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THE INFLUENCE OF THE VISUAL FIELD UPON THE VISUAL VERTICAL IN RELATION TO OCULAR TORSION OF THE EYE

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TABLE OF CONTENTS

	Page
LIST OF TABLES	v
LIST OF ILLUSTRATIONS	vii
Chapter	
I. INTRODUCTION	1
II. THE PLAN OF THE EXPERIMENT	27
III. RESULTS	42
IV. DISCUSSION	75
V. SUMMARY	105
REFERENCES	107
APPENDIX	114

LIST OF TABLES

Table Page

1. Symbols Representing the Seven Visual Fields . . 24

2. Means and Variances for the Estimates (in Degrees CW) of the Apparent Verticality of the Rod for the Seven Visual Field Conditions for the Last Ten Trials[a] 43

3. Summary of Analyses of Variance on the Measures of Estimates of the Mean Apparent Vertical . . . 45

4. Mean Differences Between Visual Fields on Estimates of Apparent Verticality for the Newman-Keuls and Tukey (a) Tests 47

5. Means and Variances for the Maximum Estimates (in Degrees CW) of the Apparent Verticality of the Rod 49

6. Summary of Analyses of Variance on the Maximum Estimates of the Apparent Vertical 50

7. Mean Differences Between Visual Fields on Maximum Estimates of Apparent Verticality 51

8. Intercorrelations Between the Visual Field Conditions on Mean Estimates of the Apparent Vertical 55

9. Correlations Between the Mean Difference Estimates on the Vertical for the Visual Field Conditions and the Average Deviation on the RFT 57

10. Means and Variances for the Mean Ocular Torsion. 60

11. Summary of Analyses of Variance on Measures of Mean Ocular Torsion 62

12. Group Differences on Ocular Torsion for the Seven Visual Fields 64

13. Summary of Analyses of Variance on Measures of the Maximum Ocular Torsion 67

14. Correlations Between the Difference Estimates on the Vertical Judgments and the Maximum Ocular Torsion 69

Table | Page

15. Summary of Analyses of Variance on the Mean Number of Ocular Torsions Per Visual Field Conditions 72

16. Intercorrelations Between the Visual Field Conditions on Measures of the Maximum Ocular Torsion 74

17. Correlations Between the Mean Difference Estimates of the Vertical for the Visual Field Conditions and the Average Deviation on the RFT for all Subjects (20) and for Field Independent Subjects (17) 87

LIST OF ILLUSTRATIONS

Figure | Page

1. Scaled Perspective the Apparatus Used to Measure the Apparent Vertical 31

2. Example of the Random Double Staircase Method Employed in the Present Study to Measure the Apparent Vertical 39

3. Mean Estimate (in degrees CW) of the Apparent Vertical from the Physical Vertical for the Seven Visual Fields 46

4. Mean maximum estimate (in degrees CW) of the Apparent Vertical from the Physical Vertical for the seven visual fields 53

5. Mean Amount of Ocular Torsion for the Seven Visual Fields 63

6. Mean Amount of Maximum Ocular Torsion for the Seven Visual Fields 68

7. Mean Amount of Maximum Ocular Torsion and Maximum difference in Apparent Vertical from Control for the Seven Visual Fields 96

THE INFLUENCE OF THE VISUAL FIELD UPON THE VISUAL VERTICAL IN RELATION TO OCULAR TORSION OF THE EYE

CHAPTER I

INTRODUCTION

Numerous studies have demonstrated that one's perception of the visual vertical is a complex function involving a variety of sensory and motor data: vestibulo-kinesthetic cues (Mann, Berry and Dauterive, 1949; Passey, 1950; Gloster, 1953; Woellner and Graybiel, 1959; Schone, 1964; Udo de Haes, 1970), somesthetic cues (Schone and Udo de Haes, 1968), auditory cues (Glick, 1966), visual field cues (Asch and Witkin, 1948; Witkin, 1950; Wertheimer, 1912) and subject variables such as age, intelligence and personality (Comalli, Wapner and Werner, 1959; Davies and Leytham, 1964; Witkin, Lewis, Hertzman, Machover, Meissner, and Wapner, 1954).

A major area of investigation has been the determination of the mechanism(s) by which the visual field affects the observer's perception of the visual vertical, when that observer is in the upright position. A search for possible mechanisms has been dominated chiefly by one theoretical position, i.e., the Gestalt position that holds to the importance of the visual field and its orientation in serving as a cue or frame of reference (Koffka, 1935; Witkin, 1949; Witkin, 1950). In judging the orientation of an object, the object is compared with the general orientation of the visual field. The visual field serves as an external framework or reference orientation, producing a pattern of retinal stimulation which functions as the basis for the judgment of an object's orientation. According to this view the orientation of the sensory elements stimulated is of little importance in determining the apparent orientation of the stimulus object.

An alternative explanation is provided by those working on the peripheral mechanics of the eye. Rather than the visual field providing the observer with a conceptual frame of reference for object orientation, findings on ocular torsion suggest that the orientation of the visual field interferes with the functioning of the visual system at the periphery, i.e., retina (Brever and Kreidl, 1898; Brecher, 1934; Ogle, 1950). A peripheral approach to vertical orientation emphasizes the importance of the location of the retinal receptor fields and the invariant correspondence that exists between these receptors and the orientation of the external object for a given eye position. Thus, a specific external line will stimulate a rather specific line of retinal fields with the orientation of the external line being mapped in precisely the same orientation on the retina. If the position of the eye in its orbit changes, i.e., ocular torsion, there is a corresponding change in the orientation of retinal receptor fields. According to the peripheral approach this change of orientation of the retinal elements will then affect how the orientation of objects in space is perceived. Such a peripheral explanation could account for the tilting of the vertical that is perceived under many conditions of the visual field. It is quite possible that both mechanisms, peripheral and reference, are operating, interacting with each other as a function of the nature of the visual field. The two points of view are further discussed below because a chief purpose of this study is the investigation of these two possible mechanisms under various conditions of visual field change.

The aim of the present study is to investigate the influence the visual field has upon human subjects' estimates of the visual vertical, when that visual field either undergoes rotatory motion or remains stationary. Possible mechanisms, peripheral and/or reference mechanisms, involved in the visual field's effect upon perceived visual verticality will be examined by ascertaining the following: 1) the role of ocular torsion (i.e., cyclotorsion or rotation of the eye about the line of sight when the eye is fixating a center point) in accounting for the observed changes in the perceived vertical when rotatory motion and/or definite lines of orientation are introduced into the visual field, 2) the relationship that exists between a subject's estimates of verticality under conditions of a rotating visual background and under conditions of the standard rod-and-frame test (RFT). The proposed study will be concerned solely with visual effects on perceived verticality. Thus, all estimates of the vertical will be conducted with the observer in an upright position with stimulus cues other than those from the visual field held constant.

Background of the Problem

Before a more detailed presentation of the proposed study can be undertaken a review of relevant background material is essential. The question of how the human organism perceives vertical orientation and the reasons for nonveridical perception of the vertical has a long history.

Early History of Problem

In 1861 Aubert noted that when subjects regarded a stationary upright visual target, i.e., single luminous line in a darkened room, it appeared tilted when observed with the head inclined to the side. The apparent tilt was in the direction opposite from that of the head tilt and was considerable, amounting to 45^{o} when the head was tilted 90^{o} from its upright position (Aubert, 1861). Aubert's observations were further studied and quantified (Nagel, 1898; Cyon, 1902; Feilchenfeld, 1903; Sachs and Meller, 1901). Instead of using a stationary line, which made accurate measurement of the apparent tilt difficult, these later investigators used a slowly rotated line which the subject was to place at vertical.

Later, Müller (1916) reviewed the earlier work and introduced a specific nomenclature to describe the effects. He called Aubert's phenomenon the A-phenomenon and named a second effect the E-phenomenon. While Müller is often credited with the discovery of this E-phenomenon, it was actually first described by Nagel (1898). In the A-phenomenon the apparent tilt of the line is opposite to the direction of head tilt. That is if the head is tilted counterclockwise, the apparent vertical is set clockwise to physical vertical, whereas in the E-phenomenon the apparent tilt is in the same direction as head tilt. Müller noted that the E-phenomenon occurs when the head is tilted by small amounts whereas the A-phenomenon is found when the angle of head tilt is large. He also noted that the E-phenomenon is not found in all observers. Fischer (1927) showed that both pehnomena can occur when the head and body are tilted together, although the observed degree of vertical tilt is often different from that found when the head alone is tilted. The duration of adaptation while observing the line in the tilted body position also affects the results (Aubert, 1861; Müller, 1916).

