invariance or physical measurements of stimulation, i.e. physical cosine function, but at the same time, one does not fall into the trap of expecting some fixed degree of veridicality from responses. Perception is not left stimulus bound in such a simple way as occurs when invariance is measured by formulas commonly employed (e.g. shape error minus slant error).

Second, Nelson considers invariances or universals as theoretical abstractions arising from bodies of perceptual measurement data, rather than being directly observable employing phenomenological methods of analysis. Further, he does not make the assumption that experimental phenomena are operating upon a Euclidean space theory, and thus does not assume responses are bound to Euclidean abstractions.

The Problem

The present investigation attempts to empirically fix the shape-slant invariant component manifested in response to a fixed range of stimulus transformations. The shape-slant (response) invariant will be defined by fitting a function to shape and slant data arising from perception of various forms, each of which represents a cylindrical cross-section (circles and ellipses). The experimental conditions will be such that the invariant component of stimulus transformation will be defined by various cosine functions of Euclidean geometry, that is single cylindrical cross-sections will be shown at a number of orientations, each cross-section having its own function.

Variant components of stimulus transformation will also be employed. The experiment will relate the shape-slant invariant obtained with the stimulus invariant to alterations of target surface and background. Nelson, Bartley, & Bourassa (1961) suggest that such variants may be effective in altering the form of response invariance.

The specific hypotheses are as follows:

1. A constant surround condition will produce a shape-slant invariance relation for a given target.

2. Transformation of target-surface will transform the shape-

slant function.

3. A constant target-surface condition will produce a shape-slant invariance function for a given surround.

4. Transformation of the surround will transform the shape-slant function.

If response invariance changes as target surface and background are altered, these will be further analyzed in an attempt to discover something concerning the amount of 'information' they have provided the observer concerning the physical nature of the target. 'Information' here is an empirical measure in contrast to other theoretical approaches and will be measured by the degree of correspondence between the perception (shape-slant invariance) and the physical invariance (the object as described by Euclidean geometry). The measure will be based upon the area between the curves. Complete congruity or perfect physical communication will result in superimposition of the curves and an area equal to zero. Increasing incongruity or decreasing physical communication will result in curves with areas progressively greater than zero.

Method

Subjects

Sixty four male university students and staff served as observers. All had normal, corrected or uncorrected, visual acuity as shown by a standard Snellen chart and were naive with respect to targets, field conditions, and experimental hypotheses. Only male observers were used as some researchers (Witkens,) suggest there may be sex differences in studies using an undifferentiated field similar to that to be reported here.

Apparatus

Targets were forms of a special class described as "circles" and "ellipses" varied three ways in respect to frontal plane minor/major axis ratio when major axes are equated for length and three ways in respect to surface condition. Presentation varied two ways in respect to background conditions and four ways in respect to target inclination from the frontal plane. More specifically, the four classes of variables were:

A. TARGET FORMS

1. circle
2. 4 x 5 ellipse
3. 2 x 5 ellipse

B. TARGET SURFACE CONDITIONS

1. outline
2. flat surface
3. texture

C. FIELD CONDITIONS

1. undifferentiated
2. differentiated foreground

D. TARGET INCLINATION

1. frontal plane
2. 22.5° from frontal plane
3. 45° from frontal plane
4. 67.5° from frontal plane

From the first two classes of variables, nine targets resulted (three target forms each with three surface conditions). All were cut from 1/8" masonite board, painted for the appropriate surface condition with fluorescent paint ("Krylon" Brand, Red Orange), and lit by one of two Black Light Eastern Corp. Spectroline (TN-150) UV sources depending upon the inclination, to provide equal surface illimination through all inclinations.

Figures 4 - 5 show two target conditions used. Specifically omitted are the outline condition with the three forms at each inclination. In addition a Figure of the surface condition is absent. Figure 4 the texture, and Figure 5 which is a texture condition with a differentiated foreground are shown. Table 2 gives the absolute physical sizes and visual angles of the minor axis for the three target forms at the four orientations. The major axis did not vary. The visual angle for the major axis is identical to that of the circle in the frontal plane. Values in Table 2 were determined mathematically. Measurement directly from the photographs yields similar values.

The outline targets consisted of a one-inch outer border of fluorescent paint with the remaining interior portion painted flat black. The surface of the flat surface targets was entirely cluorescent. The texture targets were similar to the surface targets with the exception of various sized flat metal washers glued to the surface in a random manner. The density of the washers was similar for the three target forms although they presented different surface areas.

An undifferentiated background (field) was provided by presenting the targets in a carefully darkened room, with surfaces in view of <u>O</u> painted flat black. Two rooms were used. The experimental room, containing the targets and the experimenter, was separate from the one in

TABLE 2

SIZE AND VISUAL ANGLES OF MINOR AXES FOR THREE TARGET FORMS AT FOUR ORIENTATIONS

TARGET FORMS

	CIRCLE		4 x 5 ELLIPSE		2 x 5 ELLIPSE	
ORIENT.	SIZE	VA	SIZE	VA	SIZE	VA
0°	20.00"	4.10°	16.00"	3.25°	8.00"	1.62°
22.5°	18.48"	3.79°	14.78"	3.00°	7.39"	1.50°
45°	14.14"	2.90°	11.31"	2.30°	5.66"	1.15"
67.5°	7.66"	1.57°	6.13"	1.24°	3.06"	0.62°

TABLE 2. Size values, given in inches and visual angle values, given in degrees, for the minor (smaller or horizontal) axes of the circle, 4 x 5 ellipse, and 2 x 5 ellipse at orientations of 0°, 22.5°, 45°, and 67.5°. Size and visual angle of the major (larger or vertical) axis did not change with orientation. Size was fixed at 20.00" with visual angle fixed at 4.10°

Figure 4. Appearance of texture condition for 3 ellipse at 4 orientations.

FIGURE 4

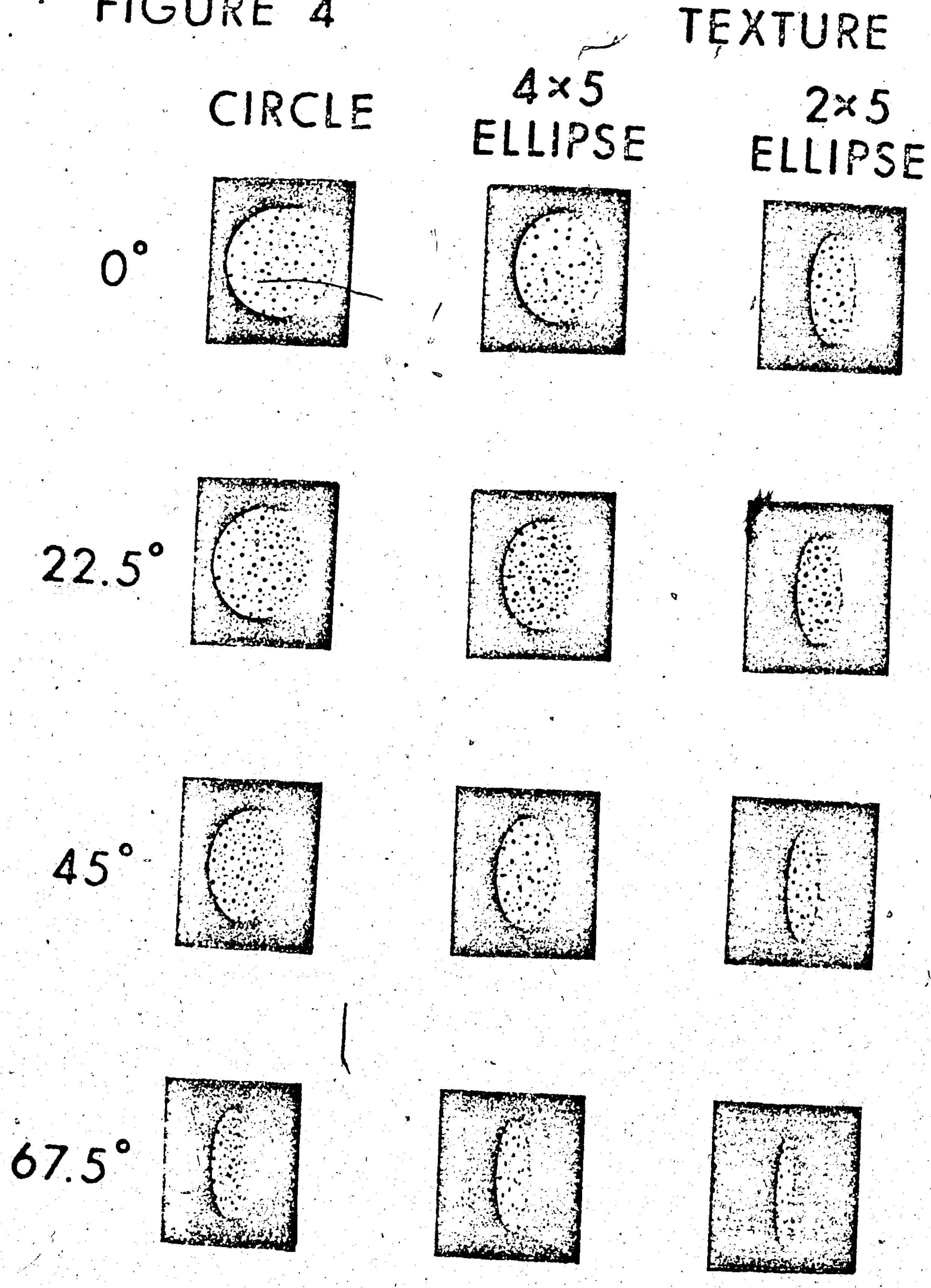
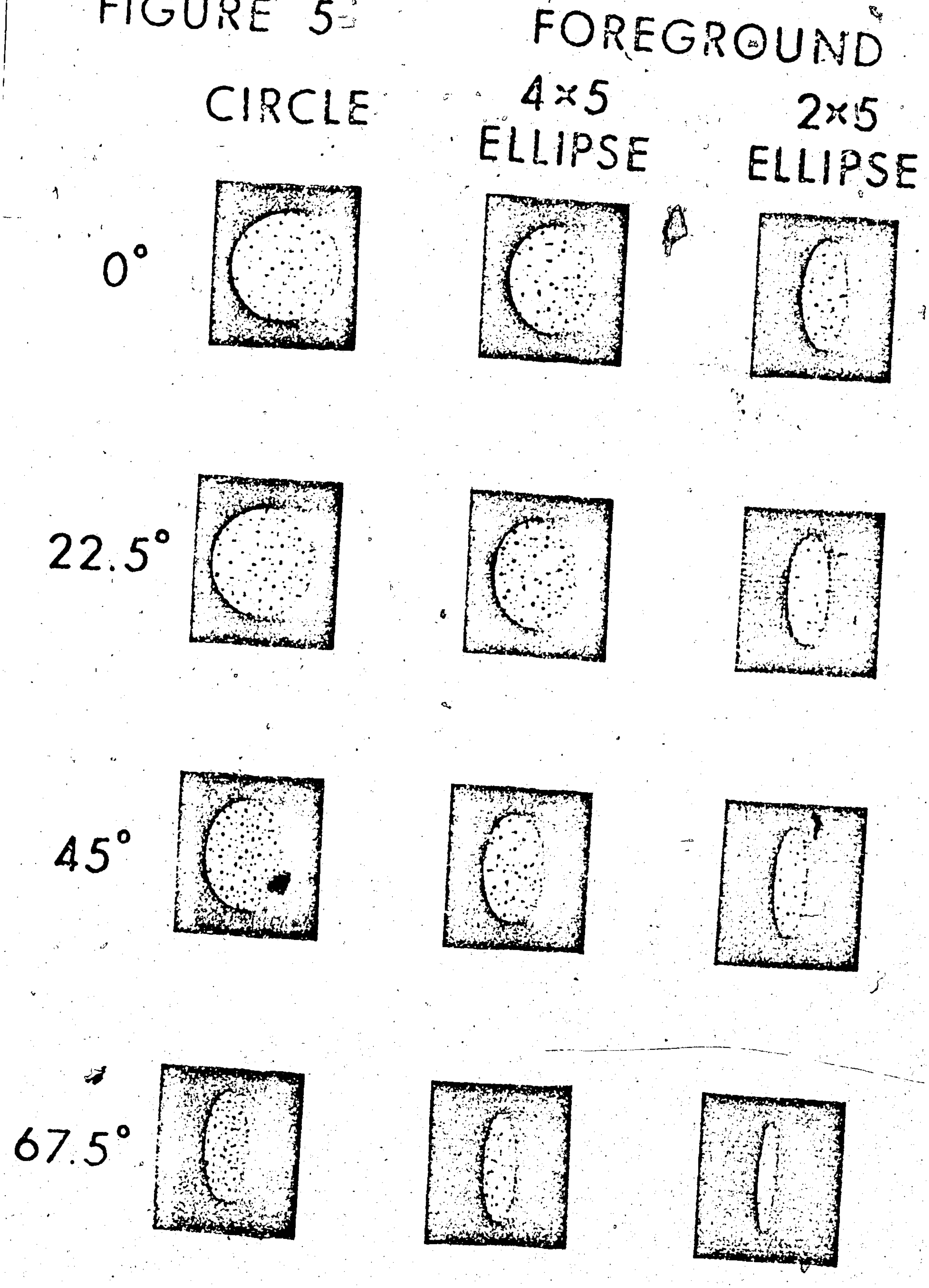


Figure 5. Appearance of texture condition without presence of differential foreground. The three forms and 4 orientations used are shown.

FIGURE 5



which the observer was situated. They were connected by a standard door-way blocked off in the upper portion leaving a 31 1/2 x 52 1/2 inch passage. Further control for an undifferentiated field was provided by reducing the intensity of the UV sources and also by placing a 0.4 log neutral density filter mounted in "B" glass (does not pass ultraviolet radiation) between O and the target. The differentiated foreground was accomplished simply by lowering in the frontal plane a heavy, 1 inch wire screen 18 feet 11 inches from O, painted with fluorescent paint contrasting in color to the targets' ("Krylon" Brand, Lemon Yellow). Only the textured targets were used with the differentiated field, however. The screen was lit by a third UV source (TF-250), also of reduced intensity.

Varying orientations were accomplished by a tongue and groove arrangement pre-cut to the four orientations used, which allowed rapid changes of targets. Apparatus was fixed so the major axis remained vertical. Increasing orientation from the frontal plane moved the right-hand edge of the target away from and the left-hand edge toward the observer, effectively reducing the minor axis, but not the major.

The viewing apparatus consisted of a chin rest, 1/2 inch field stop, electric shutter, and a 1 3/4 x 1 1/2 inch reduction screen 1 foot distant from O, all appropriate in height for viewing in a sitting position. Two mirrors were adjusted to allow for a 23 1/2 foot viewing distance not otherwise obtainable between the two rooms. Observation was monocular, with preferred eye. A 10-watt red bulb, place over-head and to Os right was used constantly to light O's immediate area and the response apparatus.

Shape was expressed by drawing on an 8 1/2 x 5 1/2 inch pad of news-print with a soft pencil. Neither major nor minor axis was indicated on the paper prior to response. Slant was expressed using a 9 3/8 x 10 1/4 inch wide tilt board placed 20 inches distant on O's right. The board was attached to an auto-transformer (Variac), which itself was connected to a volt meter in the experimental room. The surface of the tilt board, painted a color 'similar' to the targets', was lit by the over-head red bulb. A stop w[illegible]ovided on the tilt board which set the board in the frontal [illegible] was in a standard sitting position. Shape and slant were both [illegible]nder binocular conditions.

Procedure

Four ex[illegible]mental groups were arranged, one for each of the three surface condi[illegible]s in the undifferentiated background and one for the textured surf[illegible] condition presented in the differentiated foreground, and one for t[illegible] textured surface condition presented in the differentiated foreground, each group containing all three target forms. Observers were randomly assigned to one group, with a total of 16 Os in each. Observers were tested for normal visual acuity, seated in a standard position before the viewing apparatus, and given approximately the following general, verbal instructions: You are about to see a series of 48 forms or targets. I will not tell you what they are at this time but it should be q[illegible]e obvious once you see them. Some will appear to be oriented or turned to various degrees. We will go through this series twice, once recording shape and once slant. You will see one form at a time through this hole (field stop). Your task will be to observe the target, taking as much time as you wish, and then responding. Please do not move the chair or lean back or to the side when responding or you will not be in the necessary standard position.

Half the observers gave shape responses on the first series and half gave slant responses, the order being randomly determined prior to experimentation. The instructions for shape response was approximately as follows: Beside you is a pad of paper. After observing the target for a sufficient period of time, noting its shape, I would like you to draw the shape you have seen. Use any size you feel is convenient, but pay particular attention to the major and minor axes. Put one drawing on each page. The approximate instructions for slant response were: Here you see what is called a tilt board. Observe the target for a sufficient period of time, noting its orientation, then reproduce that orientation using the tilt board. Consider the tilt board at the frontal plane when it's pushed up against the stop. All targets will be tilted toward the right, just as the tilt board turns. When responding, try to ignore any changes in 'lightness' on the tilt board that might occur. After each response, turn the board back to stop or frontal plane. All instructions were flexible, allowing for mis-statement and demonstration.

Observer's questions were answered. The Os were then readjusted into standard sitting position and the chin rest adjusted for proper height and prefered eye. The shutter was manually opened by E to be sure 0 could see a test target placed in the presentation apparatus.

The test target consisted of an 8 x 17 1/8 inch wide rectangle also painted with fluorescent paint. Five trials were given with this target at various orientations, but no responses were recorded. The purpose was to show 0 the types of changes that take place with increasing orientation from the frontal plane.

Three targets of a series (circle, 4 x 5 ellipse, 2 x 5 ellipse) were presented at the four orientations in random order, but with the same order retained for both shape and slant responses. Each target at a given orientation was seen a total of eight times by each observer, four times for slant and four for shape.

The slant responses were recorded by E from the volt meter and later converted to degrees. The minor and major axes of the shape drawings were measured in centimeters, providing a statement of the minor/major axis ratio for that presentation.

Results

Let me begin by describing the results in a general way. Of the comparisons which may be made between stimulus and response, the simplest is that comparison of the metric variables of frontal plane projection and shape, both represented as minor/major axis ratios. Figures 6a and 6b showing the photic variables outline-surface and texture-foreground respectively indicate shape response is closely tied to the characteristics of the frontal plane projection. The diagonal line would indicate a perfect relationship. The curves are essentially the same for the four surface-field conditions. The only matter worth discussing is that in no case are the points evenly distributed on both sides of the theoretical function over the entire range of the graphs. With the smaller axis ratios describing impingement, response ratios are greater than the corresponding impingement values. In the middle and upper ranges response ratios are less than corresponding impingement values.

"Constancy" is seen to exist when the frontal plane projection gives axis ratios which are small, but when ratios are relatively great there is a condition opposite that of constancy explanations. Using the language of constancy theory, points falling above the theoretical function indicate "regression _away_ from the real object." The effect occurs for all forms and has been reported before (Nelson, Bartley, & Bourassa, 1961).

Another comparison which may be made between the stimulus and response characteristics involves inclination of the two dimensional surface and slant, both measured in degrees from the frontal plane. Figures 7a and 7b, showing outline-surface and texture-foreground respectively, indicate the degree of correspondence between the variables. The diagonal line would describe a perfect relationship. If inclination were to act as a direct determinant of the measured response, all points would have to fall on or near this line. Notice that this is not the case. At first the points appear random over the entire graph, but closer inspection reveals grouping of points on the basis

Figure 6A. The relation between shape and impingement withthe OUTLINE (top) and SURFACE (bottom) conditions. The diagonal lines on each graph describe a perfect relationship. Points marked by solid circles = circle (5 x 5), by open circles = 4 x 5 ellipse, by triangles = 2 x 5 ellipse. Values along both axes are minor/major axis ratios.