The early investigators implicated a number of related mechanisms to account for their findings. It was apparent to most investigators that vestibulo-kinesthetic stimulation was involved. In 1898, Nagel demonstrated that electrical stimulation of the labyrinths caused apparent tilting of vertical lines and more recently Holst & Griseback (1951) showed that rotary stimulation of the semicircular canals also affects the apparent vertical. Such changes in gravitational stimulation were also investigated quite early. As early as 1820 Purkinje described in some detail the effects produced while he rode a merry-go-round. He stated that the individual involuntarily tilts his body to the center of the rotating platform in order to bring the long axis of his body into agreement with perceived vertical. Mach actually demonstrated this by constructing a centrifuge to measure changes in the apparent vertical under the influence of centrifugal and gravitational forces. He concluded that the organism automatically computes the direction of the resultant mass acceleration and regards this as the vertical (Boring, 1952).

More recent research has implicated ocular torsion as one of the mechanisms responsible for the tilt observed in the perception of the vertical under conditions of body tilt or changes in vestibular stimulation. John Hunter (1786; in Nagel, 1896) was the first to describe this phenomenon. This type of eye torsion has been called ocular countertorsion because it is a compensatory rotation of the eye in the direction opposite to that of the body tilt. It increases with increases in body tilt up to about 70 degrees producing a maximum of 7 to 10 degrees of countertorsion (Aarons and Goldenberg, 1964; Day 1969; Howard and Templeton, 1966; Udo de Haes, 1970). All the results indicate that the ratio of eye torsion to head tilt decreases as the angle of head tilt increases. Consequently, the normal vertical meridian of the retina is shifted in the direction opposite that of the body tilt. This effect corrects to some extent the effect of the body tilt which makes objects appear vertical when they are objectively tilted in the direction opposite that of the body tilt. However, countertorsion of the eyes cannot account for all of the observed changes in vertical estimates under conditions of postural changes. The magnitude of countertorsion, i.e., 8° to 10.5°, is often smaller than the observed change in vertical tilt. Nevertheless, the magnitude of the deviation in judgments of the perceived vertical when only visual factors are involved appears to be within the range subsumed by ocular torsion (Brecher, 1934; Greenberg, 1960; Hughes, Brecher and Fishkin, 1972).

Reference Theory

While there exists considerable recent interest in the study of non-veridical perception of the visual vertical under only visual conditions, there have been few attempts to investigate concomitant eye torsion. Quite early, Jastrow (1893) demonstrated that under normal visual conditions subjects could make very precise estimates of the visual horizontal and vertical. He believed that this was due to the fact that the human organism lives in a world of verticals and horizontals. Witkin and his collaborators have more recently demonstrated that the visual field is of importance in such visual orientation problems, and that the orientation of the visual field affects the perceived orientation of other visual objects placed in that field (Witkin and Asch, 1948; Witkin et. al., 1954). Thus an object appears vertical when it is tilted in the same direction as the visual field. These findings have been viewed by them as supporting the theory that the lines in the visual field serve as a frame of reference for the perception of orientation.

This position is essentially the same as that held by the early Gestalt psychologists (Wertheimer, 1912; Koffka, 1935). Koffka (1935) was of the opinion that one's precision in the perception of the visual vertical was due to the development of a visual spatial framework, an "anchorage in space". This "reference" theory was challenged by those who believed that postural cues were the chief determinents. For example, Gibson and Mowrer (1938) in discussing the perception of orientation in general state that:

> Both the visual and postural vertical are determined by visual and gravitational factors acting jointly, with orientation to gravity, however, as the more decisive factor in cases of real conflict between the two types of sensory data, and the primary factor genetically (p. 303)

Their criticism is well put and points to a definite limitation of reference theory to account for all of the observed findings in the area of orientation perception. Postural cues are important and do provide the organism with relevant feedback stimulation. However, their analysis tends to blur the problem when they treat visual and postural vertical data together. They do not ask the question of what factors are most relevant when the perception is purely a visual one and postural cues are eliminated or held constant. In visual judgments of the vertical the subject must attend to the visual data whereas in postural vertical judgments he can attend either to visual data, non-visual data or both. Thus Rock (1954) greatly reduced the salience of vestibular or postural cues by having subjects set a line parallel to their body axis while they were lying down on their backs. Subjects were about as accurate in their settings as they were when slightly tilted.

Although Gibson challenged the reference theorists on some points, he supported their contention that orientation of the retinal elements was unimportant in the determination of the apparent vertical. The Gestalt psychologists also were of the opinion that eye or retinal orientation was not a factor in the perception of the vertical, but for a different reason than Gibson. Koffka (1935) claimed that it was the visual field and its organization which led to the perception of verticality:

> The horizontal ground plane and the vertical upon it, then determine our framework. And no definite lines on the retina have the function of supplying us with framework; rather is this the function of the main lines of the total organization (p. 216).

As was mentioned previously, this view is essentially the same as the Witkin "reference" theory.

Gibson and Mowrer (1938) were of the opinion that ocular torsion could not explain the finding of shifts in the apparent vertical. They accepted the conclusion of Tschermak and Schubert (1931) which challenged the earlier findings of the existence of ocular torsion with reference to the perception of visual orientation in a centrifuge (Breuer and Kreidl, 1898). Breuer and Kreidl had concluded "It is certain, therefore, that the apparent tilting of the visual field is caused by a real, unconscious, counter-rolling (Raddrehung) of the eyes" (p. 315). However, Gibson and Mowrer (1938) in accepting the work of Tschermak and Schubert assert that "no strict relationship exists between the objective change in eye position and the location of the apparent vertical" (Gibson & Mowrer, 1938, p. 316).

It is important to emphasize that these early studies involved lateral acceleration in addition to visual field stimulation. Gibson and Mowrer may well have overgeneralized when applying their conclusion to results of studies in which lateral acceleration was absent. These two conditions are quite different because lateral acceleration introduces vestibulo-kinesthetic stimulation which does not occur otherwise. It is certainly possible that eye torsion may be a factor in one of these situations and not in the other. Yet, even this distinction is not completely warranted in light of recent research on the importance of the otolith organs for eye torsion. Woellner and Graybiel (1958,1959) compared the amount of countertorsion produced by tilting a subject with the amount of countertorsion produced by rotating the individual in a centrifuge. Amount of countertorsion was found to be a function of the force acting at right angles to the body axis in both cases, the effect being greater in the centrifuge. Schone (1962) has demonstrated that increased g enhances countertorsion, the amount of countertorsion being dependent on the shearing force in the utricle (stabolith) organ. Thus, Gibson's conclusions need to be reexamined in the light of these recent findings.

Even though Gibson, like the reference theorists, rejects the importance of ocular torsion his position with regard to the perception of the vertical is in sharp contrast to the reference theorists' emphasis on the importance of the visual framework. He states in another paper (Gibson and Radner, 1937):

> Neither the phenomenon of tilt adaptation nor the more basic fact of vertical-horizontal orientation of a line in the frontal plane would seem to be conditioned by the presence of visible reference lines in the field. Evidently we carry around with us our o own visual reference axis with respect to which a line may be seen as vertical or tilted; in short we possess a "sense" of visual direction. Judgment of visual uprightness or tilt under certain circumstances is absolute; a line perceived in another homogenous field has intrinsic direction (p. 456).

It is clear, as Gibson points out, that "reference lines" cannot be the only factor involved in determining verticality, for judgments of verticality are possible and can be quite accurate even in the absence of "reference lines". In fact Neal (1926) first pointed out that a line could be set to the vertical just as accurately when there was no frame present. As will be seen, the concept of "sense of visual direction" mentioned by Gibson can be integrated with a peripheral theoretical approach.

Peripheral Theory

A major thesis of the Gibson and Radner paper is that the concept of the visual field acting as a "cue" for the perceiver is not necessary. However, Gibson also opposes the peripheral explanation that changes in the position of the retinal elements account for orientation changes. Unfortunately, as mentioned above, Gibson treated the perception of verticality in a very general way, failing to separate such different perceptual problems as the postural vertical and the visual vertical. Thus, he does not distinguish, in his treatment of the visual vertical, those perceptions of the vertical that have a vestibulo-kinesthetic component from those that do not. This probably accounts for his rather general explanation of verticality perception: that man carries his own visual reference axis, providing a "sense of visual direction" (Gibson and Radner, 1937).

However, this explanation does not necessarily exclude the peripheral position. It is possible that Gibson's "sense of visual direction" is represented by the orientation of the retinal elements, and that the action of the visual field directly interferes with the orientation of the retinal system via uncompensated ocular torsion. Thus, the observed changes in the perceived orientation of a line might be the result of corresponding changes in the position of the retinal elements (retinal vertical meridian).

This peripheral explanation of the visual perception of the vertical is similar to Lotze's classical concept of retinal local sign (Boring, 1942; 1950). Each retinal field has associated with it a specific "space valve" which leads to that fields specific activation. Thus, the localization of an object in space is a function of the absolute retinal location of activation. This, of course, can be extended to include orientation perception, and can account for observed changes in the perceived orientation of objects when the orientation of the visual field is altered. It would necessitate that uncompensated ocular torsion occur. The result is that when the eye is torted 5^{o} clockwise, what is physically vertical will stimulate retinal elements that no longer represent the vertical meridian but have a space value which is 5^{o} counterclockwise from vertical.

Supporting a peripheral retinal explanation is the fact that visually induced torsional movements of the eye have been demonstrated in the absence of vestibulo-kinesthetic stimulation. Noji (1929) by gradually tilting a visual line upon which he projected a linear afterimage demonstrated small torsional movements of his own eye in the direction of the tilt. Brecher (1934) was able to induce larger torsional movements (4^{o} to 6^{o}) by rotating a 16 sectored black and white disc while having the observer fixate upon the center point of the disc. Torsion was in the direction of disc rotation. More recently

Howard & Templeton (1964) and Kertesz & Jones (1969, 1970) validated Brecher's earlier findings of ocular torsion by using more exacting measuring techniques.

However, in order to support a peripheral retinal explanation of shifts in the apparent vertical, it is necessary not only to demonstrate that a frame and/or a rotating background produce ocular torsion but also that rotating backgrounds affect the perception of the visual vertical and do so in much the same way as the frame. If ocular torsion mediates one's perception of the vertical then changes in ocular torsion should correspond with changes in the perceived vertical. Unlike the frame in the RFT which remains stationary, the rotating disc produces a visual framework which at best is unstable because of its constant shift in the direction of rotation. It is hard to see how such an unstable visual field could be used as a frame of reference, especially since it has been recently demonstrated that rotating sandpaper discs produce greater shift in the apparent vertical than spoked discs (Hughes et. al., 1972). Sandpaper discs due to their random structures are poor sources for frame of reference for either vertical or horizontal orientation. Yet, they produce effects on vertical judgment quite similar to those of the RFT. A demonstration of ocular torsion with disc rotation and also with the frame would support a torsional theory rather than a reference theory.

Ogle (1950) suggested that the findings of Noji and Brecher on visually induced eye torsion might account for the observed changes in vertical perception which occur after inspection of tilted visual stimuli, i.e., tilt after-effect (cf. Gibson, 1933). While Ogle's idea is similar to the peripheral position presented in this paper it differs in that the tilt after-effect to which he refers is an adaptation phenomenon. There is at present little evidence that mere inspection of a tilted object can induce ocular torsion. In fact Howard and Templeton (1964) showed that ocular torsion apparently does not occur in the tilt aftereffect. However, under the influence of a tilted frame Greenberg (1960) has shown that ocular torsion apparently occurs. He used the rather crude afterimage method of measuring eye position, a method questioned by Howard and Evans (1963). Although this is the only direct evidence bearing on the question of whether a tilted frame will influence eye torsion, Brecher's (1934) early observation that a rotating sectored disc produced both eye torsion and vertical displacement in the direction of disc rotation does provide some support for a torsional theory.

The Problem

A chief reason for the dominance of reference theory over peripheral retinal theory is the early experimental evidence against uncompensated ocular torsion. Tschermak and Schubert (1931) were unable to replicate the earlier results of Breuer and Kreidl, i.e., that ocular torsion is related to the apparent tilting of the visual field. As was discussed earlier, Gibson and Mowrer (1938) accepted this finding against the ocular torsion position and generalized it to the perception of orientation in general. However, this early research was concerned with the problem of verticality perception under conditions of lateral acceleration, and unfortunately was generalized to include other verticality conditions not including lateral acceleration.

One must be careful to avoid this same problem with respect to the present question under examination. The present study is interested in determining what mechanism(s) account for the changes that occur in the perceived orientation of an object when influenced by various visual fields. Yet, it should be realized that what has been termed the "visual field" in this paper has two main elements that can be separated from each other: motion and lines of orientation. First the visual field can be constantly moving with respect to the observer, i.e., rotating disc, or it can remain stationary. Secondly, the visual field can have definite lines of orientation, i.e., frame, or it can lack any definite lines of orientation, i.e., random patterned disc. While one mechanism could possibly explain the effect of both types of visual field influences upon verticality, it is quite conceivable that more than one mechanism is involved. This has been found to be the case when vestibulo-kinesthetic stimulation is introduced into the RFT (Day, 1969).

The frame of reference theory holds that it is the cues inherent in the visual field that determine the orientation of objects, retinal orientation or eye movements being unimportant.

A rotating visual field, especially the spoked discs that have been used, contains cues for orientation despite the fact that it is in motion. This motion of the visual field merely makes the determination of the cues in the field more difficult. The crux of the problem is not whether ocular torsion occurs, but whether it can account for the resulting perception. The proponents of the reference theory say "no" and the peripheralists say "yes".

Although it is certainly conceivable that an observer uses the visual field as a cue to an object's orientation, a demonstration that a more basic physiological explanation, such as change in retinal orientation via ocular torsion, can account for the effects of a rotating visual field, would constitute empirical support for this alternative physiological explanation. If it can be further shown that a close relationship exists between a subject's estimate of the vertical under conditions similar to Witkin's rod-and-frame test (RFT) and under the condition of a rotating disc, and that ocular torsion occurs in corresponding amounts for both situations, then the ocular torsion hypothesis can be extended to include the influence of non-moving visual fields upon nonveridical perception of the visual vertical. Of course, it should be realized that even with this model the visual field must serve as a cue. It is a cue which induces ocular torsion of the eye. The important point is that if such relationships are demonstrated then a peripheral mechanism of eye torsion must become an essential part of any theory which tries to account for such phenomena.

Although the peripheral theory is tenable and has some support when the visual field is in motion, it seems less tenable when the visual field is stable and has definite lines of reference. Yet, it is possible that ocular torsion does occur under the influence of such stable visual fields and that the torsion effect is highly correlated with behavioral verticality judgments, but that it is not of sufficient magnitude to account for all of the behavioral data. Thus, both reference cues and ocular torsion might interact together in producing the perceived orientation of an object in the stable visual field. Possibly, ocular torsion is the principal mechanism when the visual field is in motion, providing no obvious lines of reference for orientation. Reference cues may become more important when the visual field is stationary and definite lines of reference exist, i.e., frame. Furthermore these stable cues in the visual field might be utilized more by some observers than by others.

The interesting findings of the Witkin group (Witkin _et_. _al_., 1954; and Witkin et. al., 1962) concerning results on the RFT might be examined in terms of a dual mechanism approach. They found what they called "field dependent" and "field independent" perceivers. With a fitted frame, the latter showed little change in the apparent from the physical vertical whereas the former showed large differences. The reference theorists believe that the field independent perceiver relies on "internal cues" to maintain constant perception of the vertical, these internal cues being relatively independent of the of the position of the frame.

This concept of "internal cues" of reference is very similar to Gibson's "sense of visual direction" (Gibson and Radner, 1937) and might well be represented by the orientation of retinal elements, changing as a function of ocular torsion. Thus, the field independent individual's perception of the vertical can be mainly the result of changes in the orientation of the retinal elements via uncompensated ocular torsion. The field dependent individual might also rely on ocular torsion, but in addition might utilize the orientation cues in the visual field to a greater degree than the field independent observer. A chief purpose of this study is to discover whether both these possibilities occur, whether only one mechanism is responsible for all effects, or whether one mechanism holds for one type of visual field influence and the other mechanism for the other type of visual field. Unfortunately there is almost no research investigating these various alternative possibilities.

A dual mechanism approach to the field independent, field dependent dimension fits in a general way the behavioral data obtained from RFT research. An average deviation from the physical vertical of 10^{o} or more has been set as the dividing point between the two groups when viewing a frame tilted 28^{o} from the physical vertical. This average deviation of 10^{o} is close to the physiological limit of ocular torsion, and points to the fact that any deviation greater than this must be the result of factors other than ocular torsion. Further, it has been observed that rotating discs do not result in deviations from physical vertical greater than 10^{o}. Hughes et. al. (1972) did find that some subjects had deviations as great as 8^{o}, but not many. Ocular torsion could, thus, easily account for their results.