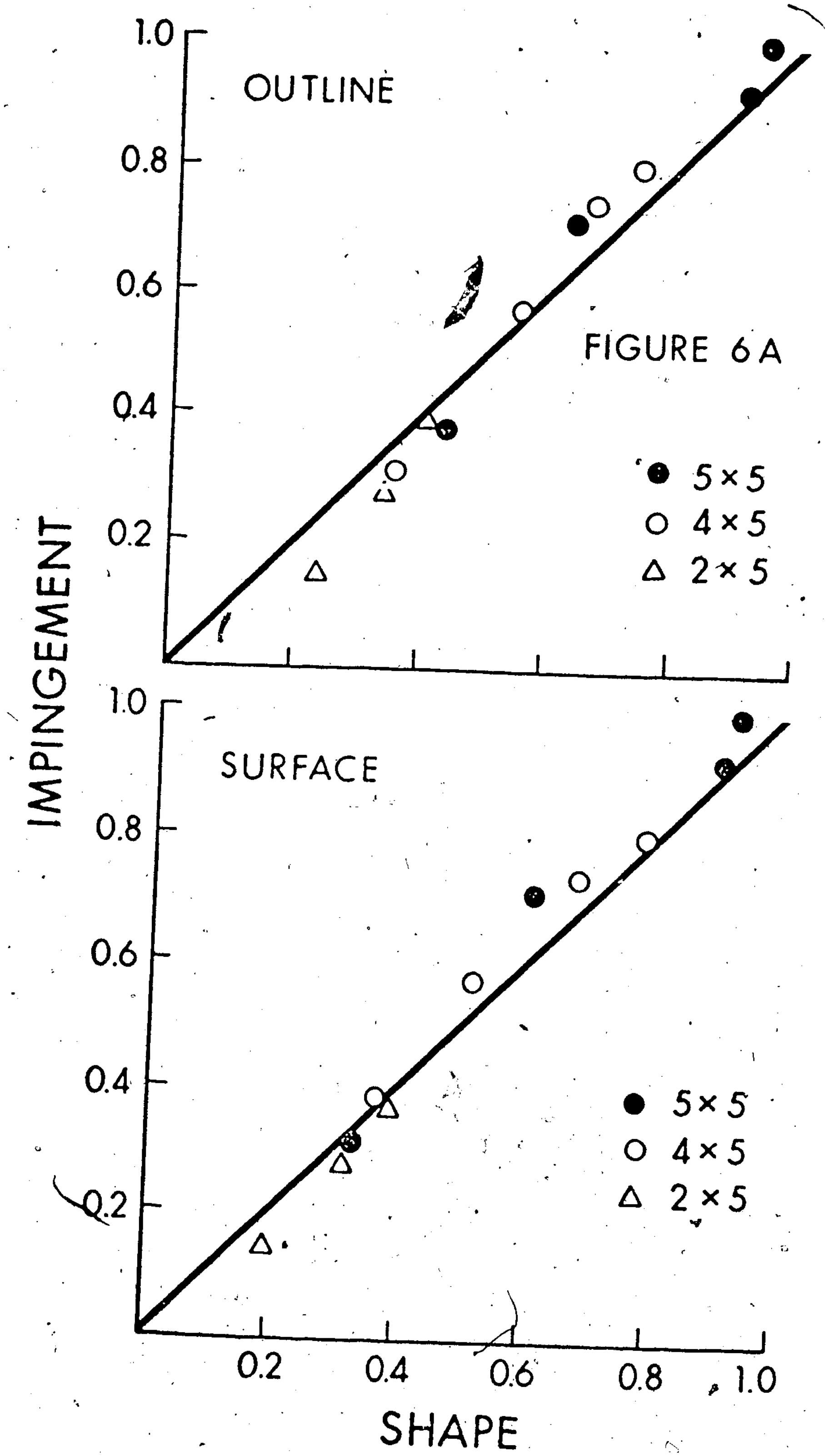

OUTLINE
SURFACE
IMPINGEMENT
SHAPE
1.0
0.8
0.6
0.4
0.2
0.2
0.4
0.6
0.8
1.0
● 5×5
○ 4×5
△ 2×5

FIGURE 6A

Figure 6B. The relation between shape and impingement with the TEXTURE (top) and FOREGROUND (bottom) conditions. The diagonal lines on each graph describe a perfect relationship. Points marked by solid circles = circle (5 x 5), by open circles = 4 x 5 ellipse, by triangles = 2 x 5 ellipse. Values along both axes are minor/major axis ratios.

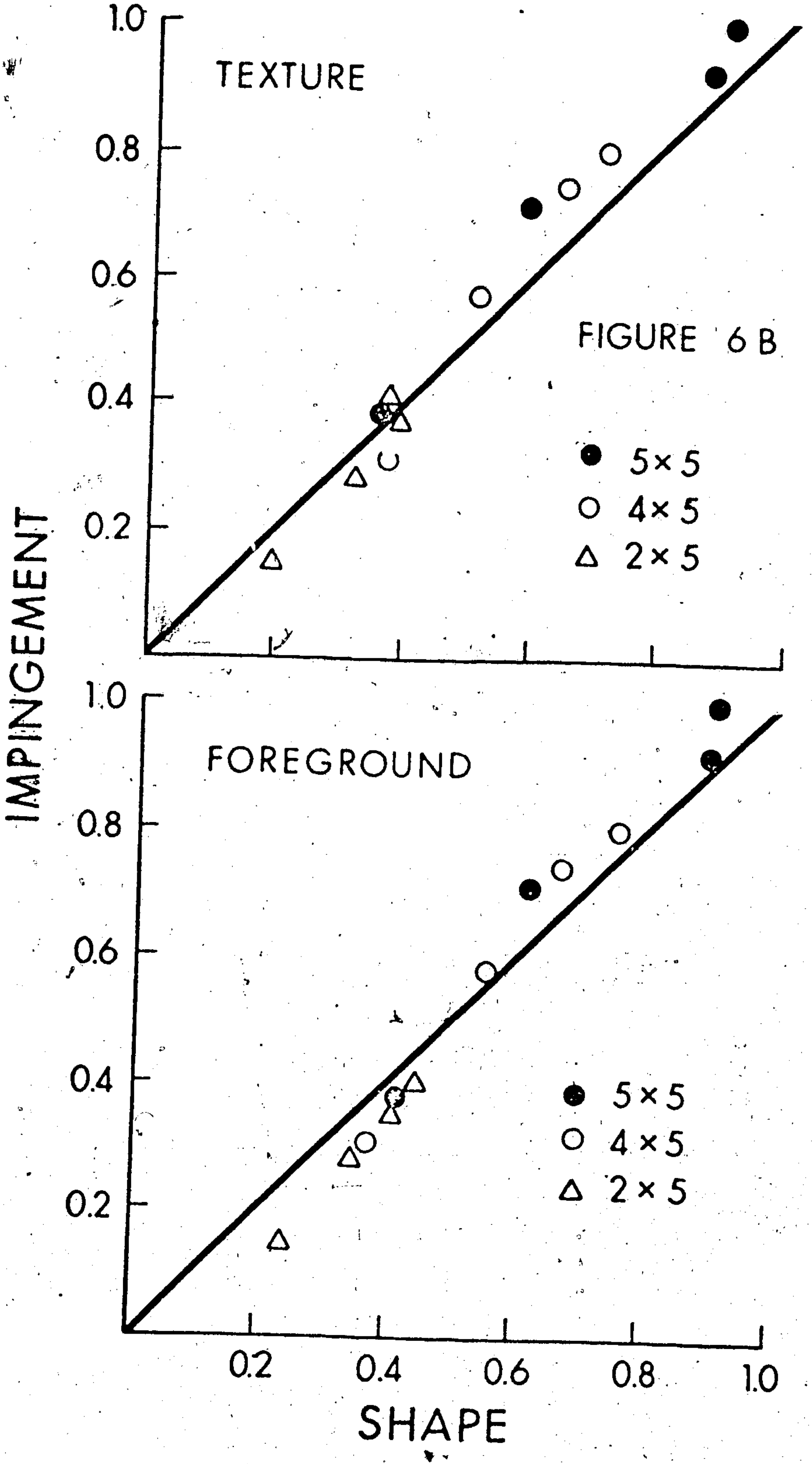


FIGURE 6 B

TEXTURE
FOREGROUND
IMPINGEMENT
SHAPE
1.0
0.8
0.6
0.4
0.2
0.2
0.4
0.6
0.8
1.0
● 5×5
○ 4×5
△ 2×5

of the target form used. The fit to theoretical function is best for the circle, with the ellipses grossly overestimated in inclination. The degree of departure is positively related to the thinness of the form. The differences are reliable and conform to data presented by others (Nelson, Bartley, & Bourassa, 1961).

This lack of correspondence between stimulus and response evident in Figures 6a, 6b, 7a, and 7b can be expressed as average error. For this purpose, stimulus and response may be regarded as anchored to identical points, ie. 0° and 90° for inclination-slant for all forms; and 0 and 1.00 for impingement-shape if the circle is considered, 0 and 0.80 if the 4 x 5 ellipse is considered, and 0 and 0.40 if the 2 x 5 ellipse is considered. Thus, average error of slant perception and shape perception expressed as Stimulus - Response/N must fall within these ranges. In the case of shape, disregarding direction and form used, error is 0.05 or 5% of the usable range. Table 3 gives a breakdown of the errors for the various forms used. Notice that shape error values are similar for all forms used. Slant error values, on the other hand, increase considerably as impingement values of the targets in the frontal plane decrease.

The lack of correspondence between slant and orientation in conjunction with the close adherence of shape to frontal plane image projection (proportion), precludes successful interpretation of data using the error invariance hypothesis discussed earlier. This being the case, are we to disregard invariance or is it possible to express the data as psychological rates of change?

Figures 8 - 19 present data bearing upon the response invariance

Figure 7A. The relation between slant and inclincation with the OUTLINE (top) and SURFACE (bottom) conditions. The diagonal line on each graph describes a perfect relationship. Points marked by solid circles = circle (5 x 5), by open circles = 4 x 5 ellipse, by triangles = 2 x 5 ellipse. Values along both axes are degress from the frontal plane.

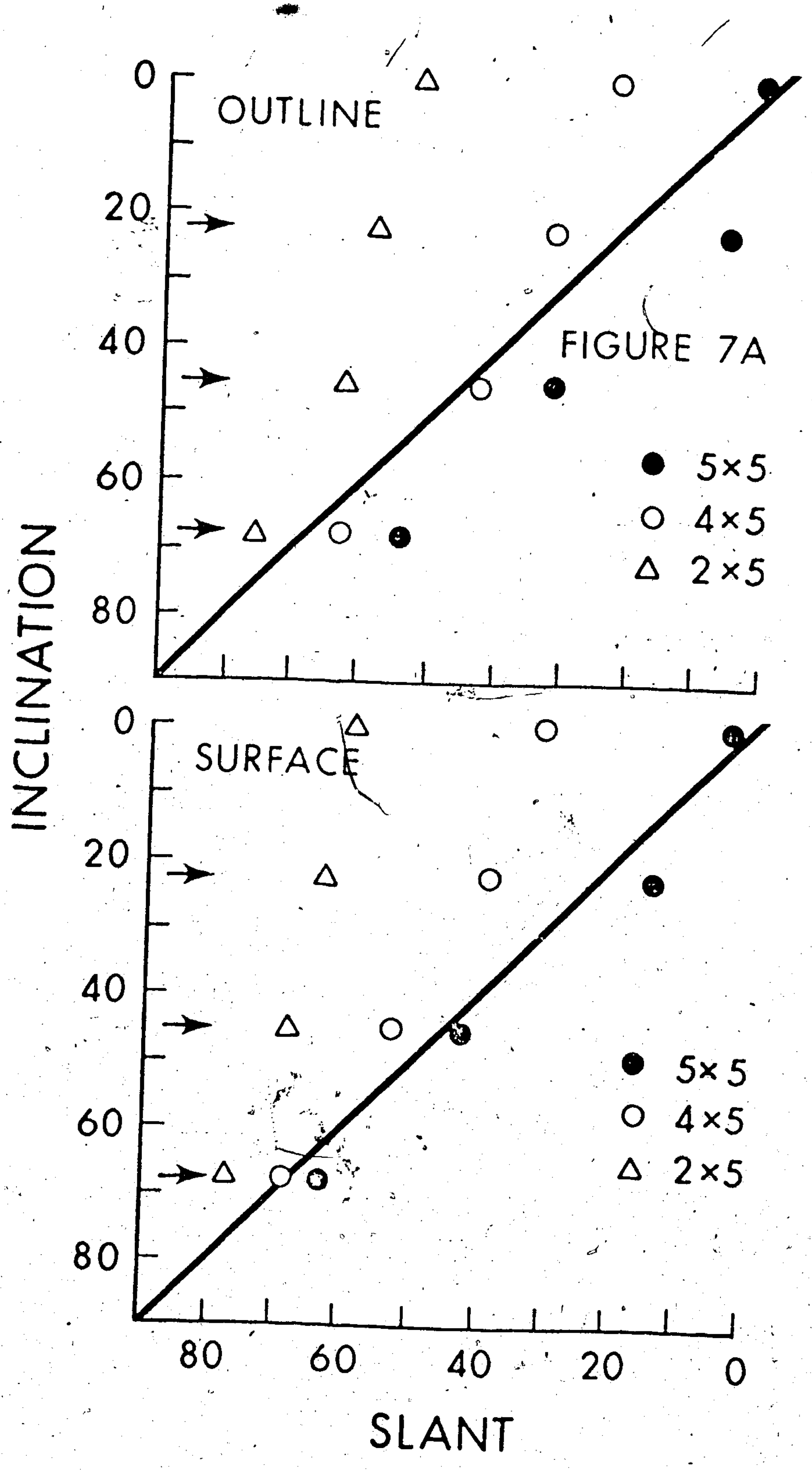


FIGURE 7A

OUTLINE
SURFACE
INCLINATION
SLANT
0
20
40
60
80
80
60
40
20
0
● 5×5
○ 4×5
△ 2×5

Figure 7B. The relation between slant and inclincation with the TEXTURE (top) and FOREGROUND (bottom) conditions. The diagonal line on each graph describes a perfect relationship. Points marked by solid circles = circle (5 x 5), by open circles = 4 x 5 ellipse, by triangles = 2 x 5 ellipse. Values along both axes are degrees from the frontal plane.

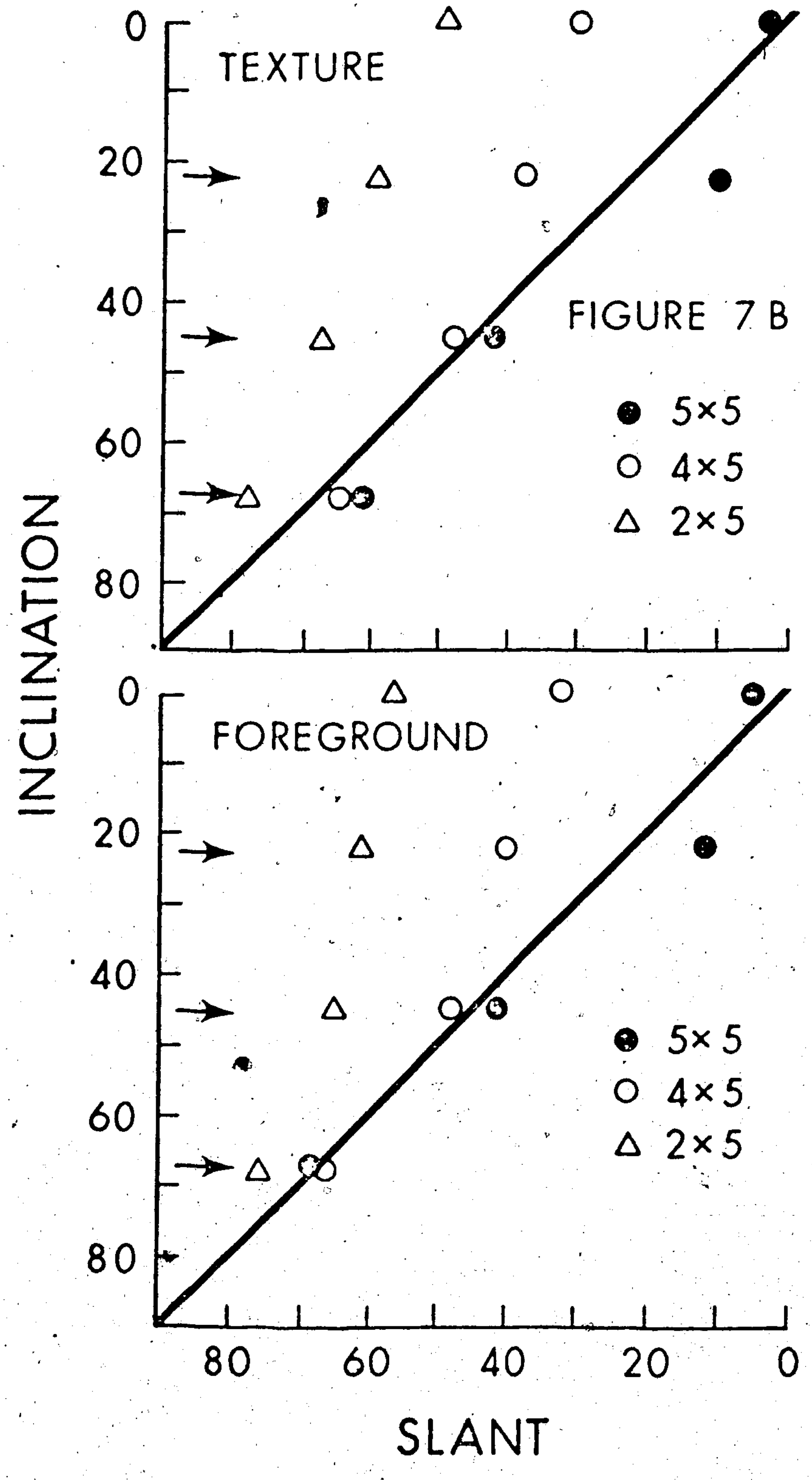


FIGURE 7 B

TEXTURE
FOREGROUND
INCLINATION
SLANT
0
20
40
60
80
80
60
40
20
0
● 5×5
○ 4×5
△ 2×5

TABLE 3

MEAN SHAPE ERROR VS. MEAN SLANT ERROR

TARGET FORM	MEAN SHAPE ERROR (ratio)	MEAN SLANT ERROR (degrees)
CIRCLE	0.053 5.3%	6.032 6.7%
4 x 5 ELLIPSE	0.047 4.7%	12.722 14.1%
2 x 5 ELLIPSE	0.046 4.6%	30.451 33.8%

TABLE 3. Top number in each set of values gives mean shape error (left) or mean slant error (right) provided by the formula STIMULUS - RESPONSE/N for three target forms: circle, 4 x 5 ellipse, and 2 x 5 ellipse. Mean shape error is given as a ratio. Mean slant error is given as degrees. Bottom number in each set gives percent of range the top number includes. For shape, this range is 0.00 to 1.00 for the circle, 0.00 to 0.80 for the 4 x 5 ellipse, and 0.00 and 0.40 for the 2 x 5 ellipse. For slant, range is 0° to 90° for all forms.

hypotheses. [illegible] re[illegible] obtained from the four surface-field conditions (outline, su[illegible]e, [illegible]ture, and foreground) over the three target forms, i.e. 5 x 5 (ci[illegible] 4 x 5 ellipse, and 2 x 5 ellipse are represented. Each point fixi[illegible]e response curve (heavy line) represents the mean shape response p[illegible]ted against the mean slant response for the particular condition indicat[illegible] Two other curves appear on each graph. The upper line is the physic[illegible] invariant (cosine function) and the lower the physiological invar[illegible]t described by Nelson, Bartley, and Bourassa (1961). These additional functions describe two kinds of theoretical invariants which might be expect[illegible] to operate in perception of the circle (Fig. 8-11), 4 x 5 ellipse (Fig. [illegible] 15), and 2 x 5 ellipse (Fig. 16 - 19).