Results from many RFT studies, using large numbers of subjects, reveal that less than 5% of the subjects tested can be classified as field dependent (Vaught, 1971). In other words, 95% of the population is field independent, relying on "internal cues" of reference. It appears that if a peripheral mechanism is responsible for these internal cues then it is by far the major mechanism accounting for the observed results in the majority of observers. It may be more appropriate to view the field dependent, field independent dimension as a continuum with those observers revealing small shifts in the vertical relying mainly on ocular torsion and those exhibiting larger shifts relying on ocular torsion plus external cues. The greater the shift in the apparent from the physical vertical the greater the contribution of external cues to the individual's perception of the vertical.

A number of predictions might be generated from such a dual mechanism approach. One would predict that a positive correlation exists between what a subject perceives as vertical and the amount of shift in the vertical judgment not accounted for by the magnitude of the ocular torsion (i.e., difference score representing the observer's deviation from the physical vertical minus the amount of ocular torsion). Thus, subjects perceiving large shifts in the vertical will rely more on external cues and have a greater discrepancy between their amount of ocular torsion and their judgment of the apparent vertical. Those having small shifts will have much less discrepancy.

It is also expected that subjects viewing a visual field containing simultaneously a frame tilted 28^{o} counterclockwise and a clockwise, rotating disc will be more influenced by the cues in the frame than the ocular torsion produced by the disc if they fall more on the field dependent side of the continuum. Thus, we can expect less shift from physical vertical for field dependent subjects under this condition, with those on the field independent side of the continuum having greater shifts. This assumes that the rotating disc produces more torsion than the frame, resulting in an overall effect in the direction of the disc rotation when the more stable external cues of the frame are not considered. The more the external cues have an effect via the counter-clockwise oriented frame the less the total effect of the clockwise rotating disc in the opposite direction.

This use of various combinations of disc and frame presented alone or simultaneously in the same visual field, should help shed some light on the mechanisms involved in the visual perception of the vertical. If ocular torsion is the mechanism responsible when only a random, rotating visual field is employed, not being important when lines of orientation and/or stability are introduced, then one would expect maximum torsion when only the rotating disc is used. The adding of a frame tilted 28° in the direction of rotation of the disc would increase only the non-veridical perception of the vertical without further increasing the amount of torsion. With this agreement, the frame is adding to the vertical shift via a mechanism other than ocular torsion. However, if ocular torsion is important for both the frame and disc then increases in ocular torsion should occur for the frame/disc and even for only the frame when tilted. A dual mechanism of the type suggested above, i.e., one which uses ocular torsion to account for disc effects and ocular torsion plus reference cues to account for frame effects, predicts increased torsion when the frame is added to the visual field containing the rotating disc, but not of sufficient magnitude to account for all of the observed shift in the vertical.

The experiment which follows is designed to test and examine the particular points elaborated above, especially the validity of peripheral and/or reference theory in accounting for observed changes in the perceived vertical. The specific issues to be examined are the following: 1. The involvement of ocular torsion and/or reference cues in non-veridical perception of the vertical under the influence of a rotating visual field; 2. The involvement of ocular torsion and/or reference cues in non-veridical perception of the vertical under the influence of a visual field containing only a tilted vs. rectilinear frame: 3. The relationship of the subjects' non-veridical perception of the vertical with a rotating visual field or a frame to his perception of the vertical on the standard RFT; 4. The involvement of ocular torsion and/or reference cues in the perception of the vertical when the visual field contains both frame and disc under various conditions, i.e., disc stationary with frame rectilinear, disc rotating CW with frame rectilinear, disc rotating CW with frame tilted 28^{o} CCW and disc rotating CW with frame tilted 28^{o} CW.

The following hypotheses will be examined and tested by the appropriate statistical tests. Table 1 presents the symbols to be used for the seven visual field conditions.

Apparent Verticality

Hypotheses 1: The various visual fields will produce significant differences in the orientation of the rod to apparent vertical i.e., significant one way analysis of variance.

1a. The RCW, TF, RD fields will have the greatest effect, i.e., shift, on the apparent vertical, in decreasing order of effect.

1b. The RF, SD fields will have no significant effects on the apparent vertical.

1c. The RCCW field will produce a conflict between the two types of fields, frame and disc, resulting in a compromise between them, such that the shift in the apparent vertical will be less than if only the RD or TF had been used.

1d. The RR field will produce a stabalizing effect resulting in less shift in the apparent vertical than the RD

TABLE 1

SYMBOLS REPRESENTING THE
SEVEN VISUAL FIELDS

Visual Field	Symbol
Rotating Disc	RD
Stationary Disc	SD
Rectilinear Frame	RF
Rotating Disc with CCW Tilted Frame	RCCW
Rotating Disc with Rectilinear Frame	RR
Rotating Disc with CW Tilted Frame	RCW
CW Tilted Frame	TF

field.

Hypothesis 2: Due to the similar nature of the perceptual task certain visual field conditions will have high intercorrelations between each other and others will have low intercorrelations.

2a. The RD, TF, and RCW fields will have the highest intercorrelations with each other.

2b. The SD and RF fields will not have significant intercorrelations with any of the visual fields.

The RFT and the Apparent Vertical

Hypothesis 3: The various visual fields will produce shifts in the vertical which significantly correlate with the subjects' average deviation from physical vertical on the RFT.

3a. The average difference score for (TF minus RF) will have the highest positive correlation with results on the RFT.

3b. The (RD minus RF) and (RCW minus RF) scores will also positively correlate with results on the RFT.

3c. The (RR minus RF) and (RCCW minus RF) scores will negatively correlate with the results on the RFT.

3d. The SD and RF scores will not correlate significantly with results on the RFT.

Ocular Torsion

Hypothesis 4: The various visual fields will produce differences in the amount of ocular torsion produced.

4a. The RCW and RD fields will result in the greatest amount of ocular torsion.

4b. The TF field will result in a significant amount of ocular torsion but of less magnitude than for the RD field.

4c. The RF and SD fields will not produce any significant amount of ocular torsion.

4d. The RCW field will produce a significantly greater amount of torsion than the RD field.

4e. The RCCW and RR field will produce a significant amount of torsion, but significantly less than the RD field.

Hypothesis 5: The ocular torsion produced by certain visual fields will be of an amount large enough to account for the changes in the apparent vertical.

5a. There will be no significant difference between the amount of ocular torsion for the RD field and the amount of difference for (RD minus RF) on the apparent vertical.

5b. There will be significant positive correlations between the RCW, TF and RD fields and their respective amounts of ocular torsion.

5c. There will be a significant difference between the amount of ocular torsion for the TF field and the amount of difference for (TF minus RF) on the apparent vertical.

5d. The amount of shift in the vertical for the TF field which is not accounted for by ocular torsion, i.e., (TF minus RF minus ocular torsion), will positively correlate with the respective results on the RFT.

CHAPTER II

THE PLAN OF THE EXPERIMENT

The present investigation examined subjects' estimates of whether a line was vertical or not vertical when viewed in conjunction with a visual field composed of a rotating or stationary disc and/or surrounding frame. Ocular rotation of the right eye was measured photographically to ascertain if changes in eye rotation were systematically related to subjects' estimates of the vertical.

The investigation was based on a previous study by Hughes, Brecher and Fishkin (1972) which had investigated the magnitude of non-veridical perception of the visual vertical when induced by various types of rotating discs. Previous to this study it had not been systematically demonstrated that a rotating disc had any effect upon one's perception of the vertical.

Hughes *et. al.* (1972) found that a number of variables produced significant changes in the subjects' estimates of the apparent verticality of a line moved toward the physical vertical. The speed of rotation of the background disc was highly significant with maximal vertical displacement occuring at 6 rpm. The direction of line movement, i.e., the line to be judged vertical, also had systematic effects in that maximal vertical displacement occurred when the line was moved toward the physical vertical in opposition to the direction of the disc rotation. The type of disc employed, i.e., spoke, spiral, sandpaper or white, made a significant difference in the subjects' estimates only when the line movement was opposite from the direction of disc rotation. It was also shown that rotating discs with inadequate stimulus contours (i.e., relatively contour free white field) produced no significant effect upon verticality judgments. Thus, the magnitude of shift of the apparent vertical increased in the direction of disc rotation with an increase in optical texture of the disc. As the number of black-white alternations across a retinal field increases per revolution of a disc, there is also an increase in effect upon the vertical estimate. It was found that a spiral disc, which produced only 2 alternations per revolution had the least effect, sandpaper the greatest effect, and a sixteen sectored disc an intermediate effect on the subjects' estimate of apparent verticality. Thus the disc containing the greatest amount of optical texture, i.e., the sandpaper disc, produced the greatest effect. This effect of sandpaper on the perception of the visual vertical is of importance for it demonstrates that a randomly patterned visual field, which does not emphasize any one specific orientation in its elements, is capable of inducing change in one's estimates of the vertical. Frame of reference cues for determining a specific orientation are essentially eliminated by the very nature of the disc.

Several of these findings were utilized by the author in planning the present experiment. The finding that 6 rpm rotation of a disc produced the maximum effect led to the use of this rotation speed throughout the present study. Incidentally, this speed is also within the optimal range for maximal firing of receptor units (Hubel and Wiesel, 1965, 1968; Campbell and Maffei, 1971). A random patterned disc was also employed in the present study; however, unlike sandpaper it had small black triangles randomly placed on it. The work of Hubel and Wiesel (1959, 1962, 1965, 1968) and the claim of Campbell and Maffei (1970) that the human visual system has an orientational mechanism similar to that found in the cat and monkey, suggested that triangles with their angled edges would elicit greater firing of receptor units.

One important change was made in the present design from that of the Hughes _et_. _al_. (1972) study. They had found that the method of limits, where the line to be judged is gradually moved toward the physical vertical, resulted in a significant interaction of direction of line movement with disc rotation. In the present study instead of the method of limits, a double random staircase procedure was employed. In this procedure the line is viewed only in a stationary position.

Subjects

Twenty subjects from University of Oklahoma general psychology classes participated in the investigation. Participation was voluntary and all subjects were paid $4.80 for the approximately two hour experimental session.

During recruitment, the subjects were informed that the experiment was perceptual in nature and involved the photographing of the eye. They were told that only subjects with normal, uncorrected vision were to be employed and that they would be tested by placing a typed page approximately 35 cm from the eye to see if they could read the print. The subjects ranged in age from 18 to 22 years of age ($\overline{X}$=19.5).

Apparatus

A specially designed apparatus containing all the various combinations of visual fields used in the investigation was built by the experimenter. The outer frame of the apparatus was composed of wood with a biting board firmly mounted at one end of the frame and the visual field with vertical line mounted at the other end. Figure 1 is a scaled picture of the apparatus as viewed from above.

The interior of the apparatus contained a black reduction screen which allowed the subject to view only the visual field and line when viewed from the biting board. The reduction screen presented only curved surfaces to the subject, thus eliminating any general orientation cues.

The visual field mounted at one end of the apparatus could be manually changed by the experimenter depending upon the experimental condition. A 12.7 cm diameter white disc

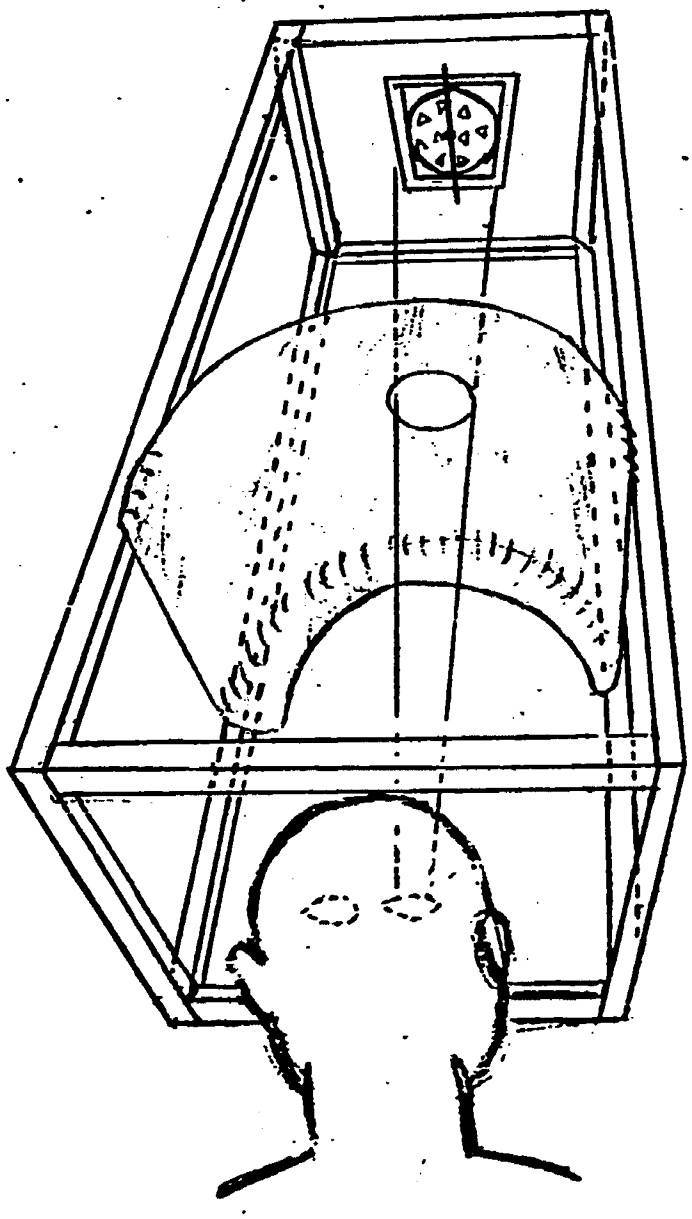

Figure 1. Scaled perspective of the apparatus used to measure the apparent vertical.

containing 4.8 mm sided equilateral black triangles was centered on the 3.2 mm diameter shaft of a synchronous motor. The motor rotated the disc clockwise at 6 rpm when a switch mounted on the apparatus was in the "on" position. The shaft of the motor, being also the center point of the disc, served as the center point of the visual field and was the point of fixation for all subjects. Centered directly behind the disc was a square white frame. The sides of the frame were 13.8 cm long and 6.0 mm thick. The orientation of the frame could be varied by the experimenter but its movement was independent of the disc's movement and thus did not rotate with the disc. If only the frame was to be in the field of vision a black disc was placed over the disc containing the triangles, with the result that it blended into the background and allowed view only of the white frame. The same could be done with the frame by placing a black reduction screen over the visual field so that only the disc was visible.

Mounted directly in front of the disc and shaft was a 15 cm long and 3.0 mm thick metal rod which served as the line for verticality judgments. The rod could be manually rotated with the center of rotation being coincident with the center point of the disc and/or frame. The angle of the rod with respect to physical verticality was determined by a scale placed on the back of the apparatus. The scale was marked off in one degree intervals and the rod could be changed by increments of one degree or more by the experimenter.

The biting board was mounted on the apparatus such that the right eye was approximately centered on the center point of the visual field at a distance of approximately 52.1 cm. The position of the head was held constant on the biting board by a dental impression mount which was fastened securely on the board. Dental impressions were made for each of the subjects directly before the experiment began by using alginate impression powder (Supergel).

A 35 mm single lens reflex camera with a 200 mm Medical Nikor lens and power pack was used to photograph the right eye. The lens was placed at a 45^{o} angle to the right of the eye, at approximately 34 cm distance from the eye. Reproduction (the ratio of film object size to physical size) was set at 2/3, and Plus X black and white, ASA 125, film was employed for all pictures.

A standard luminous rod-and-frame (Research Instrument Laboratories Model V-1260) was also used in the study and was positioned 12 feet from the subject.

Procedure

The procedure consisted of two parts. In one part all subjects were tested on the standard RFT in the dark with the frame tilted clockwise (CW) 28^{o} and/or counterclockwise (CCW) 28^{o}. The tilt of 28^{o} produces the maximum perceptual effect and has become the standard and accepted degree of tilt of the frame for the RFT (Vaught, 1971). A total of eight judgments were taken, four from each of the two stationary positions of the frame by the experimenter gradually moving the luminous rod toward the true vertical, twice from the CCW position and twice from the CW position. The subject was instructed to respond by saying "now" when the luminous rod appeared to him to be vertical. The RFT part of the experiment was given to half of the subjects (10) in the beginning of the experiment and to the other half at the close of the experiment.