The purpose of this research, in part, is to find conditions which will produce response functions approaching the physical invariant in an attempt to establish measures of information. The additional curves on each graph provide base lines against which the response functions may be measured. However, before turning to the problem of information, let's give consideration to the hypotheses as they appear in the introduction.

Data presented as Figures 8 - 10, 12 - 14, and 16 - 18 (outline, surface, and texture with the circle, 4 x 5 ellipse, and 2 x 5 ellipse) confirm hypothesis 1 which states that "a constant surround condition will produce a shape-slant invariance relation for a given target." Plotting mean shape responses against mean slant response for a given experimental condition produces identifiable response functions with possible minor exceptions. These possible exceptions are seen in Figures 16 and 18. In Figure 16, showing the response function to the outline condition with the 2 x 5 elliptical target, an increase in perceived slant without a corresponding decrease in shape appears. In Figure 18 (texture with the 2 x 5 ellipse), an increase in both shape and slant within the range of the largest impingement values used appears.

In the same way, Hypothesis 2 was confirmed by data presented as Figures 8 - 10, 12 - 14, and 16 - 18. Hypothesis 2 stated: "transformation of the target-surface will transform the shape-slant function."

Consideration of data presented as Figures 10 & 11, 14 & 15, and 18 & 1[illegible] (texture and foreground with circle, 4 x 5 ellipse and 2 x 5 ellipse) shows these to confirm the expectations of hypotheses 2 and 4 which were stated as "a constant target-surface condition will produce a shape-slant invariant relationship for a given surround" and "transformation of the surround will transform the shape-slant function," respectively. Again, plotting mean shape response against mean slant response for a given experimental condition produces identifiable response functions.

Let's consider the hypotheses more closely and at the same time consider the problem of information and its measurement by examining Figures 8-19 individually. The functions representing response to the outline, surface, texture, and foreground conditions using the circle (Figures 8-11) all show a fairly constant decrease in apparent shape as the apparent slant increases, ie. a constant change in rate. The greatest portion of all the response functions lie below the cosine function and generally between the psychological and physical functions. One exception is found with the background condition (Figure 11) where a portion of the response function lies above the cosine at the largest physical inclination used. The function describing response to the outline condition (Figure 8) is fairly linear throughout its range and lies close to the psychological function describing true linearity between shape and slant. Functions of the other surface conditions depart from linearity in the middle and larger axis ratios and appear to differentially approach the cosine function. The four functions therefore appear distinctly as responses to non-Euclidean conditions.

Visual inspection alone, however, does not reveal small differences between the four functions in a manner adequate to distinguish four response invariants as regained by the Hypothese nor does it reveal the unique relationships of the functions to the cosine and psychological invariants enscribed on each graph and consequently does not give a measure of information. Measurement of the total areas between the cosine invariant function and the response functions extended by a straight line (dashed lines) to the points where the cosine functions intersect the axes (anchor points, ie. 1.00 at 0° and 0 at 90°), provides comparison on an arithmetic scale relative to graph size. "Total area" expresses differences in the descriptions made by the two functions on each graph. It is that area between the curves found by adding the areas falling on either side of the cosine function. To indicate the direction of the major area above or below the cosine in the tables stating measured values,

Figure 8. Points describe the relationship between shape and slant (heavy line) for the OUTLINE condition with the circle target. Also shown are the physical (cosine) invariant (upper curved) and psychological invariant (lower linear) functions describing relationship of impingement and inclination of a circle.

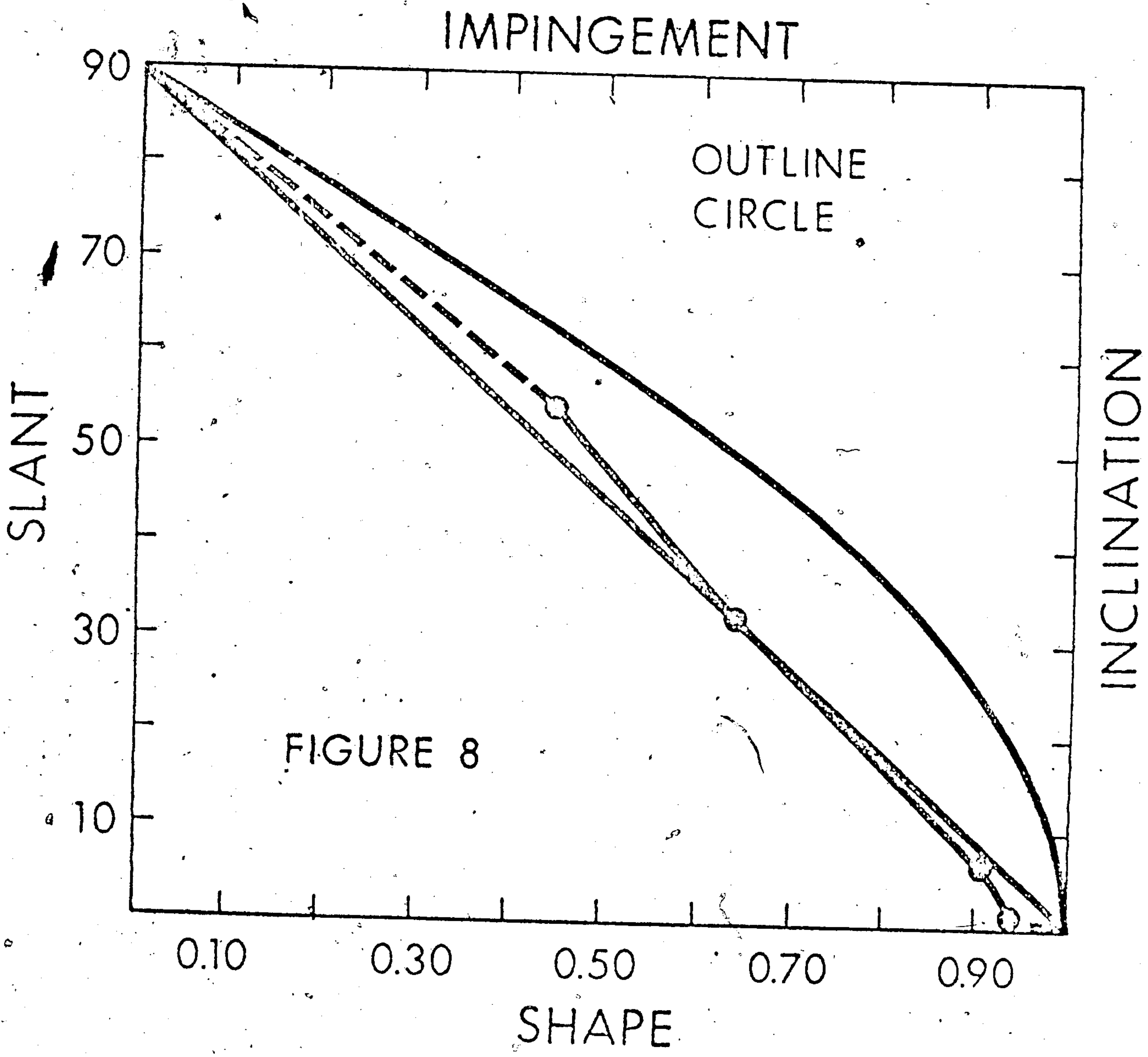


FIGURE 8

IMPINGEMENT
OUTLINE
CIRCLE
SLANT
90
70
50
30
10
INCLINATION
0.10
0.30
0.50
0.70
0.90
SHAPE

Figure 9. Points describe the relationship between shape and slant (heavy line) for the SURFACE condition with the circle target. Also shown are the physical (cosine) invariant (upper curved) and psychological invariant (lower linear) functions describing relationship of impingement and inclination of a circle.

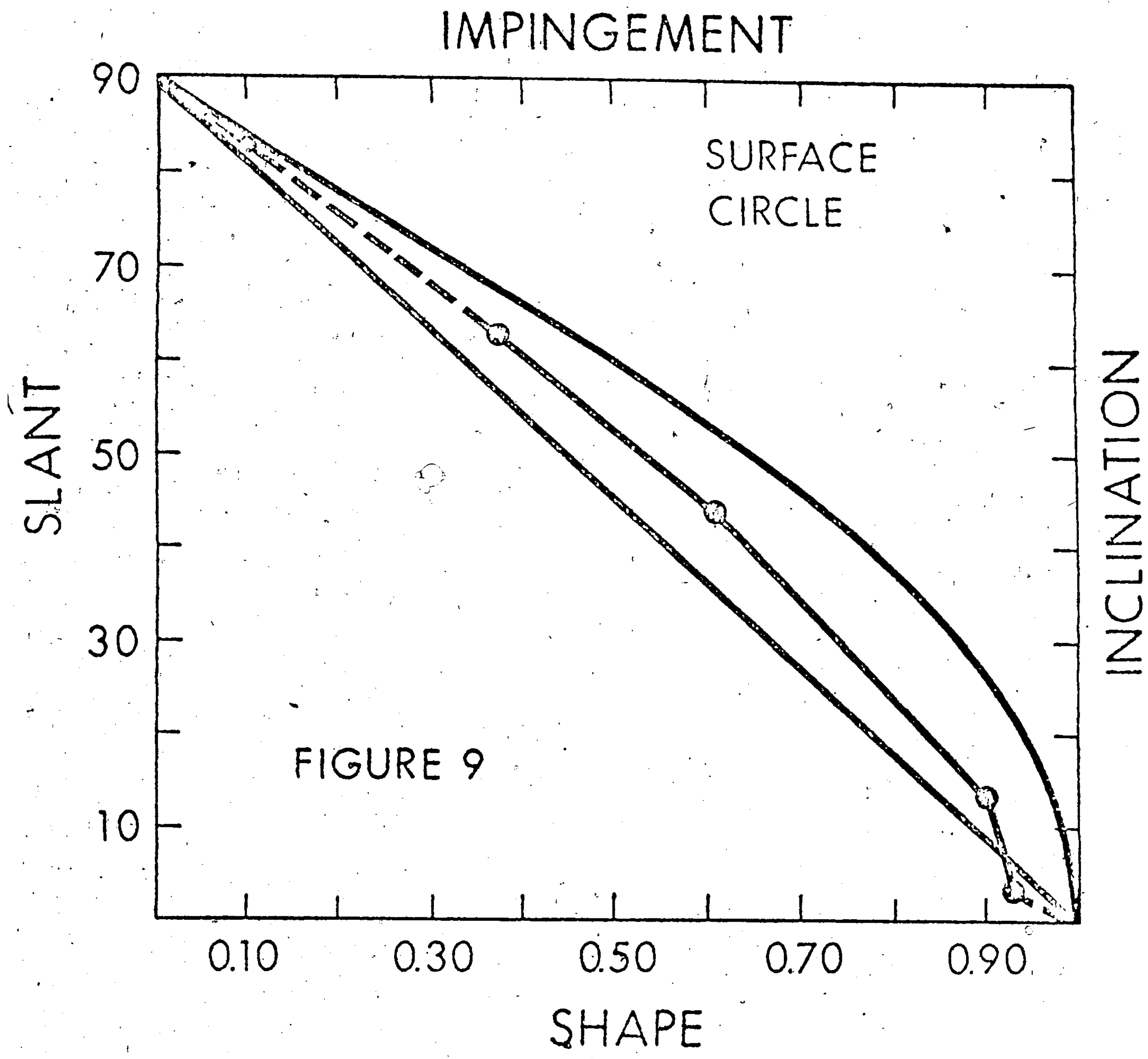

IMPINGEMENT
SURFACE
CIRCLE
SLANT
90
70
50
30
10
INCLINATION
0.10
0.30
0.50
0.70
0.90
SHAPE

FIGURE 9

Figure 10. Points describe the relationship between shape and slant (heavy line) for the TEXTURE condition with the circle target. Also shown are the physical (cosine) invariant (upper curved) psychological invariant (lower linear) functions describing relationship of impingement and inclination of a circle.

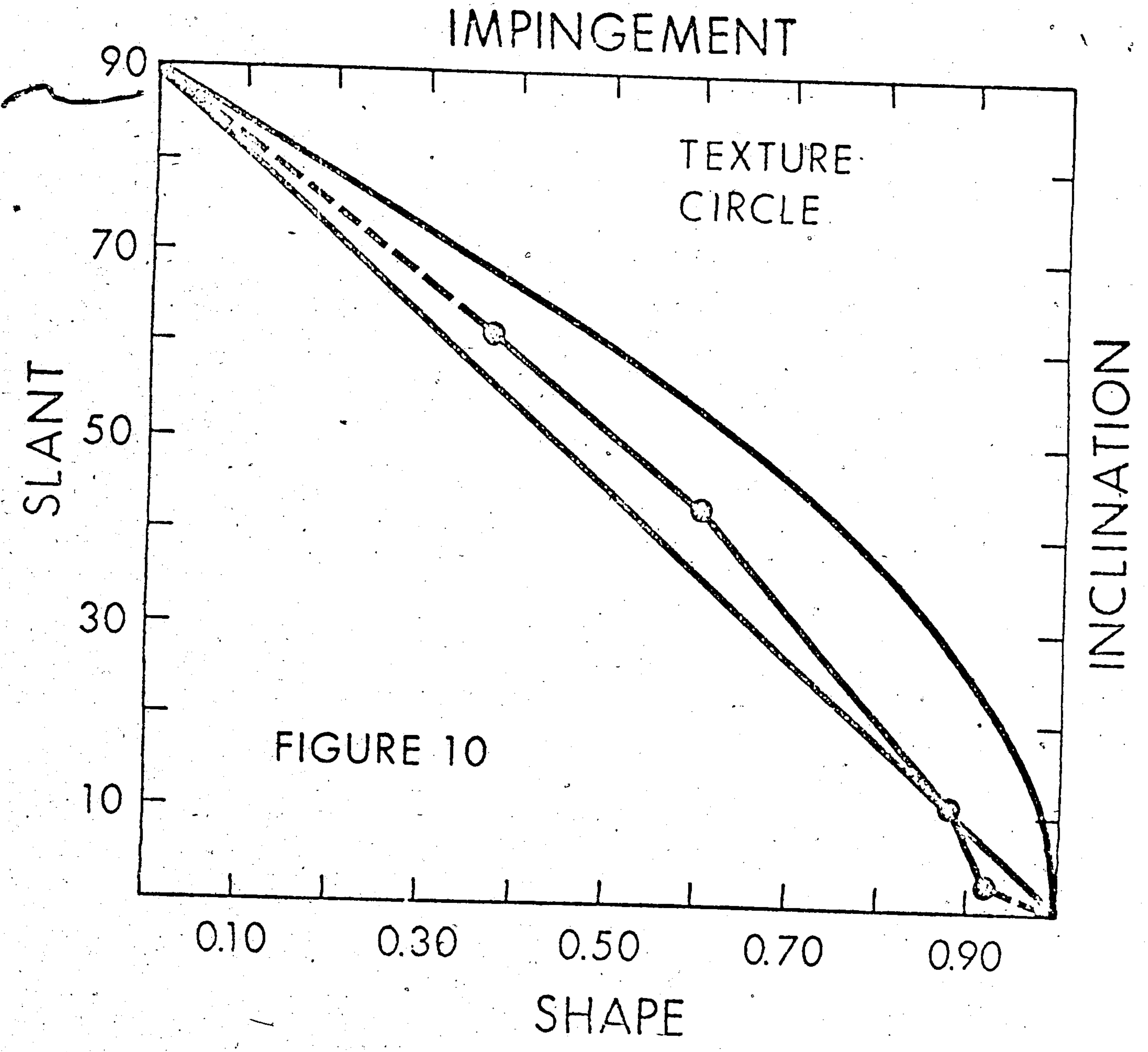

IMPINGEMENT
TEXTURE
CIRCLE
SLANT
90
70
50
30
10
INCLINATION
0.10
0.30
0.50
0.70
0.90
SHAPE

FIGURE 10

Figure 11. Points describe the relationship between shape and slant (heavy line) for the TEXTURE condition with the circle target. Also shown are the physical (cosine) invariant (upper curved) and psychological invariant (lower linear) functions describing relationship of impinement and inclination of a circle.

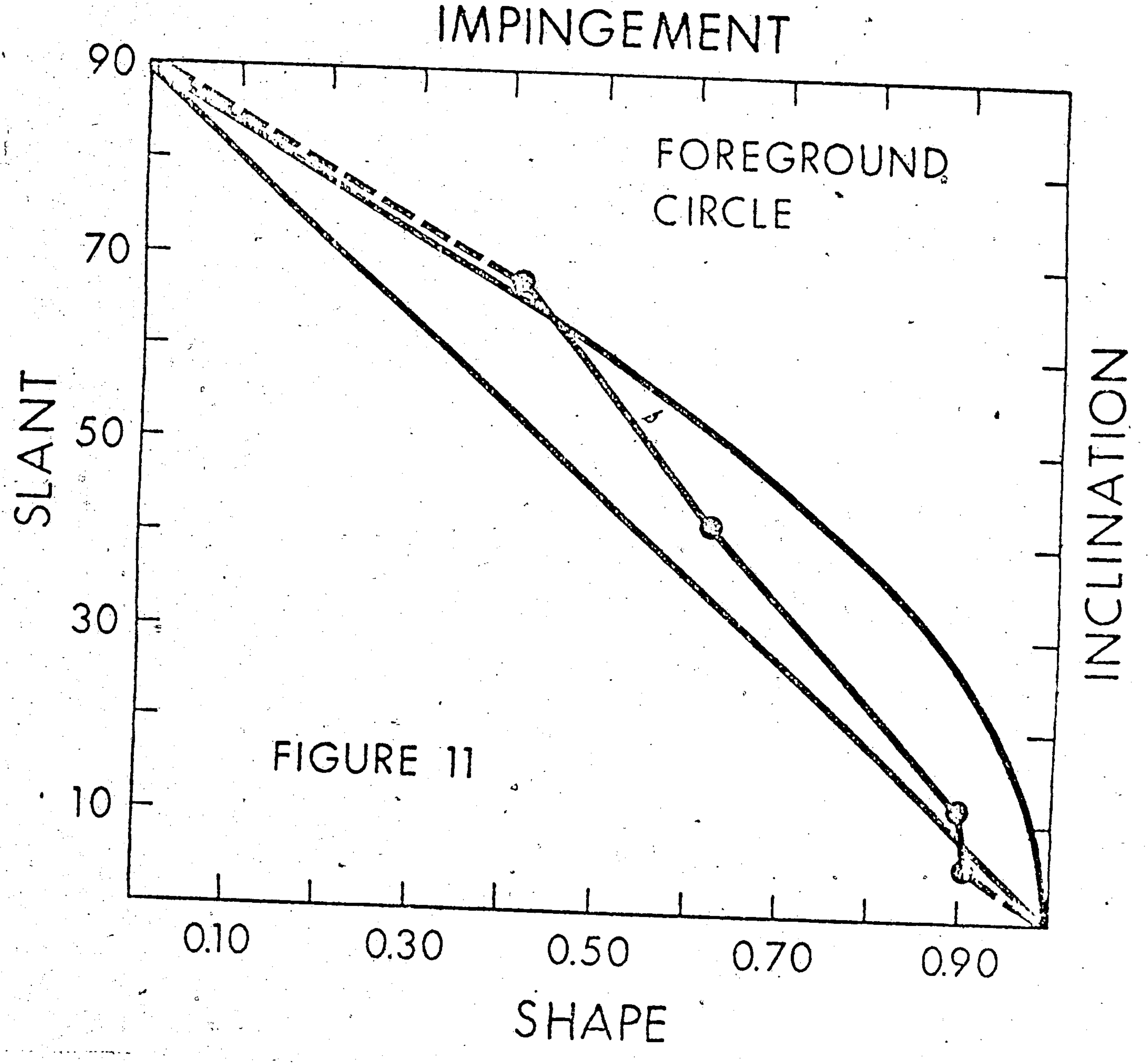

IMPINGEMENT
FOREGROUND
CIRCLE
SLANT
90
70
50
30
10
INCLINATION
0.10
0.30
0.50
0.70
0.90
SHAPE

FIGURE 11

positive and negative signs are employed. A negative sign following values given indicates the major proportion of the total area lies below the cosine function. A positive sign, conversely, would indicate the major proportion of the total area to be above the cosine function.