The second part of the experiment involved testing the subjects on the specially designed apparatus with its various visual field displays. The visual field was varied in 7 ways with the specific order of presentation randomized for each subject. The content of the 7 visual field displays was as follows: 1. The randomly patterned disc viewed stationary (SD), 2. The randomly patterned disc viewed rotating clockwise (RD), 3. The white frame viewed in a rectilinear orientation without the presence of the disc (RF), 4. The white frame viewed in a 28° CW orientation without disc (TF), 5. The disc viewed rotating CW with the white frame in a rectilinear orientation (RR), 6. The disc viewed rotating CW with the white frame in a 28° CCW position (RCCW), 7. The disc viewed rotating CW with the white frame in a 28° CW position (RCW).

The subjects were told that they were to judge whether or not the stationary target rod appeared to them to be vertical as the rod was presented to them for inspection. Only the right eye was used, a black patch being placed over the left eye. After a dental impression was made of the subject's teeth and the biting board checked to make certain that it properly lined up the subject's right eye with the center of the visual field, the following instructions were read to the subject:

> "Look carefully at the center of the disc. Do you see the center point of this disc, the shaft? (E points to the center shaft). During each trial you are to keep your eye fixed upon this center point, try not to move your eye from this point. Do you understand? This rod (E points to it) is directly in front of the disc. I will be placing it in different orientations, one for each trial. I want you to tell me when it appears straight up and down or vertical, like the hands of a clock at 12:30 or 6 o'clock. For example, I'll have you close your eyes, you can close them now (E sets rod at 10^{o} CW), then I'll say open them, open them now. Tell me if the rod appears to you to be vertical. Just say "yes" if it does and "no" if it does not. I'm not interested in you taking a long time in deciding, just tell me as soon as you can. After answering I want you to close your eyes again, at which time I will reset the rod in another position. Then I will say open them and we will repeat the same procedure. We will be doing this for about 20 or 30 trials and then I will give you a rest. It is important that you keep your head from moving by keeping your teeth firmly on the biting board. I will tell you when you can rest. Two things are quite important. One, that you open your eye wide when I tell you to, and avoid blinking the eye. This is important because during some trials I will be photographing your eye, but not every trial. Secondly, always keep your eye fixed on this center point I mentioned, this shaft. O.K.! Now, do you have any questions?"

The subjects were reminded to keep their right eyes fixed upon the center point of the disc or frame and to open their eyes wide. At each trial the experimenter would say: "Open your eye wide; Is the rod straight up and down?"

Each subject went through approximately 30 trials for all seven conditions of visual fields with a five minute rest between each condition. Subjects were allowed to take their teeth from the biting board during these rest periods.

The double random staircase method was employed to measure the point at which the rod was observed to appear vertical. This method is rather efficient requiring the presentation of fewer trials than other psychophysical methods. It reduces many of the problems encountered in other techniques, such as subject biases. This method was used for all conditions and subjects (see Figure 2).

The method calls for the use of two staircases or series which are run concurrently. The choice of which of the two series is run on a particular trail is randomly predetermined by the experimenter. One series begins by having the rod at an extreme CCW position and the second series begins with the rod at an extreme CW position. Thus there is a CCW series and a CW series which are intermixed with each other, the determination of which series occurs on a trial being randomly predetermined.

The starting point for each series was between 9 degrees and 15 degrees from physical vertical, the actual position being randomly determined. Each series was composed of one degree increments or steps. Thus, if the series began at 12^{o} it would take 12 steps before it reached the physical vertical position. If the CW series is called for on trials 1, 3, 4, 6, etc., the CCW series on trials 2, 5, 7, etc., and each series starts 12^{o} either side of physical vertical, then the following presentations of the rod occur. On trial one the rod is presented to the subject with an orientation of 12^{o} CW and on trial two it is presented at 12^{o} CCW because this trial calls for the CCW series. The orientation of the rod after these two trials depends upon the response of the subject. Assuming during the first 7 trials the subject responds "no" as to whether the rod appears vertical or not vertical, then on trial 3 the rod would be moved one step closer to the vertical position, i.e., 11^{o} CCW, trial six 9^{o} CW, and trial seven 10^{o} CCW. It should be noted that on each trial the rod is viewed only in a stationary position, never when moving.

Suppose that on trial 14 the subject reports for the first time that the rod appears vertical at the 3^{o} CW position but still does not appear vertical for the CCW series which was at 2^{o} CCW on trial 13. This positive response by the subject on the CW series calls for a change in the presentation when next this series is to be presented. Thus if the CW series is to be presented on trial 16 the rod is <u>not</u> presented one increment closer at 2^{o} CW, as was previously done for "no" responses, but instead is presented one degree or increment further away from the vertical, i.e., 4^{o} CW. This change of one degree steps in the opposite direction is continued for this series only, until the subject again responses that the rod does not appear vertical. At this point the procedure of presenting the rod one degree closer is reverted to for each trial of this series.

This change in procedure does not affect what happens during the trials for the other series, for the two series are independent of each other in that the results on one series do not change the procedure for the other series. When a positive response is given for the other series then the new procedure of reversing direction is used. After 15 to 20 trials the two series come together and cross and recross each other. Variability of response begins to decrease greatly after each series has undergone about 2 reversals. At this point 10 more trials are given to the subject. Figure 2 presents an example for one subject on one of the conditions.

Prior to the start of each of the seven conditions the camera was focused on the right eye while the subject was biting the biting board. It was possible to focus the camera on specific episcleral blood vessels by means of a focus light mounted within the camera. The subjects did not know how many pictures would be taken during a condition, although he was told that one would not be taken every trial. For each subject 61 pictures or frames were taken, giving a total of 1220 frames for all 20 subjects. For each condition 9 frames were taken except for the conditions which had only the white frame in a rectilinear position or the disc in a stationary position. In these two conditions only 8 frames for each condition were taken.

At the start of each experiment black ink marks were placed on the boney area surrounding the orbit of the right eye. Superiorly one mark was placed on the skin surface of the frontal bone directly in the center of the eye brow; inferiorly one mark was placed on the center point of the