Consider Table 4. The values given in Part A are those areas measured from Figures 8 - 11. The foreground function is seen to enclose the least area, while the outline function encloses the greatest. Functions given by surface and texture enclose respectively smaller areas in relation to that given by the outline target. If differences in area are considered to be measures of the similarity of response process to physical invariance (given by the cosine function), the response curve with the foreground target is seen to most closely resemble the physical, with the physical function less well represented with the surface, texture, and outline targets, in that order. Fulfilling the goal of defining conditions which will lead to response functions differentially approaching the physical invariant, the values in Table 4, Part A may be considered as measures of information presented to the observer in each case.

Examining the table in more detail, an approximation of the psychological function would be given by a value of 3.10 (-). The outline function most closely fills this requirement. In regard to variance measured between individuals and also presented in Table 4, Part A, it appears that closer approximations of the physical conditions reduce the variance. Surface and background give the least. However, notice that the outline function, which closely approximates the psychological function gives less variance than the texture. In each case, the sign

TABLE 4

PHYSICAL INVARIANT - RESPONSE INVARIANT
CORRESPONDENCE WITH CIRCLE.

PART A

MEASURED AREA
PHYSCIAL TO RESPONSE

SURFACE CONDITION	AREA(IN.^{2})	VARIANCE
OUTLINE	2.86(-)	1.74
SURFACE	1.97(-)	1.02
TEXTURE	2.43(-)	2.15
FOREGROUND	1.62(-)	1.08

TABLE 4: PART A. The mean area, in square inches, between the cosine function describing the CIRCLE and the response invariant provided by four specified surface-field conditions. Negative sign following area indicates major proportion of area lies below the physical cosine function. See figures 8-11. Variance between individuals is given in the right hand column.

PART B

RESPONSE - RESPONSE DIFFERENCES

	OUTLINE	SURFACE	TEXTURE	FOREGROUND
OUTLINE		0.89	0.43	1.24
SURFACE	$t = 2.17$ $p<.025$		0.46	0.35
TEXTURE	$t = 0.95$ N.S.	$t = 1.04$ N.S.		0.81
FOREGROUND	$t = 3.02$ $p<.00$[illegible]	$t = 0.97$ N.S.	$t = 1.84$ $p<.05$	

TABLE 4: PART B. The difference values between those area values given in Part A, disregarding direction of difference above the diagonal. Values of t and p for these differences below the diagonal. d.f. = 30.

indicating direction of the area is negative.

Now consider Table 4, Part B. Here the technique of area measurement provides comparison between the response functions themselves. The table is in matrix form. Above the diagonal, the values represent the differences between those values presented in Part A of Table 4. Below the diagonal, the t-values and if significant the values of p for each difference are given. With the circle targets, significance was found between outline-surface (reconsider Hypotheses 1 and 2), between outline-foreground, and between texture-foreground (reconsider Hypotheses 3 and 4). Other differences were not reliable with $p < .20$ in all cases.

Let's now consider data derived from the outline, surface, texture, and foreground conditions using the 4 x 5 elliptical targets. Figures 12 - 15 show response functions graphically set to points to show mean apparent shape at mean apparent slant.

Visual inspection of the four figures reveals each response function to be essentially invariant in respect to apparent shape and apparent slant in that there are again fairly regular decreases in shape indexes as slant indexes increase. However, the response functions with the 4 x 5 ellipse are found to differ from those encountered with the circle in respect to their relationship to the physical and psychological functions. Comparison of corresponding surface-field conditions of the circle and 4 x 5 ellipse show the outline function with the 4 x 5 ellipse (Figure 12) to be essentially a portion of the physical invariant, where previously it lay close to the linear psychological function (Figure 8). Here, the outline function retains its linearity in rate of change but changes its position in respect to the cosine. Response functions with the surface

Figure 12. Points describe the relationship between shape and slant (heavy line) for the OUTLINE condition with the 4 x 5 elliptical target. Also shown are the physical (cosine) invariant (upper curved) and psychological invariant (lower linear) functions describing relationship of impingement and inclination of a 4 x 5 ellipse.

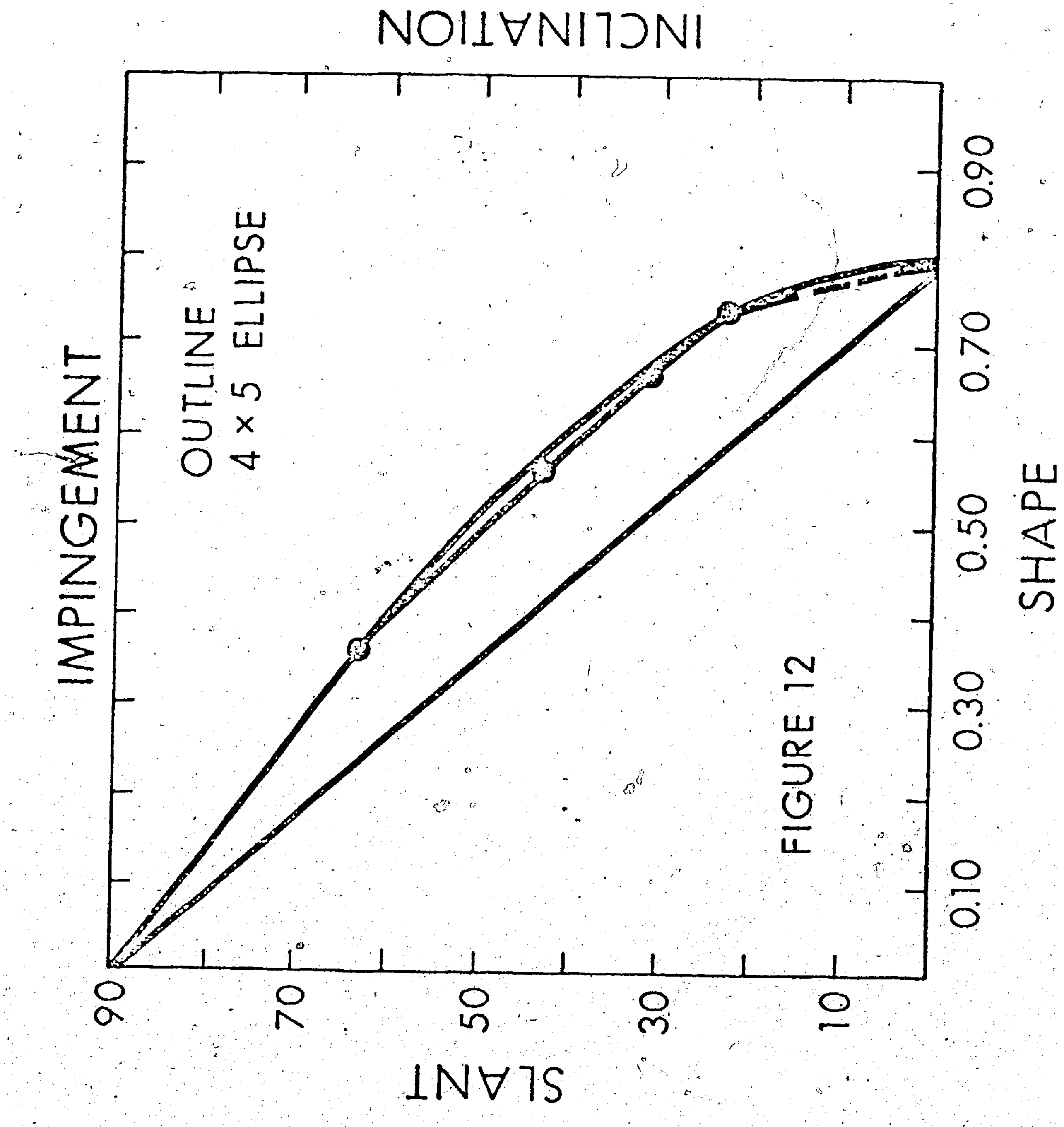

IMPINGEMENT
INCLINATION
OUTLINE
4 × 5 ELLIPSE
SLANT
90
70
50
30
10
SHAPE
0.10
0.30
0.50
0.70
0.90

FIGURE 12

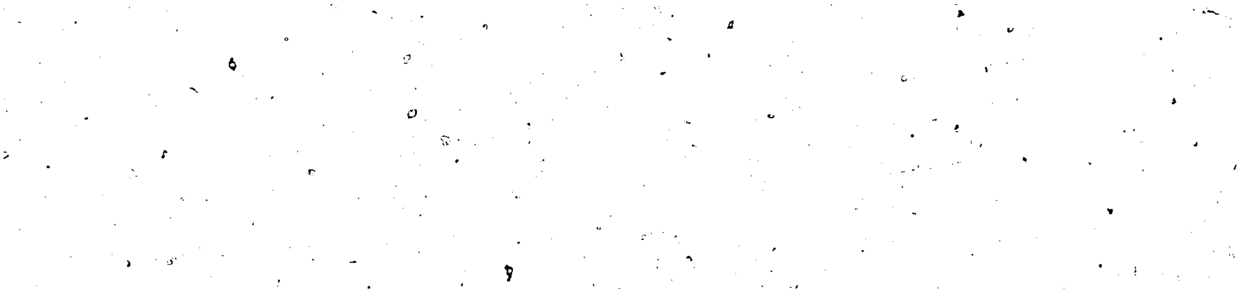


Figure 13. Points describe the relationship between shape and slant (heavy line) for the SURFACE condition with the 4 x 5 elliptical target. Also shown are the physical (cosine) invariant (upper curved) and psychological invariant (lower linear) functions describing relationship of impingement and inclination of a 4 x 5 ellipse.

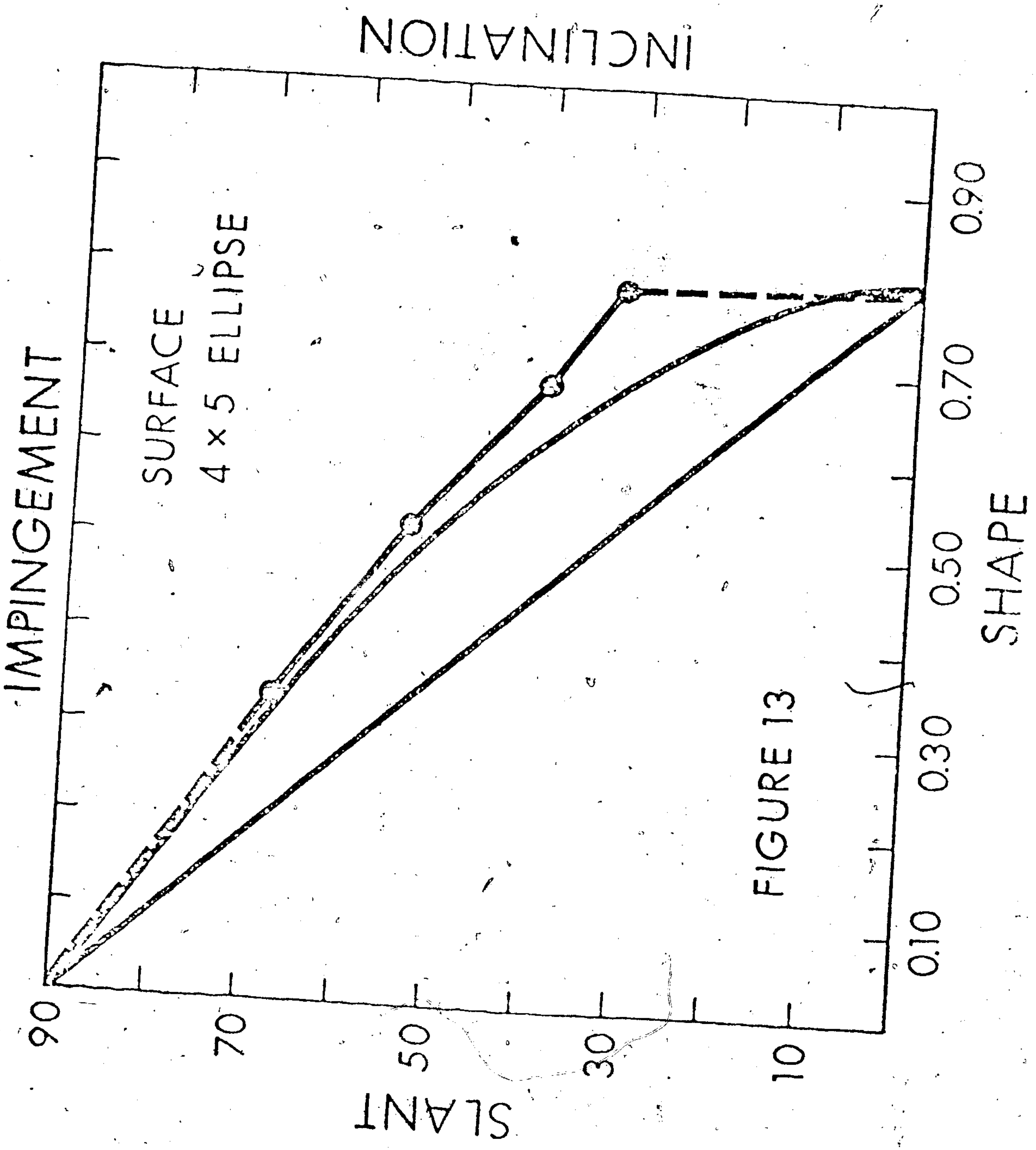

IMPINGEMENT
INCLINATION
SLANT
SHAPE
SURFACE
4 × 5 ELLIPSE
90
70
50
30
10
0.10
0.30
0.50
0.70
0.90

FIGURE 13

Figure 14. Points describe the relationship between shape and slant (heavy line) for the TEXTURE condition with the 4 x 5 elliptical target. Also shown are the physical (cosine) invariant (upper curved) and psychological invariant (lower linear) functions describing relationship of impingement and inclination of a 4 x 5 ellipse.

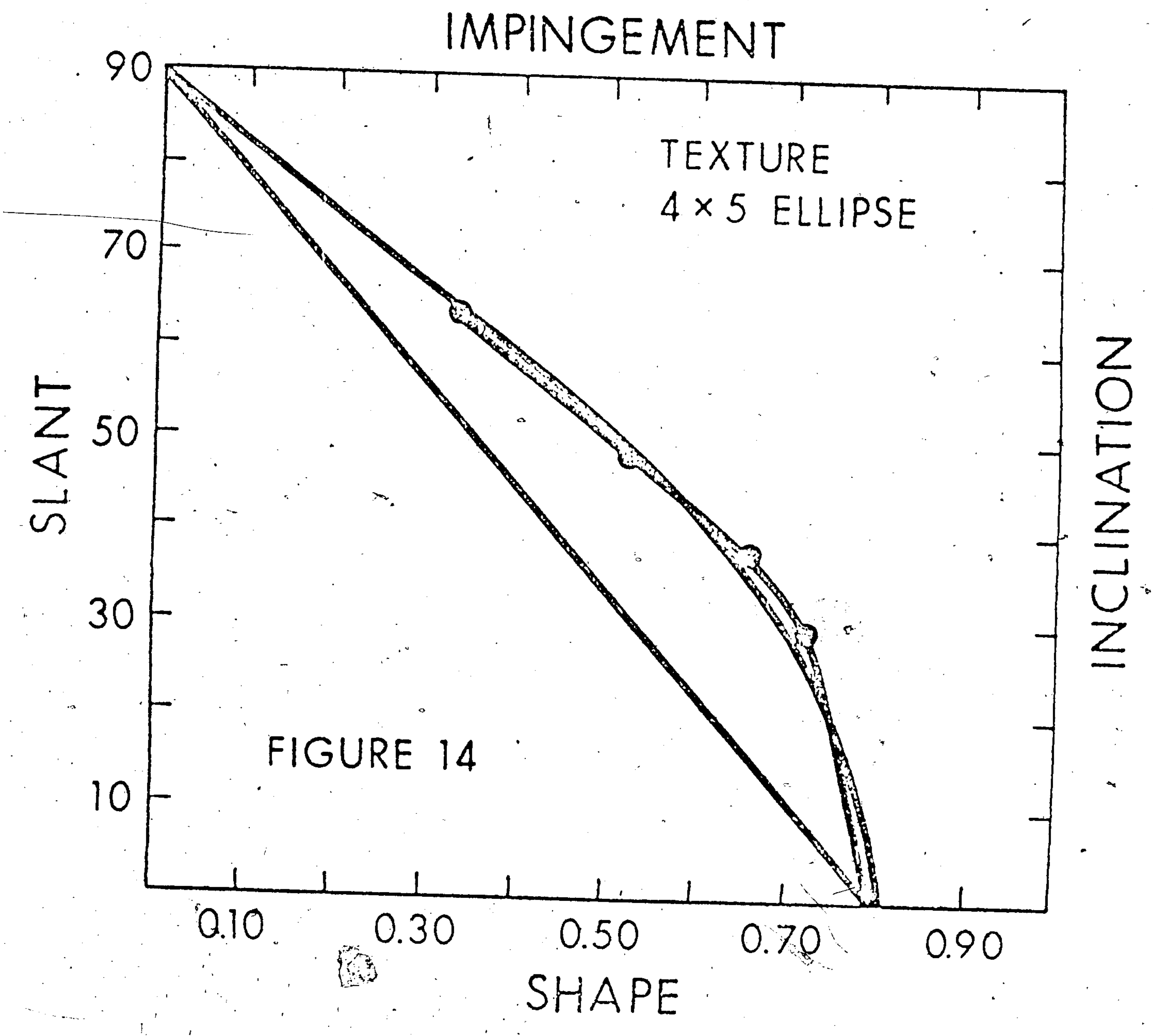


FIGURE 14

IMPINGEMENT
TEXTURE
4 × 5 ELLIPSE
SLANT
90
70
50
30
10
INCLINATION
0.10
0.30
0.50
0.70
0.90
SHAPE

Figure 15. Points describe the relationship between shape and slant (heavy line) for the FOREGROUND condition with the 4 x 5 elliptical target. Also shown are the physical (cosine) invariant (upper curved) and psychological invariant (lower linear) functions describing relationship of impingement and inclination of a 4 x 5 ellipse.

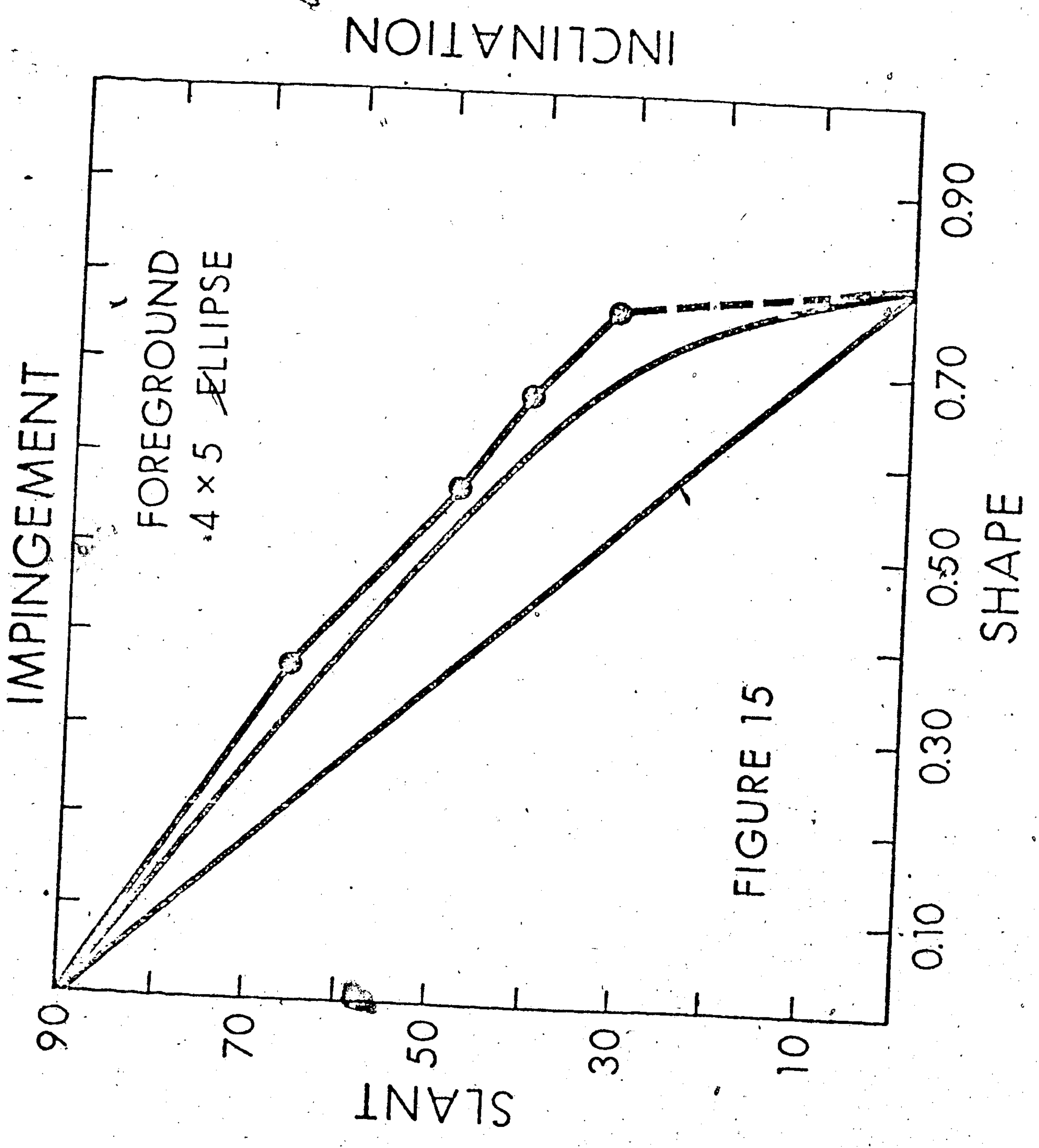

IMPINGEMENT
FOREGROUND
4 × 5 ELLIPSE
INCLINATION
SLANT
90
70
50
30
10
SHAPE
0.10
0.30
0.50
0.70
0.90

FIGURE 15

(Figure 13) and background (Figure 15) conditions are seen to lie above the physical, opposite the case previously seen with the circle (Figures 9 & 11). The function for the texture condition (Figure 14) lies above the physical function at larger axis ratios but under this function at smaller ratios. As with the functions describing response to the various surface-field conditions with the circle, visual inspection reveals detectable differences between the four functions themselves. Again, however, visual inspection alone is not adequate.

Mean total area between the four response functions described by Figures 12 - 15 are presented in Part A of Table 5. The technique used in obtaining the values is the same as described for those presented in Table 4.

As visual inspection alone suggested, the outline function encloses the least area, with texture, foreground, and surface enclosing progressively greater areas. This represents an ordering of area values different from that with the circle, ie. outline, texture, foreground, and surface with the 4 x 5 ellipse versus foreground, surface, texture, and outline ~~with~~ the circle, greatest to least. Here, the sign is positive in three cases and negative in only one (outline).

This would suggest that although the response functions reflect conditions which lead to closer and closer approximations of the physical invariant, the information, as measured area, apparently provided by a given surface-field condition was not the same as that provided if the surface-field condition appeared on another target form. Thus it might seem that the target form used affects the information given by various surface-field conditions.

TABLE 5

PHYSICAL INVARIANT - RESPONSE INVARIANT

CORRESPONDENCE WITH 4 x 5 ELLIPSE

PART A

MEASURED AREA
PHYSICAL TO RESPONSE

SURFACE CONDITION	AREA (IN.^{2})	VARIANCE
OUTLINE	0.27 (-)	0.55
SURFACE	0.71 (+)	0.44
TEXTURE	0.41 (+)	0.84
FOREGROUND	0.55 (+)	0.93

TABLE 5: PART A. The mean area, in square inches, between the cosine function describing the 4 x 5 ellipse and the response invariant provided by four specified surface-field conditions. Positive sign following area indicates major proportion of area lies above cosine function. Negative sign indicates major proportion of area lies below the cosine function. See figures 12-15. Variance between individuals is given in the right hand column.

PART B

RESPONSE - RESPONSE DIFFERENCE

	OUTLINE	SURFACE	TEXTURE	FOREGROUND
OUTLINE		0.44	0.14	0.38
SURFACE	t = 1.76 p<.05		0.30	0.06
TEXTURE	t = 0.48 N.S.	t = 1.07 N.S.		0.24
FOREGROUND	t = 1.27 N.S.	t = 0.21 N.S.	t = 0.75 N.S.	

TABLE 5: PART B. The difference values between those area values given in Part A, disregarding direction of difference, above the diagonal. Values of t and p for these differences below the diagonal. d.f. = 30.

A brief inspection of Figures 20 - 23, to be dealt with in greater detail later, may provide a partial answer to the structure of the data. Notice that in the four figures, surface-field conditions are graphed independently of target form. The curves are related to the physical invariant functions describing the circle, 4 x 5 ellipse and 2 x 5 ellipse. Consider only the open circles and imagine them as connected to describe the response functions as seen in Figures 12 - 15 (4 x 5 elliptical targets), or if you wish, imagine the physical invariants describing the circle over-layed on Figure 12 - 15. Measuring the area between the response functions given with the 4 x 5 ellipse and the physical invariant describing the circle, using measurement technique outlined above, it is seen that the outline function is the most discrepant with texture, foreground, and surface functions respectively less so. The values are 2.54, 2.40, 2.16, and 2.10 square inches, respectively. This order is now like the case with the circle with the exception of foreground and surface conditions, which remain reversed. However, when one considers the difference between the values of these two conditions is an area difference of 0.06 square inches, it is not impossible to imagine that the order could easily be exactly the same as that of the circle.

Rather than the image projection of the target in the frontal plane effecting the information presumably contained within a given condition, the perceived slant (refer to Figures 7a and 7b) may have altered the relationships of the response functions to their physical correlates which would in turn effect measured area values upon which information content is based.

Returning for a closer inspection of Part A~~-of T~~able 5, an approximation of the psychological invariant would have a value of 2.48(-). As seen above, with the 4 x 5 ellipse no response function is remotely close to this value. Outline and surface conditions give the least variance, with texture and background giving more. This does not correspond to cases reported with other forms. Surface, with the least variance, encloses the greatest area. This problem is partially resolved by considerations presented directly above.

The values giving the differences between the response functions are not affected by the base line used. Difference between surface-field conditions with the 4 x 5 ellipse are presented in Part B of Table 5. Again in matrix form, the difference values are presented above the diagonal, with the values of t and p given below the diagonal. The greatest difference occured between the outline and surface conditions and was significant with $p < .05$. Other differences were not as large and did not prove reliable. Differences between surface-texture and outline-foreground had values of $p > 15$. The one difference found significant provides further support for Hypotheses 1 and 2.

Turning now to the relationships between response functions of outline, surface, texture and foreground evoked by the 2 x 5 ellipse and the cosine and psychological functions describing transformation of this form (Figures 15-19), one immediately notices relationships different than that reported before. With the 2 x 5 ellipse, all functions lie well above both the cosine and psychological functions, and can not be considered good approximations of either. Response to the outline and surface targets (Figures 16 & 17) show sharp increases in mean apparent slant with little or no decrease in mean apparent shape when impingement values are largest. In both cases, minor/major axis ratios recorded were larger than the impingement value given by the target in the frontal plane would allow. With the textured target (Figure 18), on the other hand, there is an increase in shape with increasing slant at the larger impingement values, as pointed out before. The greatest minor/major axis does not exceed impingement values, however, it is questionable whether an invariant relation of shape and slant has been demonstrated with the texture condition as changes are not uniform throughout the range. The background target (Figure 19) gave a response function similar in rate of change as those reported before, but again, minor/major axis ratios exceeded values of the impinging stimulus. The response functions evoked with the 2 x 5 ellipse clearly describe a case where response does not describe geometric conditions.

The values of the areas enclosed by the response functions given by Figures 16 - 19 (2 x 5 ellipse) are presented in Table 6, Part A. As shown, texture provides a function which encloses the least area, followed by outline, surface, and background, respectively. Again the order differs from that expressed in Tables 4 (circle) and 5 (4 x 5 ellipse). The absolute values of measured area are all large, with all signs positive, showing only a tentative relationship to the physical and psychological invariants. This conforms to the findings of others (Nelson,

Figure 16. Points describe the relationship between shape and slant (heavy line) for the OUTLINE condition with the 2 x 5 elliptical target. Also shown are the physical (cosine) invariant (upper curved) and psychological invariant (lower linear) functions describing relationship of impingement and inclination of a 2 x 5 ellipse.

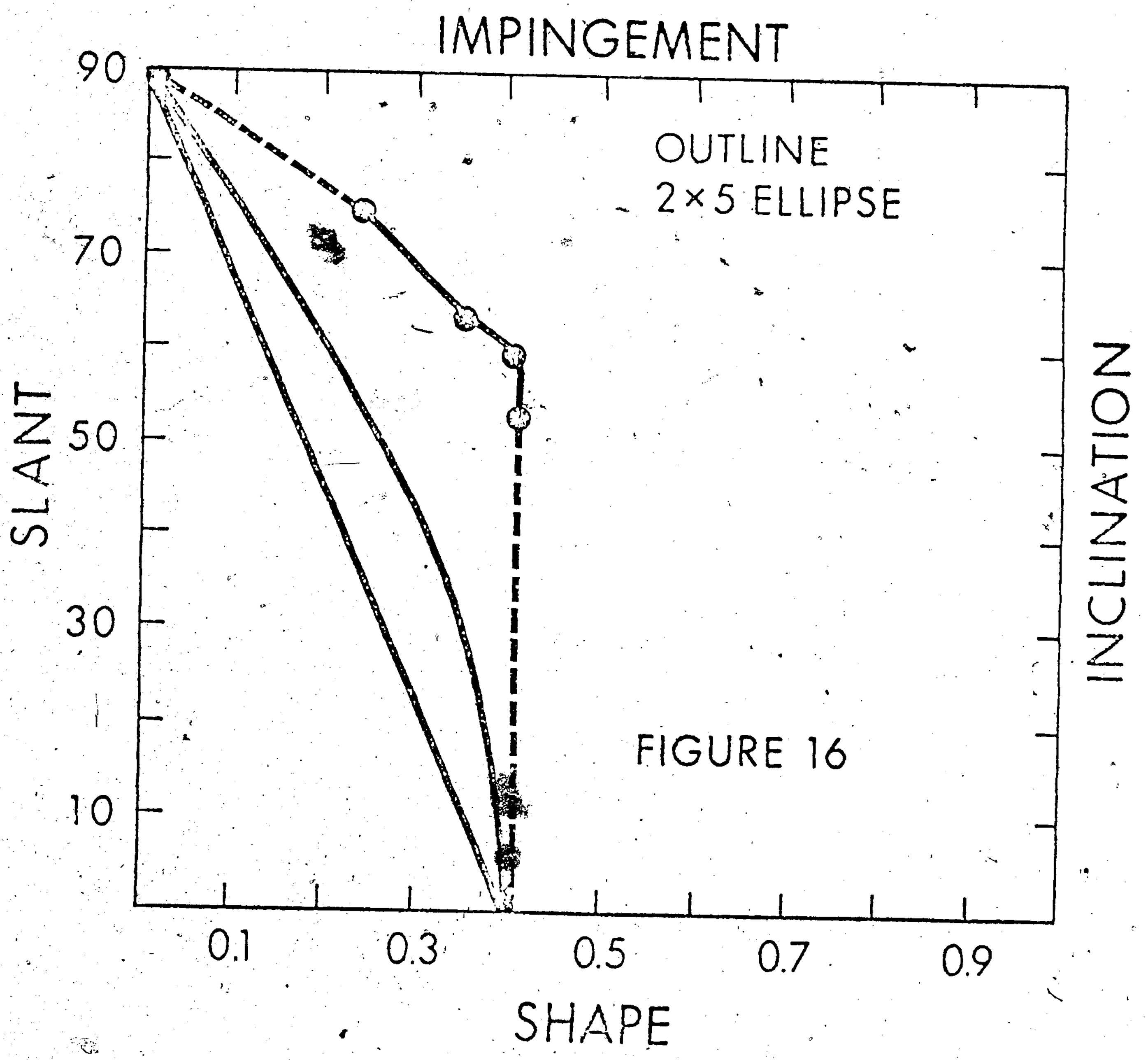

IMPINGEMENT
INCLINATION
SLANT
SHAPE
OUTLINE
2×5 ELLIPSE
90
70
50
30
10
0.1
0.3
0.5
0.7
0.9

FIGURE 16

Figure 17. Points describe the relationship between shape and slant (heavy line) for the SURFACE condition with the 2 x 5 elliptical target. Also shown are the physical (cosine) invariant (upper curved) and psychological invariant (lower linear) functions describing relationship of impingement and inclination of a 2 x 5 ellipse.

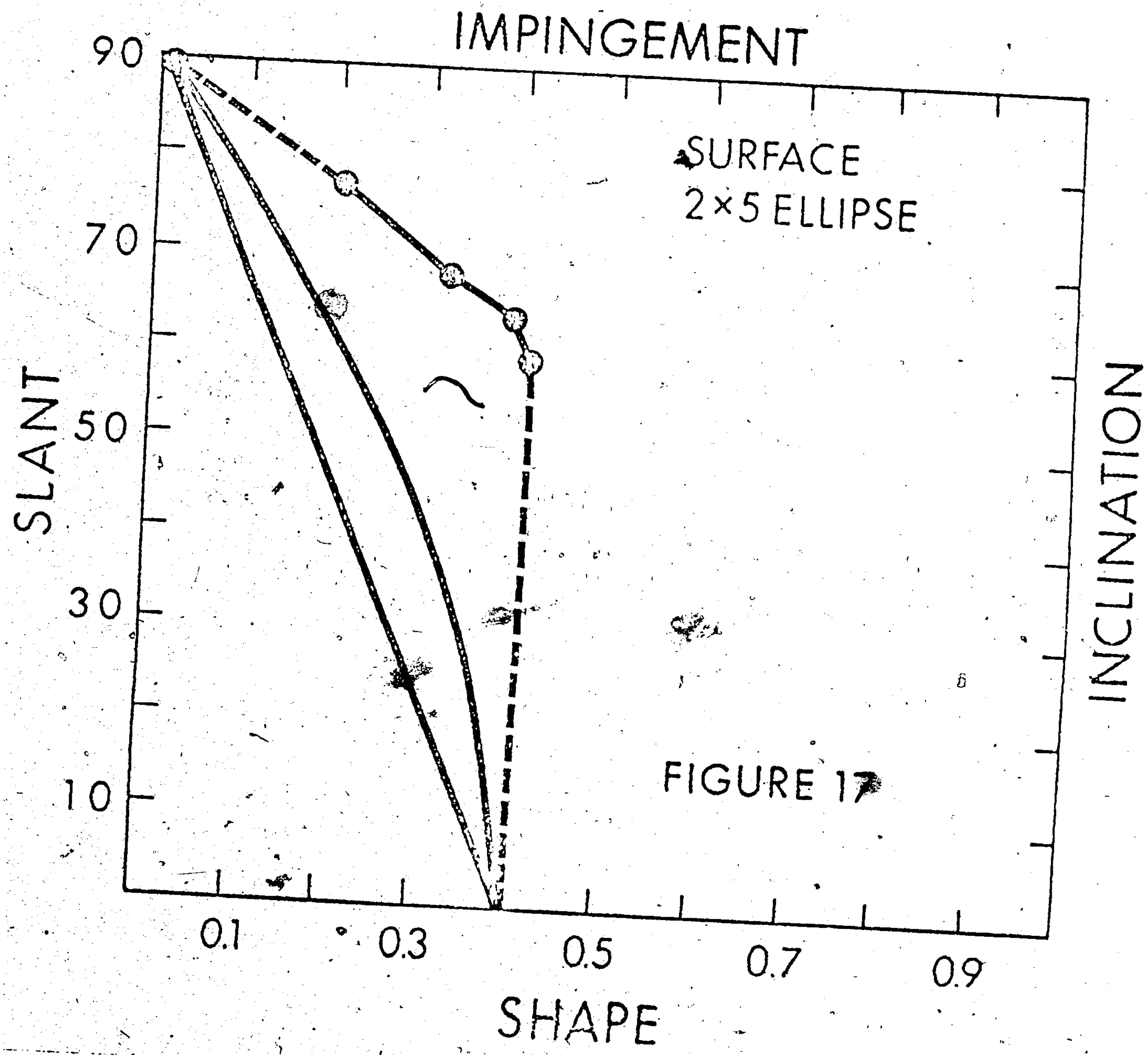

IMPINGEMENT
SURFACE
2×5 ELLIPSE
SLANT
90
70
50
30
10
INCLINATION
0.1
0.3
0.5
0.7
0.9
SHAPE

FIGURE 17
]

Figure 18. Points describe the relationship between shape and slant (heavy line) for the TEXTURE condition with the 2 x 5 elliptical target. Also shown are the physical (cosine) invariant (upper curved) and psychological invariant (lower linear) functions describing relationship of impingment and inclination of a 2 x 5 ellipse.