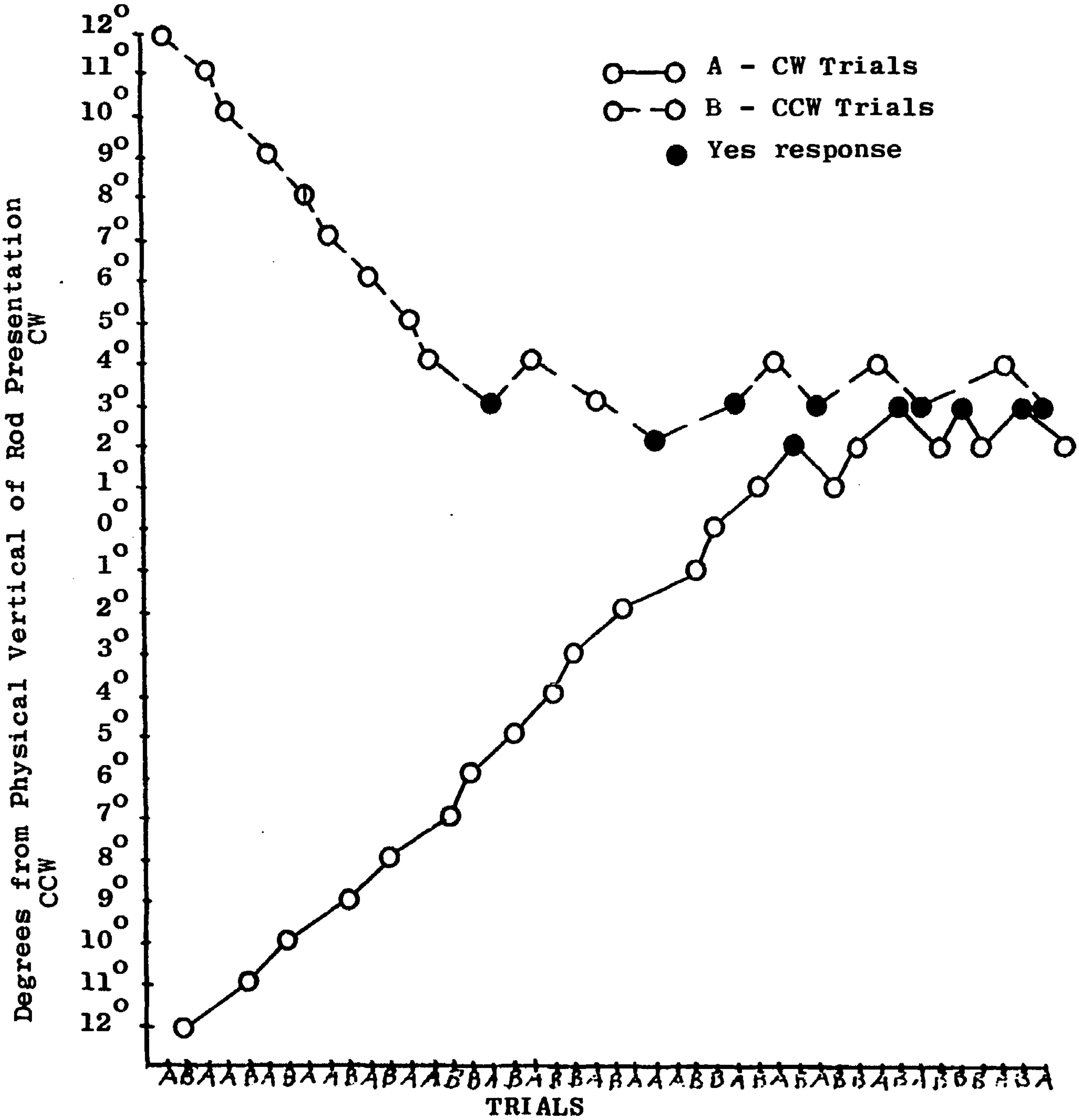

Figure 2. Example of the random double staircase method employed in the present study to measure the apparent vertical.

superior aspect of the maxilla bone where it marks the inferior wall of the orbit; and laterally one mark was placed midway between the other two marks but to the right of these on the surface of the zygomatic bone. These areas remain fairly fixed with respect to eye movements and therefore served quite well as anchor or reference points for the eye. One frame could thus be compared with another for the same subject by lining up the points for each frame with the points of the other frame. Prior to the first trial of each condition the white frame by itself was presented in a rectilinear position and the subject asked to fixate on the center shaft with his eye held wide open. A picture was then taken of the eye. This frame served as the control frame for the particular condition in which it was taken. The remaining eight frames that were taken for a specific condition were later compared with this control for measurement of ocular torsion. The experimenter was situated with respect to the subject such that he was able to observe clearly the right eye and avoid taking photographs during eye blinks. Subjects were encouraged to avoid blinking while the trial was in progress. The frames were coded for each subject by using arbitrary numbers in the bottom of the frame. The code numbers with the sequence of seven conditions associated with each code number were then consulted only after the measurements were made. This served as a good control for experimenter bias. The consistency of measuring was examined by remeasuring a sample of 120 frames.

The eight test photographs per condition were taken on specific trials the sequence being determined beforehand. Two sequences for taking photographs were used for each subject, one to be used on the even numbered visual field conditions and the other on the odd numbered conditions. The even numbered visual field conditions had photographs on trials 3,7, 11,15,18,22,25,29 and on the odd sequence trials 4,8,12,16,19, 23,26,29. These sequences provided for at least 2 non-photographed trials between photographed trials. Pictures were taken slightly before the response of the subject to the rod's orientation, approximately 3 to 6 seconds from onset of fixation.

Each of the seven conditions took approximately 10 minutes and the total experiment took about 2 hours and 5 minutes per subject.

In terms of the overall design, then, each subject participated in all seven visual field conditions and, in addition, was tested in a standard RFT. Various aspects of the data from the seven field conditions were then analyzed in terms of a one-way, seven level repeated measures analysis of variance. Other types of analyses were used as appropriate.

CHAPTER III

RESULTS

The results can best be presented by dividing them into three major categories as suggested by the hypotheses presented in Chapter 1, pp. 24-26: apparent verticality, RFT and the apparent vertical, and ocular torsion.

Apparent Verticality

The results on apparent verticality are concerned with the subject's behavioral response to the rod which is to be judged for verticality under the seven different visual field conditions. Two methods were employed in treating the raw scores from the subject's vertical judgments. One was to determine the mean point at which each subject judged the rod to be vertical by computing the mean of the last ten trials given to each subject for each of the seven visual field conditions (see p.37). The mean and variances for each visual field condition for the last ten trials are presented in Table 2.

Hartley's F_{max} test and Cochran's C test were computed and it was observed that the variances for the seven visual field conditions were homogeneously distributed (F_{max} = 2.77, df 7/19, ns; C=0.233, df 7/19, ns). Therefore a one way

TABLE 2

MEANS AND VARIANCES FOR THE ESTIMATES (IN DEGREES CW) OF THE APPARENT VERTICALITY OF THE ROD FOR THE SEVEN VISUAL FIELD CONDITIONS FOR THE LAST TEN TRIALS[a]*

	SD	RF	RD	RCCW	RR	RCW	TF
$\bar{X}$	0.44	0.46	1.03	0.83	0.58	1.60	1.49
S^2	0.09	0.10	0.14	0.12	0.18	0.21	0.25

[a]See p. 24 Table 1 for the meaning of symbols used for the seven visual fields. *See Appendix for raw score data.

analysis of variance was computed on the subject's estimates of the apparent vertical under the seven visual field conditions. The analysis of variance is summarized in Table 3. Inspection of the table reveals a highly significant F, and thus supports hypothesis 1 that the visual fields would result in significant differences in the perception of the vertical rod.

Hypotheses 1a through 1d predicted that there would be a definite order in the effect on the apparent vertical by the various visual fields. The RCW was to produce maximum shift in the apparent vertical followed by TF and RD (1a) with the RF and SD fields producing the least or not significant effect (1b). The RCCW and RR fields were to produce intermediate effects. Inspection of figure 3 which plots the means for the seven visual fields on the apparent verticality estimates supports these hypotheses. However, on computation of the Newman-Keuls Test, several of the means were found not to be significantly different from each other. The Newman-Keuls Test and the more conservative, i.e., smaller type one error, Tukey (a) Test are summarized in Table 4.

The use of the more conservative Tukey (a) test does not alter the conclusions except in the case of the difference between the RD and RCW groups. Inspection of the table indicates clearly the differences between the RCW condition and all other conditions except the TF, supporting the hypothesis that the RCW visual field causes greatest displacement of the rod

TABLE 3

SUMMARY OF ANALYSES OF VARIANCE ON THE MEASURES OF ESTIMATES OF THE MEAN APPARENT VERTICAL

Source	SS	df	MS	F[a]
Between Subjects	32.66	19		
Within Subjects	68.51	120		
Visual fields	26.43	6	4.605	12.48[a]
Residual error	42.08	114	0.369	
Total	101.17	139		

[a]$F_{.99}(1,19) = 8.18$, conservative probability estimate for within-subject effects, derived by assigning one degree of freedom to the replicated measure, i.e., visual fields and 19 degrees of freedom for the residual error (Winer, 1962, pp. 305-306).