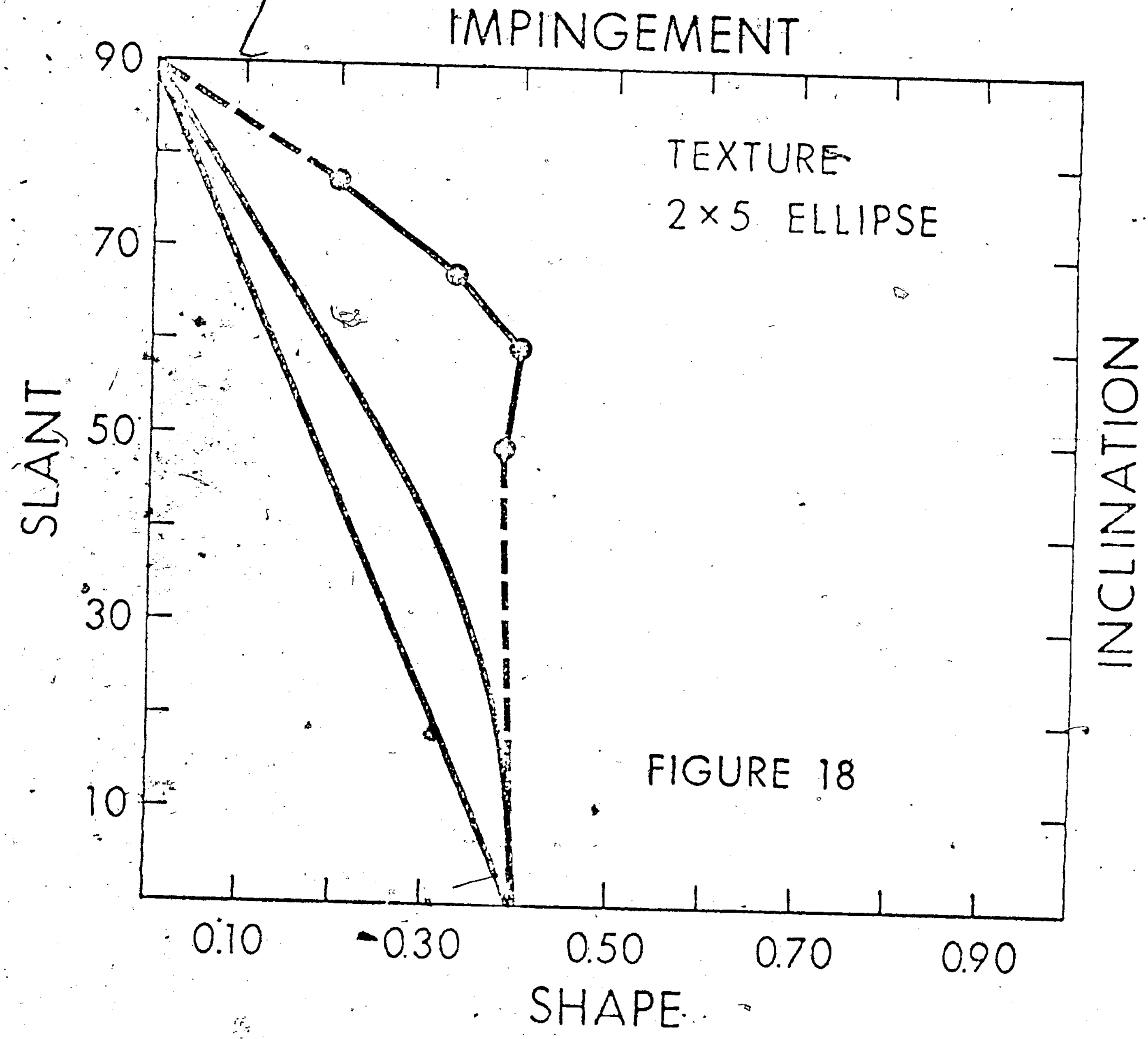

IMPINGEMENT
TEXTURE
2×5 ELLIPSE
SLANT
90
70
50
30
10
INCLINATION
0.10
0.30
0.50
0.70
0.90
SHAPE

FIGURE 18

Figure 19. Points describe the relationship between shape and slant (heavy line) for the FOREGROUND condition with the 2 x 5 elliptical target. Also shown are the physical (cosine) invariant (upper curved) and psychological invariant (lower linear) functions describing relationship of impingement and inclination of a 2 x 5 ellipse.

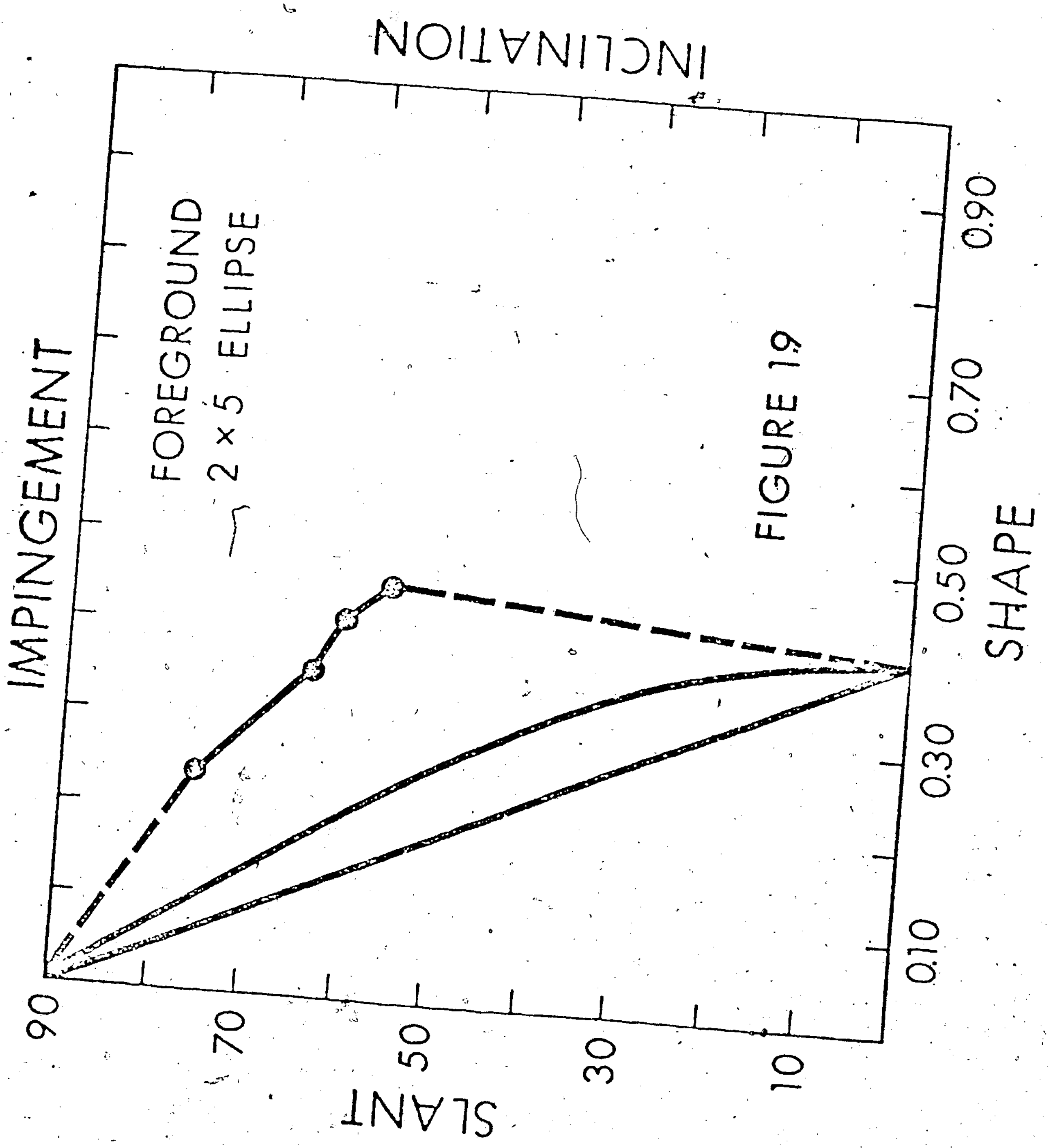

IMPINGEMENT
INCLINATION
FOREGROUND
2 × 5 ELLIPSE
SLANT
90
70
50
30
10
SHAPE
0.10
0.30
0.50
0.70
0.90

FIGURE 19

TABLE 6

PHYSICAL INVARIANT - RESPONSE INVARIANT CORRESPONDENCE WITH 2 x 5 ELLIPSE

PART A

MEASURED AREA
PHYSCIAL TO RESPONSE

SURFACE CONDITION	AREA (IN.^{2})	VARIANCE
OUTLINE	1.94 (+)	1.54
SURFACE	2.02 (+)	0.58
TEXTURE	1.76 (+)	0.62
FOREGROUND	2.30 (+)	0.83

TABLE 6: PART A. The mean area, in square inches, between the cosine function describing the 2 x 5 ELLIPSE and the response invariant provided by four specified surface-field conditions. Positive sign following area indicates major proportion of area lies above cosine function. See figures 16-19. Variance between individuals is given in the right hand column.

PART B

RESPONSE - RESPONSE DIFFERENCE

	OUTLINE	SURFACE	TEXTURE	FOREGROUND
OUTLINE		0.08	0.18	0.36
SURFACE	t = 0.22 N.S.		0.26	0.28
TEXTURE	t = 0.50 N.S.	t = 0.96 N.S.		0.54
FOREGROUND	t = 0.95 N.S.	t = 0.93 N.S.	t = 1.80 $p < .05$	

TABLE 6: PART B. The difference values between those area values given in Part A, disregarding direction of difference, above the diagonal. Values of t and p for these differences below the diagonal. d.f. = 30.

Bartley, & Bourassa, 1961).

Considering the table in more detail, no response function closely approximates the psychological, which would be given by a value of 1.24 (-). Surface response yields the least variance but encloses a relatively large area, while the outline yields a large variance but encloses a relatively smaller area than other response functions.

Let me again turn briefly to Figures 20 - 23 (surface-field conditions independent of form). By comparison of the response functions with the 2 x 5 elliptical targets to the physical function describing transformation of the circle, one can see the order of enclosed areas greatest to least is: texture, outline, surface, and foreground, with values of 3.12, 2.94, 2.86, and 2.58 respectively. As is the case with the 4 x 5 elliptical targets, the conditions not representing the order as given with the circular targets are separated by only very small areas ie. texture and outline are different by the value 0.18. However, here outline and surface are also separated by a small area (0.08). It appears ~~the~~ three functions could be represented in almost any order, when compared in this way.

Consulting Part B of Table 6, only one comparison was shown to be significant: texture vs. foreground. Support is therefore offered to Hypotheses 3 and 4 by this outcome. Other differences were not reliable.

Taken in total, the above data seem to suggest that a classif[illegible] conditions may best be accomplished on the basis of the stimulus c[illegible]istics refered to as photic ie. outline, surface, texture, and foreground without taking recourse to geometric functions for different form types.

Figure 20. Points describe a function of response to the 5 x 5, 4 x 5, and 2 x 5 target forms with the OUTLINE condition. Also shown are the physical (cosine) functions for the circle, 4 x 5 ellipse, and 2 x 5 ellipse (see Figure 1) and the psychological (linear) function for the circle.

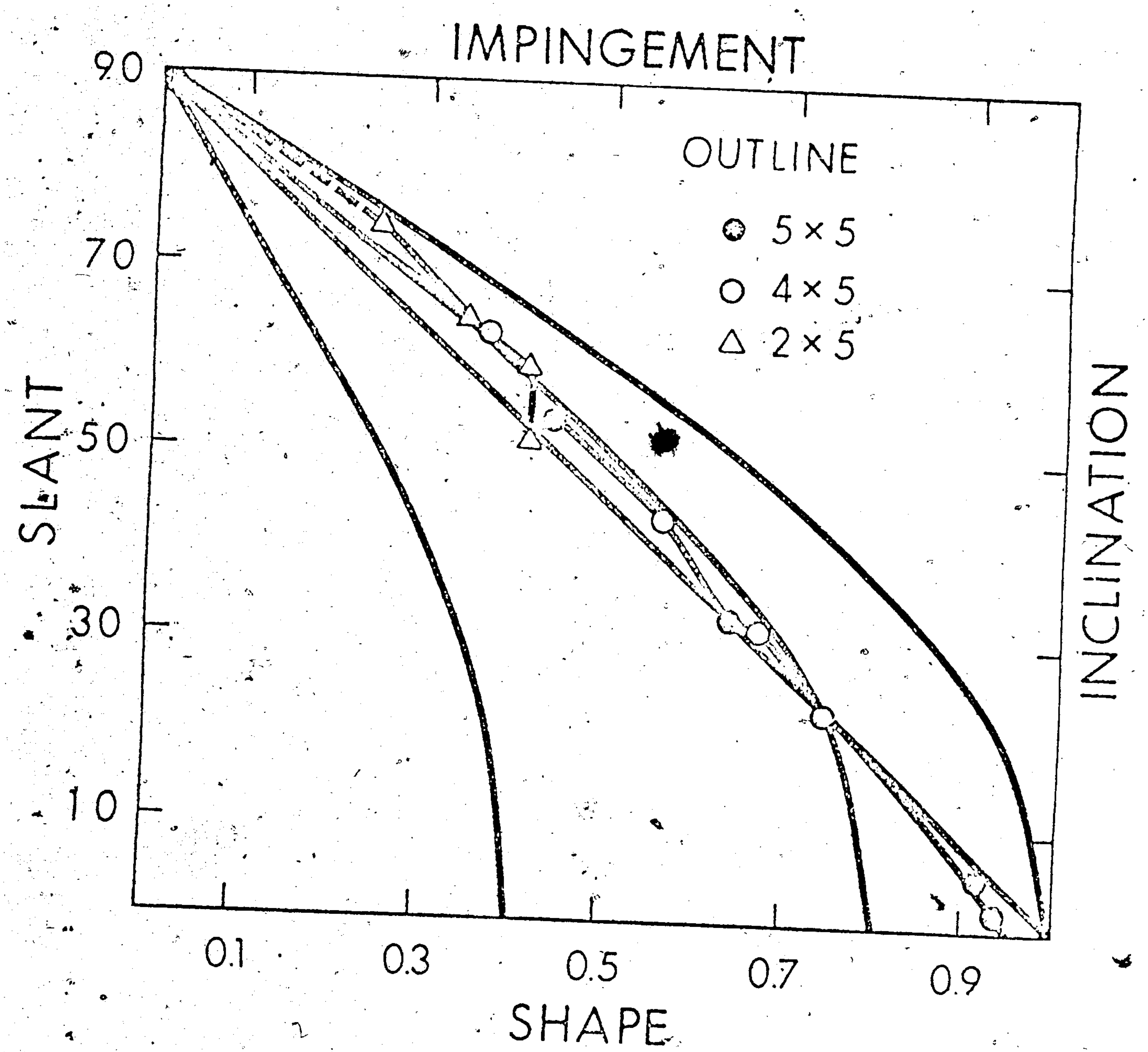

IMPINGEMENT
OUTLINE
5 × 5
4 × 5
2 × 5
SLANT
90
70
50
30
10
INCLINATION
0.1
0.3
0.5
0.7
0.9
SHAPE

Figure 21. Points describe a function of response to the 5 x 5, 4 x 5, and 2 x 5 target forms with the SURFACE condition. Also shown are the physical (cosine) functions for the circle, 4 x 5 ellipse, and 2 x 5 ellipse (see Figure 1) and the psychological (linear) function for the circle.

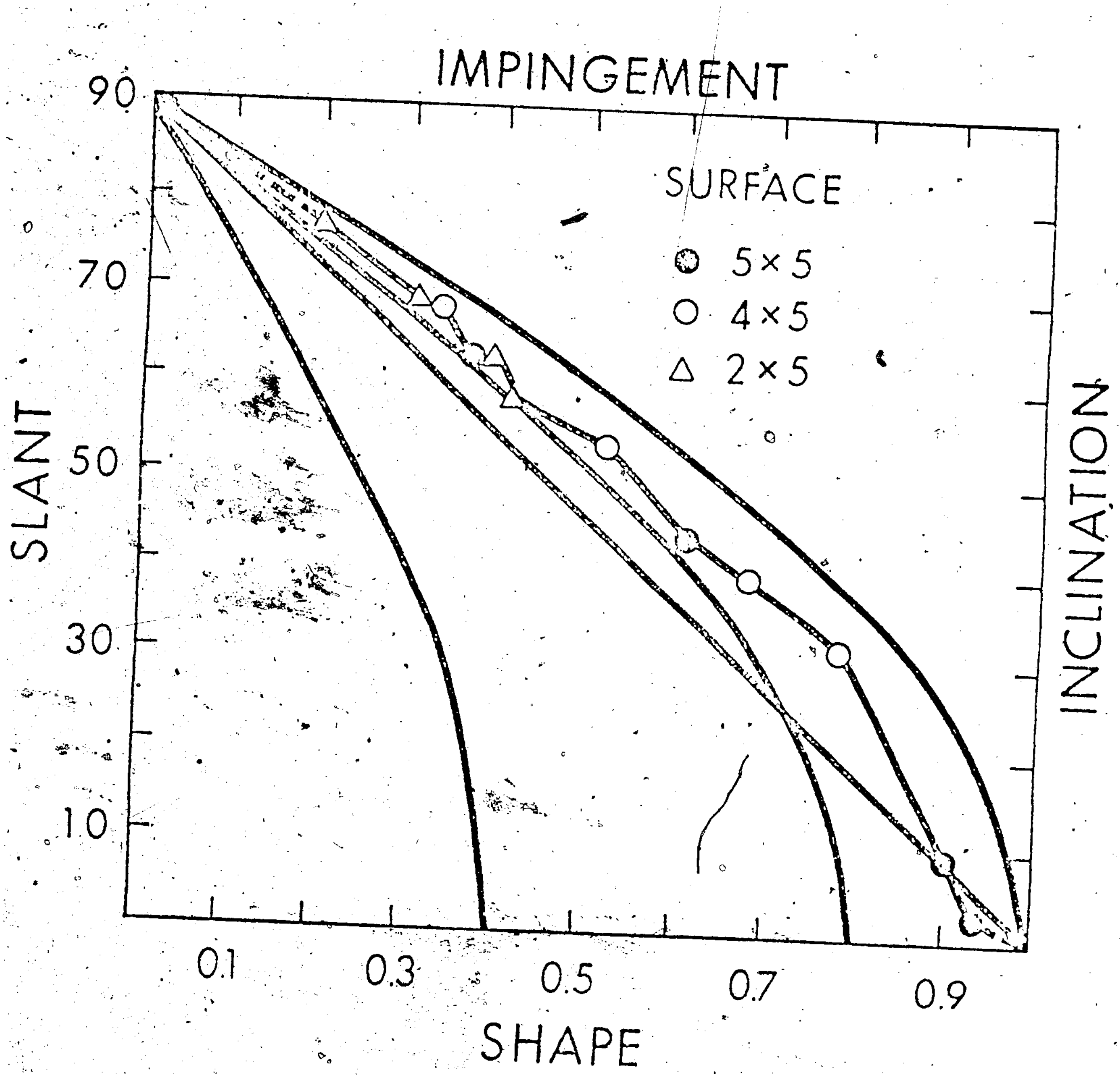

IMPINGEMENT
SURFACE
● 5×5
○ 4×5
△ 2×5
SLANT
90
70
50
30
10
INCLINATION
0.1
0.3
0.5
0.7
0.9
SHAPE

Figure 22. Points describe a function of response to the 5 x 5, 4 x 5, and 2 x 5 target forms with the TEXTURE condition. Also shown are the physical (cosine) functions for the circle, 4 x 5 ellipse, and 2 x 5 ellipse (see Figure 1) and the psychological (linear) function for the circle.

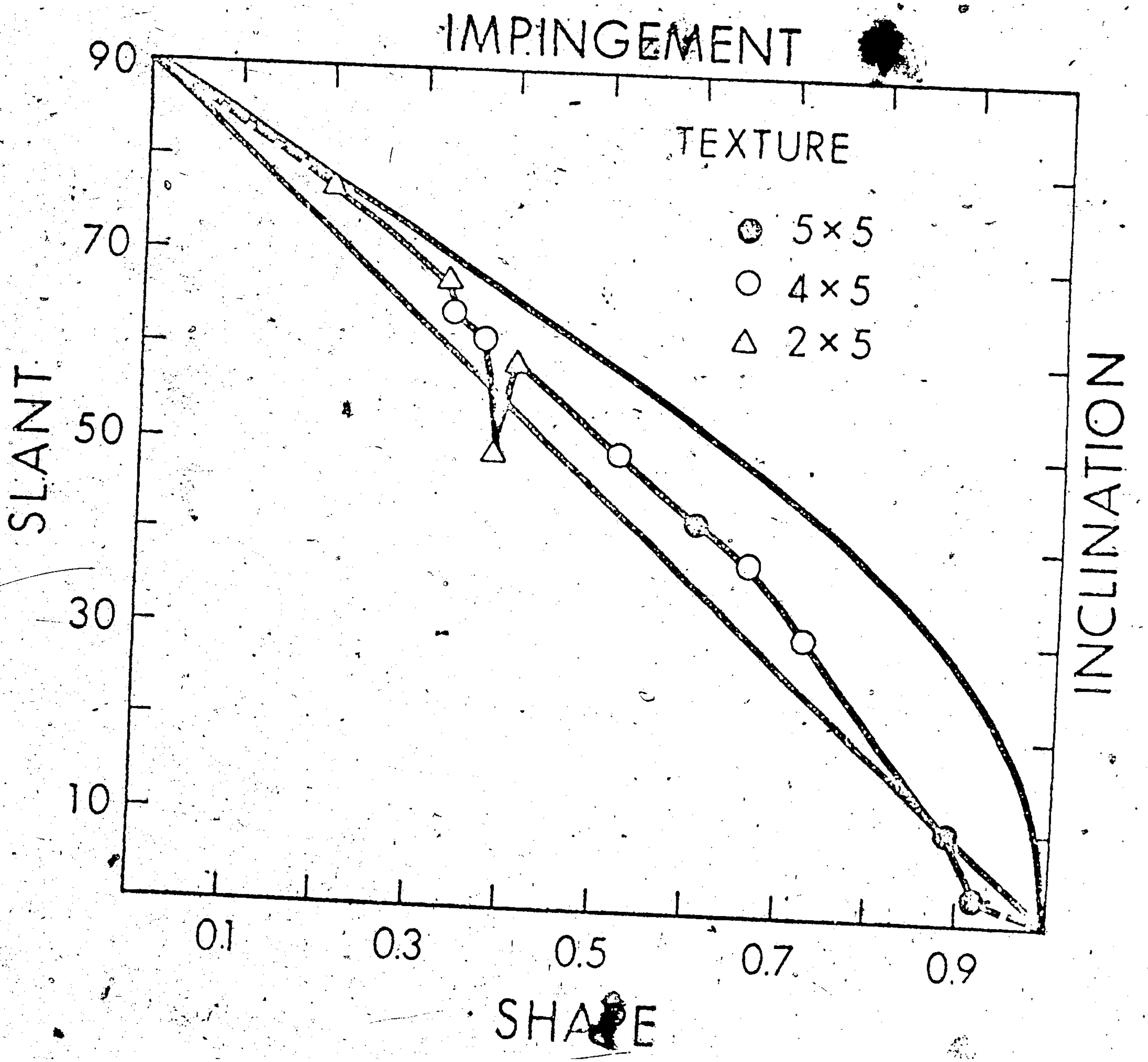
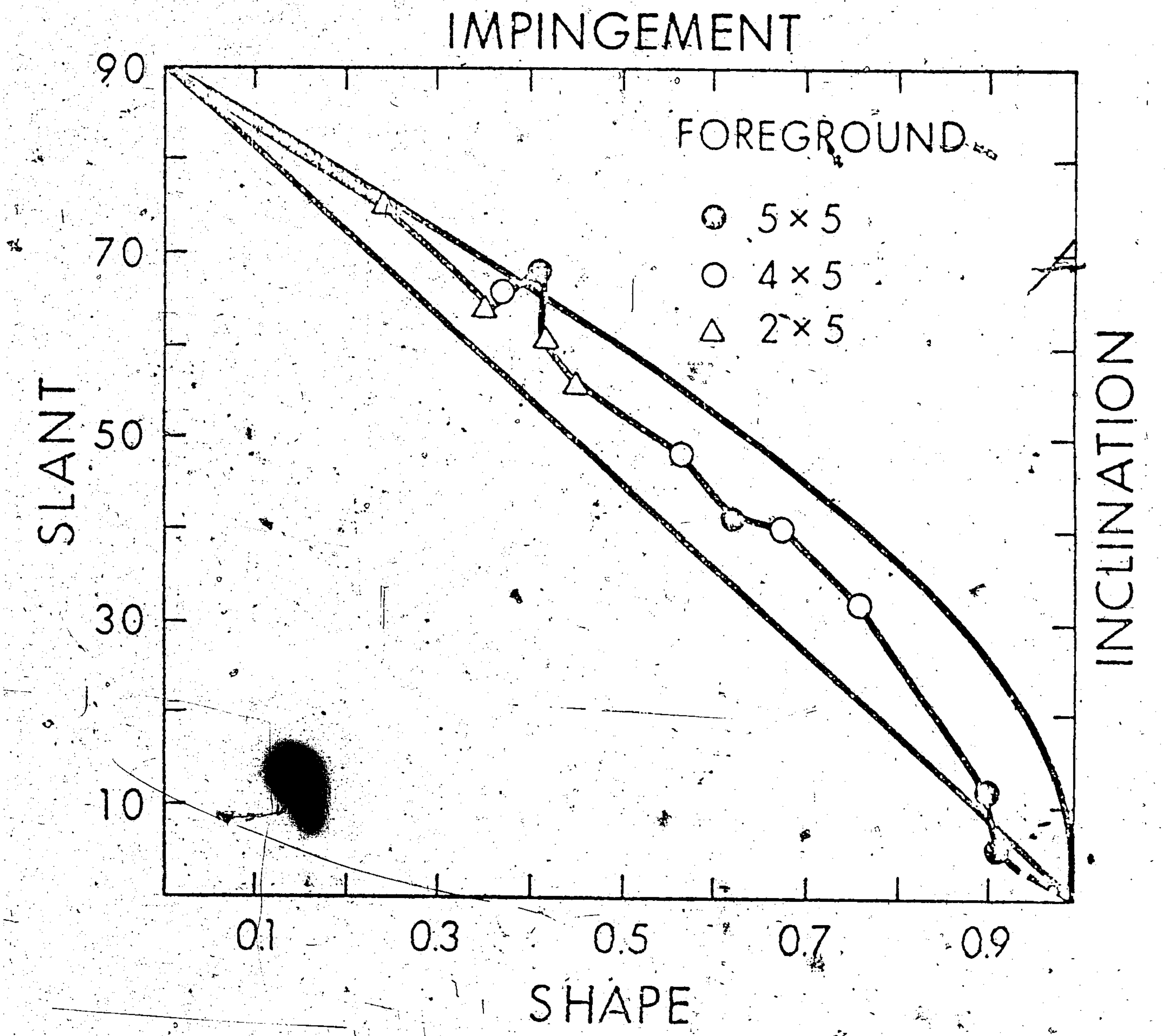

IMPINGEMENT
TEXTURE
● 5 × 5
○ 4 × 5
△ 2 × 5
SLANT
90
70
50
30
10
INCLINATION
SHAPE
0.1
0.3
0.5
0.7
0.9

Figure 23. Points describe a function of response to the 5 x 5, 4 x 5, and 2 x 5 target forms with the FOREGROUND condition. Also shown are the physical (cosine) functions for the circle, 4 x 5 ellipse, and 2 x 5 ellipse (see Figure 1) and the psychological (linear) function for the circle.


IMPINGEMENT
FOREGROUND
5 × 5
4 × 5
2 × 5
SLANT
90
70
50
30
10
INCLINATION
0.1
0.3
0.5
0.7
0.9
SHAPE

Discussion

Considerations of shape and slant have historically involved a search for variables which could relate two psychological processes in a manner adequate to reflect Euclidean conditions of space, i.e. the cosine function describing inclination and impingement. Thus, in the past, one finds Helmholtz (1925) relying upon experience and some special knowledge of the perceived object to facilitate assignment of some subjective metric size to the subject (and presumably ratio values for shape, if he were to deal with shape and slant), from the retinal projection provided. For Helmholtz, the important variables would be unconscious inference together with sensory input. Gestaltists (Koffka, 1935; Thouless, 1931a, 1931b; Eissler, 1933; Klimpfinger, 1933) developed similar variables in relating shape and slant for development of a shape-slant invariant function by suggesting ratios of perceptual error in shape and slant in relation to ratios of impingement and orientation provided by Euclidean geometry. The ratio formulas were described previously as the error invariance hypothesis.

Gibson (1947, 1948, 1950) and Beck & Gibson (1955), continuing use of the error invariance formulas, introduced optical texture and optional texture gradients as variables and consequently moved the interest from shape perception to the perception of slant. Maintaining interest in the invariance hypothesis within this same decade, Clark, Smith, and Rabe (1955, 1956) suggest retinal gradients of outline as the variable associated with shape-slant perception.

Failure to lay down functiona dependency between shape and slant has not discouraged the search for variables relevant to shape and slant perception. Flock (1962, 1963, 1964a, 1964b, 1965), following Gibson, also suggests optical texture as sufficient for perception of slant, disregarding shape. Freeman (1962, 1965, 1966a, 1966b), on the other hand, would rely upon variables of contour perspective. Winnick and collegues (1966, 1967) suggests pattern and textural gradient.

More recently, Braunstein (1968) suggests texture gradients alone are insufficient and considers velocity of textural gradient change. Smith (1967) sees perceived shape as a function of ambiguity of contour perspective while Kaiser (1967) deals with slant as the major variable. In a series of articles, Eriksson (1967a, 1967b, 1967c) found the shape-slant invariance hypothesis described by Euclidean geometry was not valid, but dependent upon field effects. He reports shape-slant functions similar to those reported here, but deals with the differences in terms of power functions in field vectors as described by Newtonian physics.

Consideration of variables of shape and slant to date generally share one common starting point, the frontal plant. It is obvious that any given projection can be provided by an infinitude of forms, or to put it in reverse, and given form can subtend an infinitude of angles. By stating the starting point as the frontal plane, I simply suggest it has been convenient to reduce this infinitude to a common base. The assumed or "real" objects of Helmholtz (1925), Thouless (1931a, 1931b), Brunswick (1956), and Hastorff (1950) are initially conceived with respect to the frontal plane. In the same way, analysis of texture gradients begins in the frontal plane, although compression of elements must be analyzed out of the frontal plane.

Consider, however, that all two-dimensional targets have another orientation providing a common measurement base. When targets are placed in the horizontal plane in respect to an observer, all are seen as an edge, varying in only one dimension, length. Of course, rotation to 90° in any plane will give an edge. Again, an infinitude of forms and angles is reduced for convenience. The study reported used rotation of the target forms in the vertical plane. However, for simplification of discussion rotation toward the horizontal plane will be considered to represent all planes of rotation. When we do this, variables measured as distortion of the frontal plane object are treated as measures from an edge, that edge being given when the target is presented to the observer in the horizontal plane.

Let's consider the target forms used in the study reported, ie. a circle and two examples of ellipses. In the frontal plane they present to the observer three axis ratios unique to the single form employed. However, if all are oriented to 90° from the frontal plane with the major axis describing the plane of rotation, all will be seen as an edge or line of equal length as all have initially equal major axes. In the case of the ellipses, the length of the observed edge would vary with rotation on an axis other than that described as the major. However, this was not the case in the study reported.

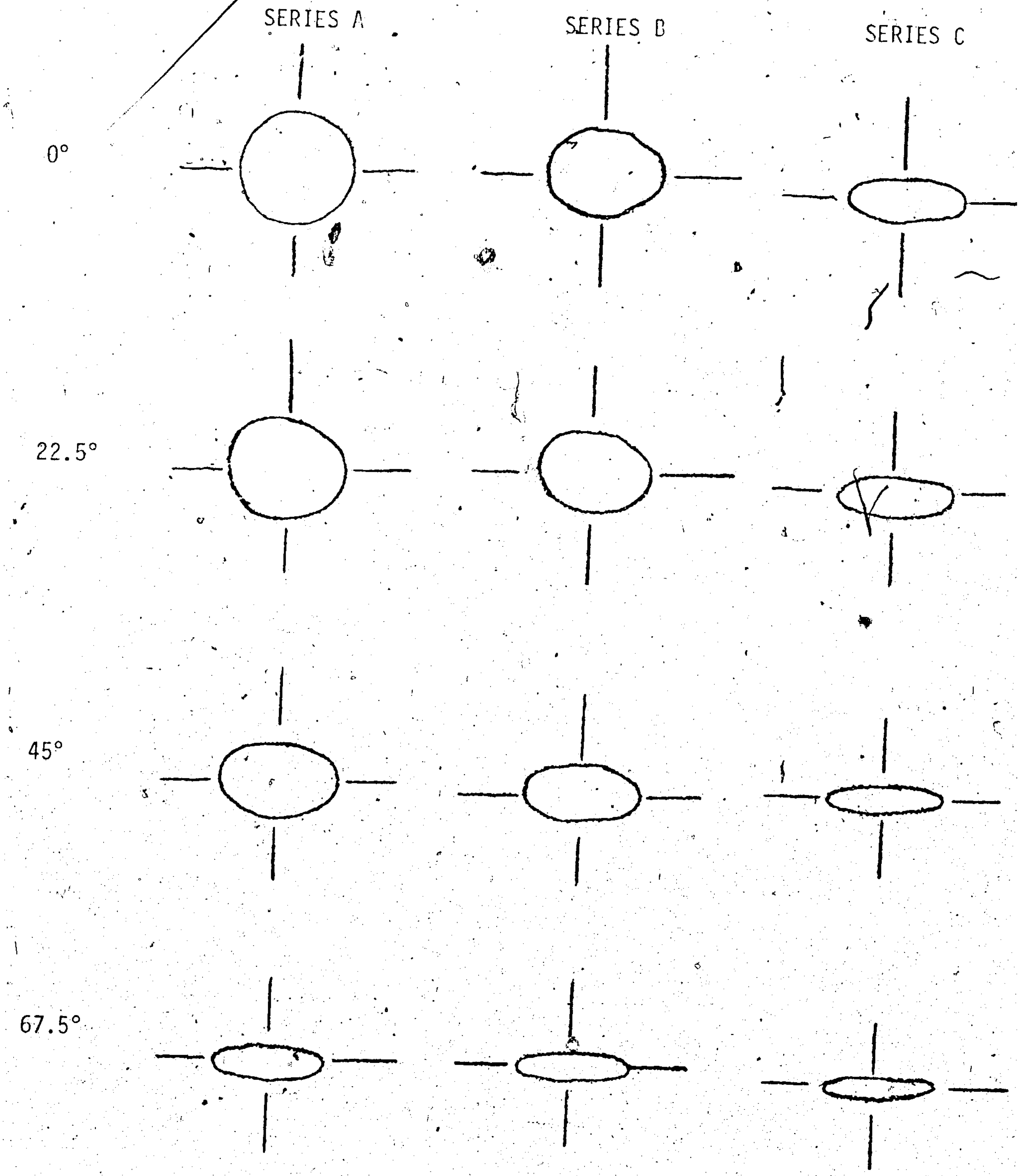
Rotation of targets out of the horizontal plane will present the observer with a surface which will be considered a distortion of an edge. As rotation begins, two variables become evident: first, the proportion of area given by any two axes and second, the symmetrical distribution of the area around the line or rotation.

Consider the changes in simple proportion and symmetry accompanying rotation on the major axis of the three target forms used in the study, presented in Figure 24. The lines bisecting the figures horizontally in series A, B, and C indicate the plane of rotation, with the vertical lines in each series indicating one base line against which symmetry may be measured. Series A shows rotation of a circle from the horizontal plane (top) to 90° from the horizontal or the frontal plane (bottom); Series B, a 4 x 5 ellipse; and Series C, a 2 x 5 ellipse.

With these forms, the changes of proportion and symmetry are regular - within the conceptual limits of Euclidean geometry. Notice that within the three series, it would be possible to construct a combined series based on the variables of simple proportion and symmetry. On the other hand, if textural elements were present (note Figure 4), compression ratios of the elements with each form would differ with rotation and thus would necessarily require response in terms of shape and slant to conform to the initial physical form. The data does not support the latter, but show the three forms were dealt with as possibly a single form seen in various orientations.

It is now postulated that the invariant component in any shape-slant transformation is carried by the simple changes of proportion and symmetry, gure 24. Rotation of a circle and two ellipses on the major axis. Series A shows rotation of a circle, Series B a 4 x 5 ellipse, and Series C a 2 x 5 ellipse at four orientations - 0°, 22.5°, 45°, 67.5°, and 90°. The major axis is represented in the horizontal plane.

FIGURE 24



both measured against an edge. Texture, target form in the frontal plane, field relations and field structure become secondary to and are carried by simple ratio measures.

The strength of our postulated variables, simple proportion and symmetry, for shape-slant invariant formulations becomes more evident when other forms are employed. Consider Figure 25. In Series A, the axis of rotation was changed from the major to the minor, with this example of an ellipse. Changes with rotation are noted to be different than those given by inspection of Figure 24. The form is initially a line or edge, becoming elliptical with the major axis in the vertical, then almost circular, and finally elliptical with the major axis in the horizontal.

If textural elements were present in Series A of Figure 25 at the same density as may have been present in those of Figure 24, much greater compression of the elements would be evident at orientations near the horizontal plane. With only the outline form shown, certain orientations may be noted to give rise to forms similar to those of Figure 24. Evidence suggests observers would treat that figure of Figure 25 as similar to that of a like form in Figure 24.

This would account for the hypothesized differences between form types measured in the frontal plane, ie. circle, 4 x 5 ellipse, and 2 x 5 ellipse. If form type accounted for differences reported in the data presented above, one would prefer to discuss variables measured in the frontal plane. But this was not the case. As pointed out above, four responses functions describe the data, where not more than three geometric

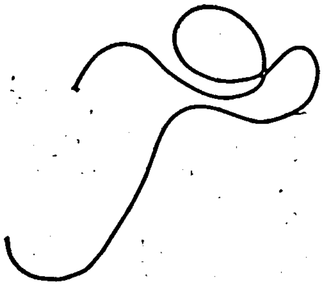
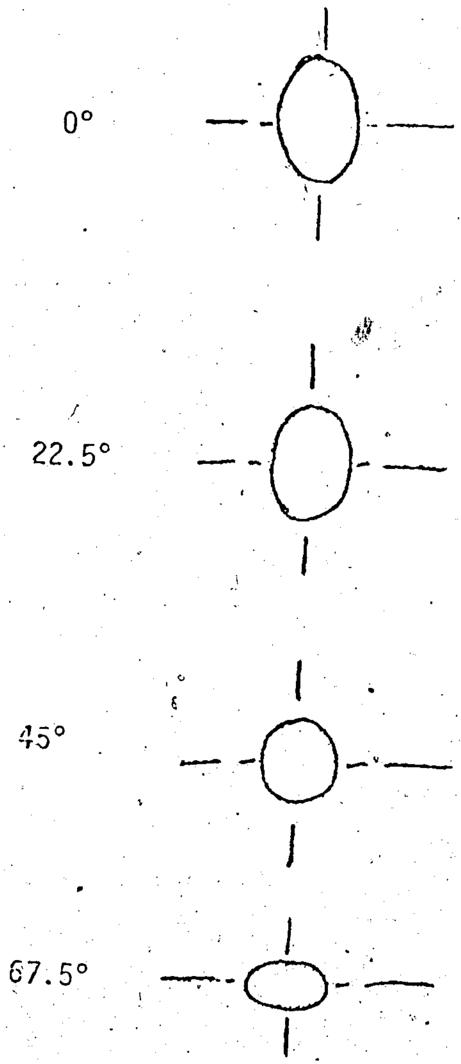


Figure 25. Rotation of an ellipse on the minor axis. Four orientations from the frontal plane are represented - 0°, 22.5°, 45°, and 67.5°. The minor axis is placed in the horizontal plane.

FIGURE 25

SERIES A



descriptions should have been necessary.

The error invariance hypothesis would have been appropriate if the three geometric functions were to describe the data. Compensation of shape and slant should yield the three geometric functions. Appendix I shows the data, collected in this study, graphed in the error invariance tradition. In no cases were predictions of the error invariance hypothesis realized. No strict relationship was found between error in perceived shape and error in perceived slant.

Indeed, large errors in slant were compensated by small errors in shape. Much larger errors in both shape and slant were in the same direction, ie. overestimation of under-estimation. The condition is directly opposite to predictions to the error invariance hypothesis.

Measures of environmental information developed in the past have usually been comprised of abstract systems. Empirical measures have not been widely developed. Considerations of psychological and physical invariance provides a basis for an empirical measure of environmental information not relying on abstract or a priori assumptions. Comparison of two sets of measures gives a direct correspondence, which in turn will be shown to reflect the information presented to an observer in any given array.

Physical invariance, as described above, may be plotted as a cosine function relating inclination and impingement of the specified form. Psychological invariance or the response function relating shape and slant may be plotted in the same manner. As suggested in the ntroduction, the area between the two functions may be measured and that area used to assign a value to the information presented to the observer.

Data of this sort was presented above in the Results section. Inspection reveals the outline condition to provide the subject with the least information, with the foreground condition providing the greatest. Contrary perhaps to predictions of Gibson (1950), the surface condition provided slightly more information than the condition with the texture surface. However, there were not large differences between the response functions given with the surface and texture conditions. The textural elements present in one case did not appear to affect the results. Within target-shape groups, consideration of proportion presented to the observer, ie. minor/major axis ratios, at given orientations appears to more reliably predict functions which will give unique correspondence between physical and psychological invariance.

Within the analysis made here, environmental information is carried by those variables attributed to the distortion of a horizontal view or an edge, ie. simple proportion and symmetry. The empirical measure becomes simple and is expressed as the area between the psychological or response function and the physical function described graphically.

The target-surface conditions used are secondary to the primary variables, but effect response to the various arrays. Thus, four response functions, given in Figures 20 - 25 (outline, surface, texture, and foreground conditions graphed over three target-shapes), represent alteration of the response to simple proportion and symmetry by the changing textural elements.

FOOTNOTES

[1] Equations for an ellipse are simplest when the curve is centered on the origin and the major axis lies along either the x- or y-axis. With the foci on the x-axis, the formula is:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1.$$

With the foci on the y-axis, the formula becomes:

$$\frac{x^2}{b^2} + \frac{y^2}{a^2} = 1.$$

[2] Some authors demonstrate circles and ellipses as cross-sections of right circular cylinders (Taylor, 1959) while others suggest cross-sections of cones (Hoelscher & Springer, 1956). Either will produce figures representative of target shapes used here.

[3] Leonard (1951) notes that a theory of measurement is a general theory considering the characteristics of a range of qualities, and that while any range of qualities may be considered for theoretical treatment, it is always some one range that is under actual consideration (Nelson & Bartley, 1961). Leonard (1951) outlined what appears to be involved prior to actual measurement as follows:

1. Isolating a range, L, of qualities that will be treated in the system.
2. Isolating the range, K, of objects that are the potential or actual possessors of these qualities.
3. Setting up operational criteria for determining what qualities in L are possessed by what numbers of K.
4. Establishing the conventional arithmetic notation by which possession of qualities in L by members of K will be recorded.
5. Ascertaining enough about K and L to fix the limits of significant mathematical transformation.

[4] <u>Inexist</u> is not found in unabridged dictionaries. Further, <u>inexistent</u> has two opposing meanings. Thus, Brentano's connotation must be taken from context.

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Appendix I

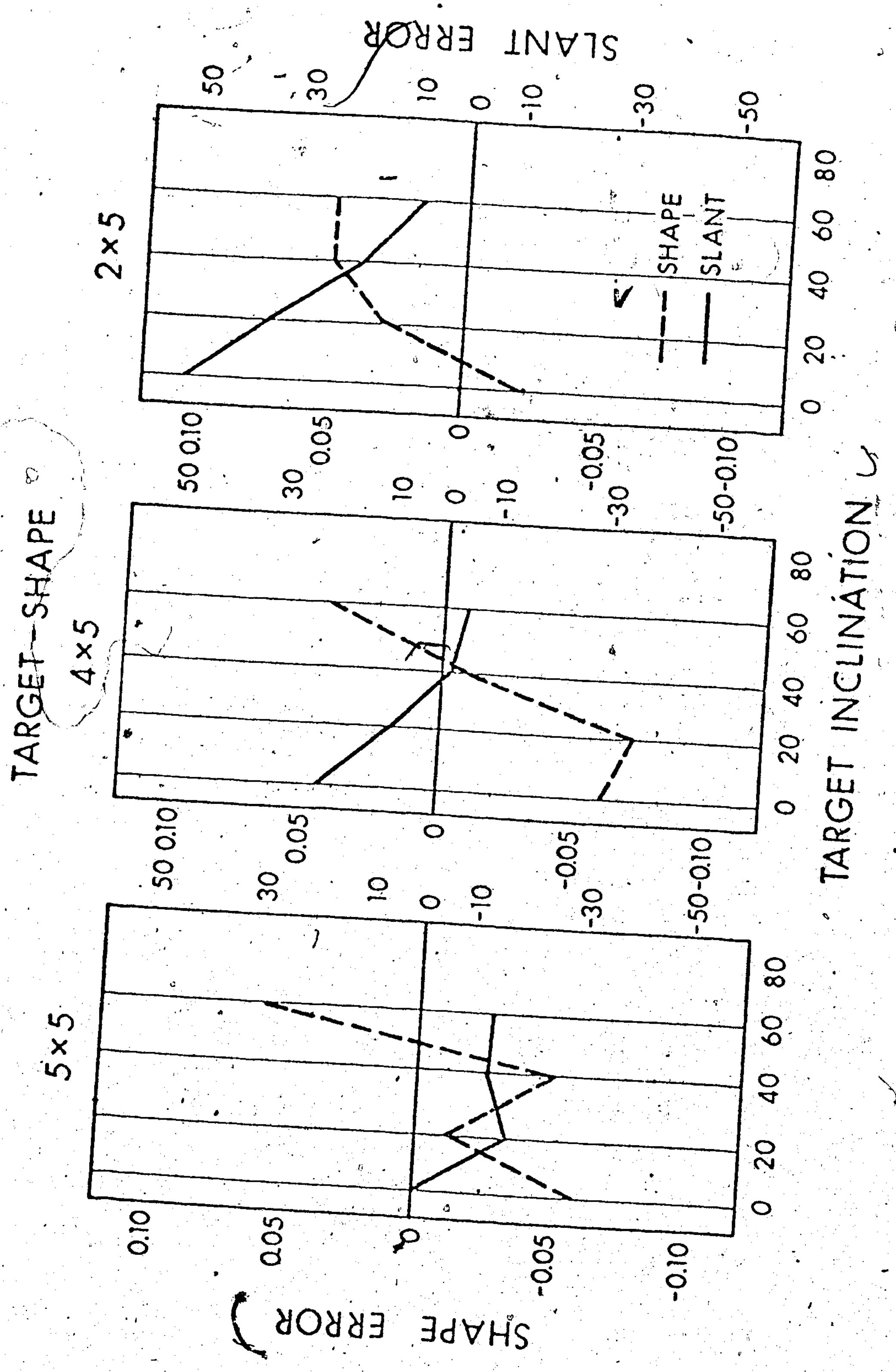
Shape and slant response is graphed as an error value. Shape error (broken line in each graph) is defined as shape response - impingement, with both values expressed as minor/major axis ratios. Slant error (solid line in each graph) is defined as slant response - inclination, with both values expressed as degrees from the frontal plane. The values pertaining to shape error are given on the left vertical axis of each graph. Slant error values are given on the right. Positive values (top half of each graph) indicate shape and slant values were greater than the corresponding impingement and inclination values, respectively. Hence, overestimation of shape and slant. That is, shape was judged as more circular and slant as more tilted than experimental conditions provided. Negative values (bottom half of each graph) indicate the reverse, or underestimation. Values along the horizontal axis indicate inclination of the targets, with the four vertical lines on each graph describing the four specific target inclinations used, ie. 0°, 22.5°, 45°, and 67.5°.

Figure 1 shows shape and slant error for three target shapes (5 x 5, 4 x 5, 2 x 5) with the outline condition, Figure 2 with the surface condition, Figure 3 with the texture condition, and Figure 4 with the foreground condition.

For the error invariance hypothesis, the error in shape response should be compensated by an error in the slant response to the extent that the two error values will correspond to impingement and inclination values on the Euclidean cosine function representing the initial form used.

That is, if errors are evident in the responses, the error invariance hypothesis would predict that the form given by the response values would fall into the infinite class of forms a single form can take with changes in inclination.

Observing the data graphed in Figures 1 - 4 reveals that the error invariance hypothesis is not upheld. The error values of shape and slant do not provide a conceptual form which would be given by other values of a cosine function. For example, consider Figure 1 and the 5 x 5 target-shape. The -.06 error in shape at a target orientation of 0° would require a slant error of +20° to fall on the cosine function. The slant error is in fact only +1°. At a target orientation of 22.5°, the shape error of -.01 requires a slant error of +3° when in fact the slant error is -16°. This is found to be true throughout all the data.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2×5
SHAPE ERROR
SLANT ERROR
TARGET INCLINATION
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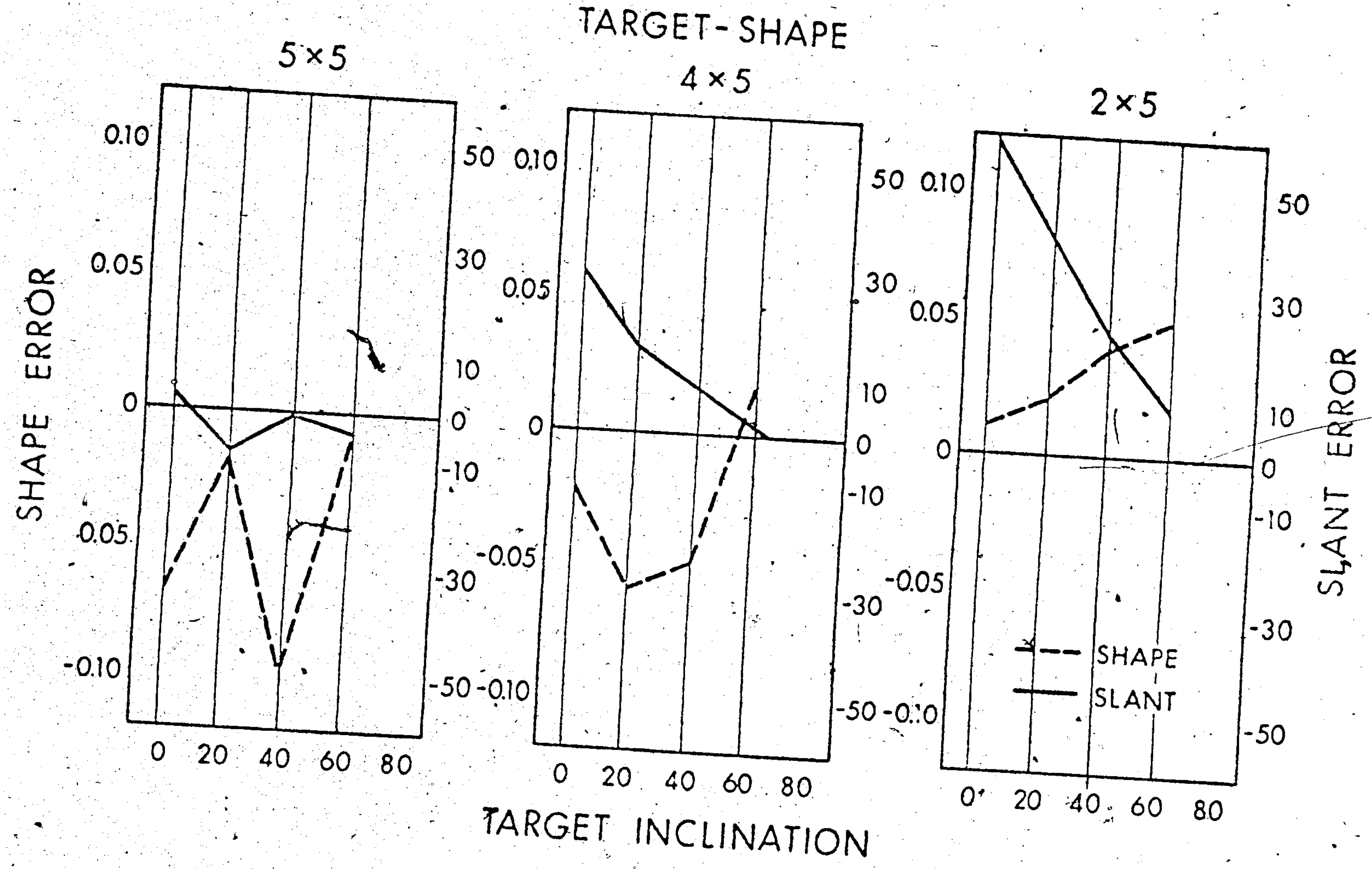
SHAPE
SLANT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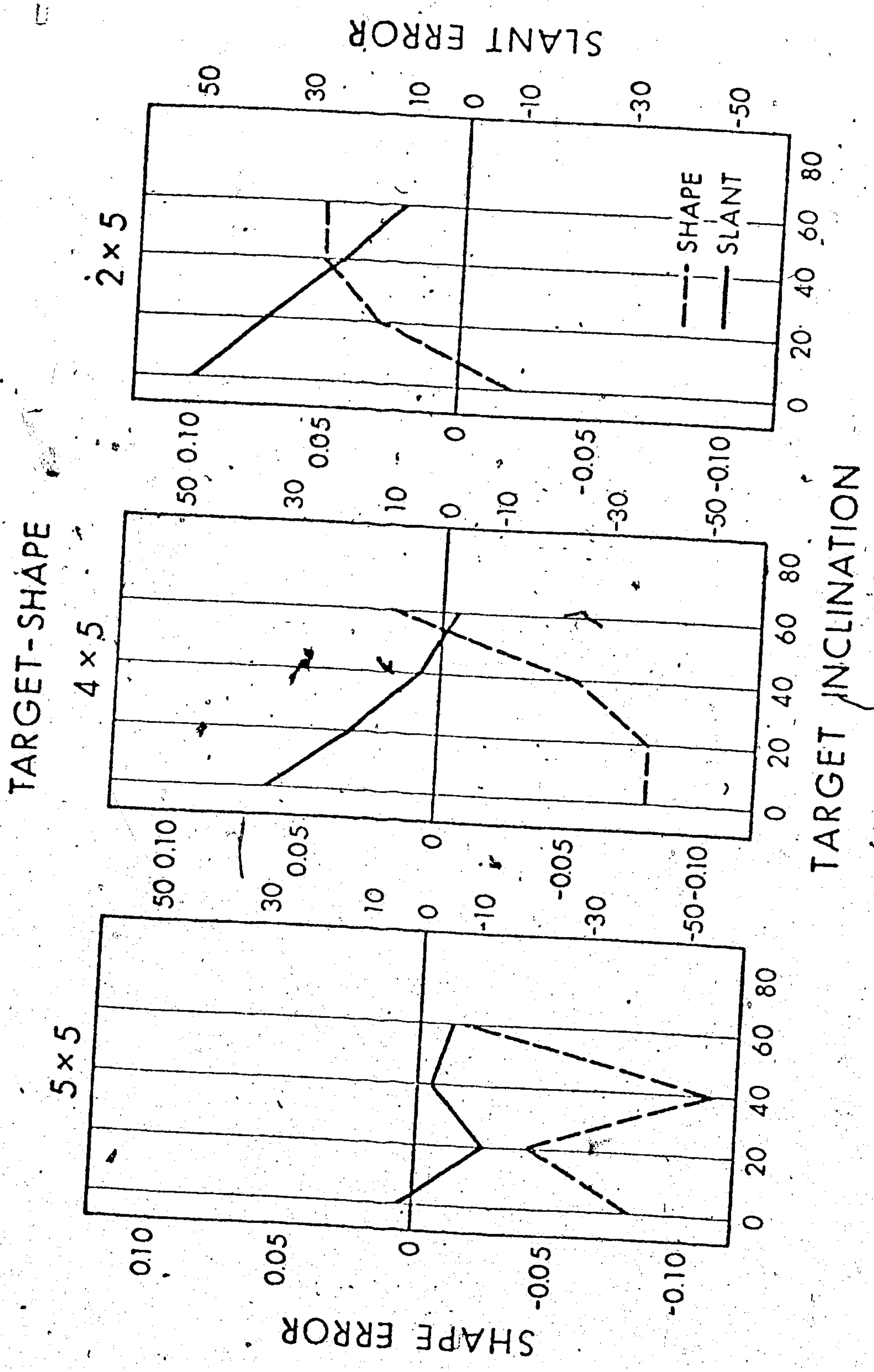
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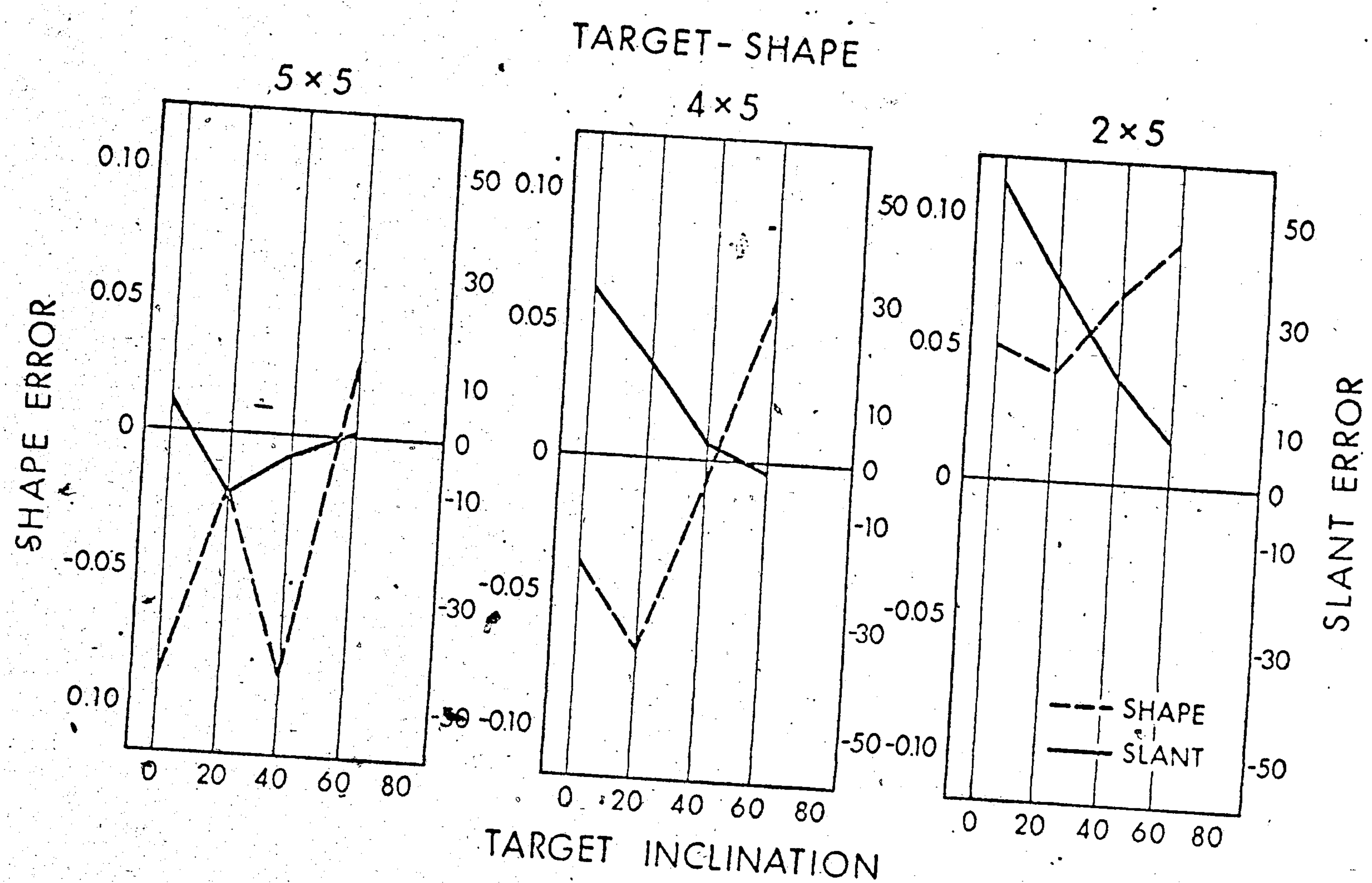
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