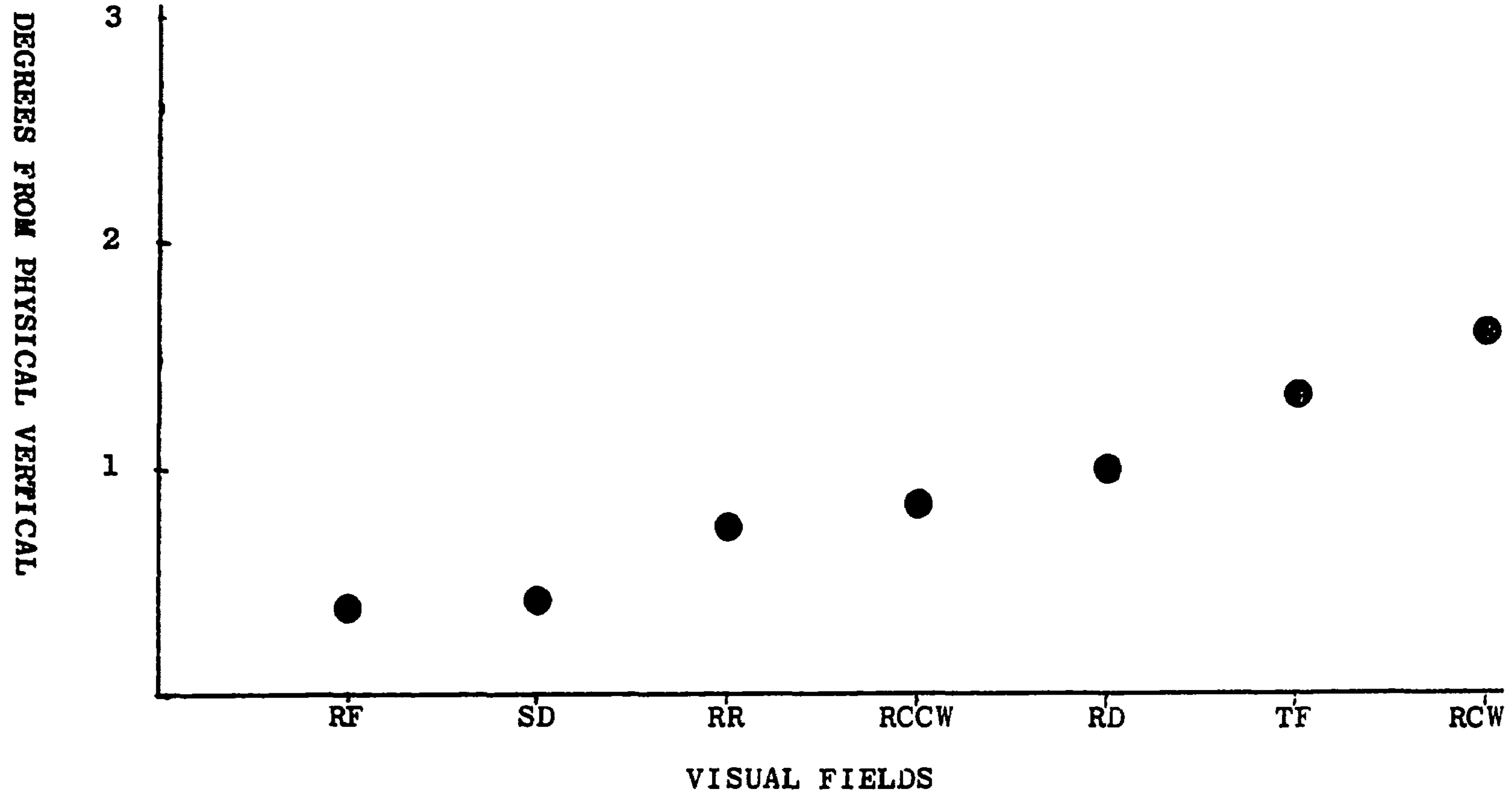

Figure 3. Mean estimate (in degrees CW) of the apparent vertical from the physical vertical for the seven visual fields.

TABLE 4

MEAN DIFFERENCES BETWEEN VISUAL FIELDS ON ESTIMATES OF APPARENT VERTICALITY FOR THE NEWMAN-KEULS AND TUKEY (a) TESTS

Visual Field	RF	SD	RR	RCCW	RD	TF	RCW
RF		0.48	2.84	8.30	11.85	18.90[a]	24.24[a]
SD			2.36	7.82	11.37	18.42[a]	23.76[a]
RR				5.46	9.01	16.06[a]	21.40[a]
RCCW					3.55	10.60	15.94[a]
RD						7.05	12.39[b]
TF							5.34
RCW							

[a] Newman-Keuls Test and Tukey (a) both significant at 0.01

[b] Only the Newman-Keuls Test significant at 0.01.

from the physical vertical. This is true also for the TF field which produced significantly greater shifts in the apparent vertical than the RF, SD, and RR fields. Judgments of verticality made in the RF and SD fields were not significantly different from zero, i.e., physical vertical, as predicted by hypothesis 1b.

Contrary to expectation the RD field did not produce a significantly greater shift than the RF, SD, RR, and RCCW but was significantly different from the RCW group. However, the use of Dunnett's *t* statistic to compare all means with a control is warranted in this case for the RF field actually served as a control condition. When Dunnett's test is employed the RD group mean is significantly different from the RF at the 0.01 level (t=3.13, df 7/114).

The use of *t*-tests for correlated means can be justified due to specific a priori hypotheses. When this is done the RD mean is also significantly different from the following means: SD and RR (t=3.52, df 18, p .01; t=3.02, df 18, p .05). Also the TF and RCCW means and the RCCW and RF means are significantly different from each other (t=2.72, df 18, p .05; t=2.11, df 18, p .05).

Another method was employed for treating the raw-scores from the verticality estimates. Rather than taking the mean of the last ten trials of each condition, the mid-point between the maximum reading for "yes" and "no" responses for apparent verticality was determined for each of the two series per condition and the mean of these two scores computed for each condition. This procedure tended to emphasize more the differences between the visual field effects, whereas with the first procedure there was an averaging out of some of the effects. Table 5 presents the means and variances for the seven visual field conditions under this second procedure.

TABLE 5

MEANS AND VARIANCES FOR THE MAXIMUM ESTIMATES (IN DEGREES CW) OF THE APPARENT VERTICALITY OF THE ROD

	SD	RF	RD	RCCW	RR	RCW	TF
$\bar{X}$	0.84	0.90	1.62	1.45	1.10	2.33	2.10
S^2	0.13	0.14	0.20	0.18	0.14	0.31	0.32

Hartley's F_{max} test and Cochran's C test were computed and it was observed that the variances of the seven visual fields were homogeneously distributed (F_{max}=2.46, df 7/19 ns; C=0.222, df 7/19, ns). A one way analysis of variance was then computed and is summarized in Table 6. Inspection of the results reveals results quite similar to those found under the first procedure. However, the computation of the Newman-Keuls and the Tukey (a) tests reveals more significant mean differences. Table 7 summarizes the findings. With this analysis, the effect of the RD field was significantly different from the RF and SD means. Also of interest are the findings with

TABLE 6

SUMMARY OF ANALYSES OF VARIANCE ON THE MAXIMUM ESTIMATES OF THE APPARENT VERTICAL

Source	SS	df	MS	F[a]
Between Subjects	40.38	19		
Within Subjects	78.59	120		
Visual fields	40.38	6	6.73	18.08[a]
Residual error	38.21	114	0.394	
Total	118.97	139		

[a] $F_{.99}(1,19) = 8.18$, conservative probability estimate for within-subject effects, derived by assigning one degree of freedom to the replicated measure, i.e., visual fields and 19 degrees of freedom for the residual error (Winer, 1962, pp. 305-306).

Dunnett's _t_ statistic that the RCCW, RD, TF, and RCW means all produce significantly different effects in the estimate of the vertical from either the SD or RF fields ($\underline{t}_{RCCW}$=3.06, df 114, $p<.01$).

Further, when correlated _t_-tests were computed, the significant mean differences observed under the first type of analysis were also significant. In addition, the TF and RCCW means were significantly different.

TABLE 7

MEAN DIFFERENCES BETWEEN VISUAL FIELDS ON MAXIMUM ESTIMATES OF APPARENT VERTICALITY

Visual Field	SD	RR	RCCW	RD	TF	RCW
RF	1.20	5.20	12.20	15.60[a]	25.80[a]	29.80[a]
SD		4.00	11.00	14.40[a]	24.60[a]	28.60[a]
RR			7.00	10.40	20.60[a]	24.60[a]
RCCW				3.[illegible]	13.60[b]	17.60[a]
RD					10.20	14.20[a]
TF						4.00
RCW						

[a]Newman-Keuls Test and Tukey (a) Test both significant at 0.01. [b]Only the Newman-Keuls significant at 0.01.

A third type of analysis of these data was undertaken. This approach was identical to the second one except that only data from the CCW series was used. When this was done the one way analysis of variance is also significant (F=12.20, df 1/114, $p<.01$). Further, when Dunnett's _t_ is computed using these data all means are significantly different from the two control fields, SD and RF. The smallest difference was for the RR field ($\underline{t}$=2.71, df 114, $p<0.05$).

In summary, the various visual fields appear to influence perception of the vertical in the general order predicted with the greatest shift in the vertical occuring when the visual field contains simultaneously a rotating field and a frame tilted in the same direction as rotation. Little, if any, effect on vertical perception occurs when the visual field is neither tilted nor in motion.

It is of interest to inquire which curve best fits the empirical data, given that the means be ordered as the data indicate, from smallest mean to largest. Figure 4 depicts the curve for the maximum estimates by the second procedure outlined above, i.e., mean of the mid-point of the maximum yes-no score for the two series. Tests for the best-fitting curve or trend were computed and only the first-degree or linear relationship was significant (F=100.61, df 6/114, $p<.01$). Of the total of 40.38 units of variation due to differences in complexity of visual fields, 39.64 or 98 per cent were predictable from the linear component. While such findings appear quite convincing it must be cautioned that not all of the statistical assumptions necessary for such curve fitting are met. Most important of these is a series of equal steps along an ordered scale (Winer, 1962). This problem will be treated at greater length in the next chapter where Kendall's W is discussed.

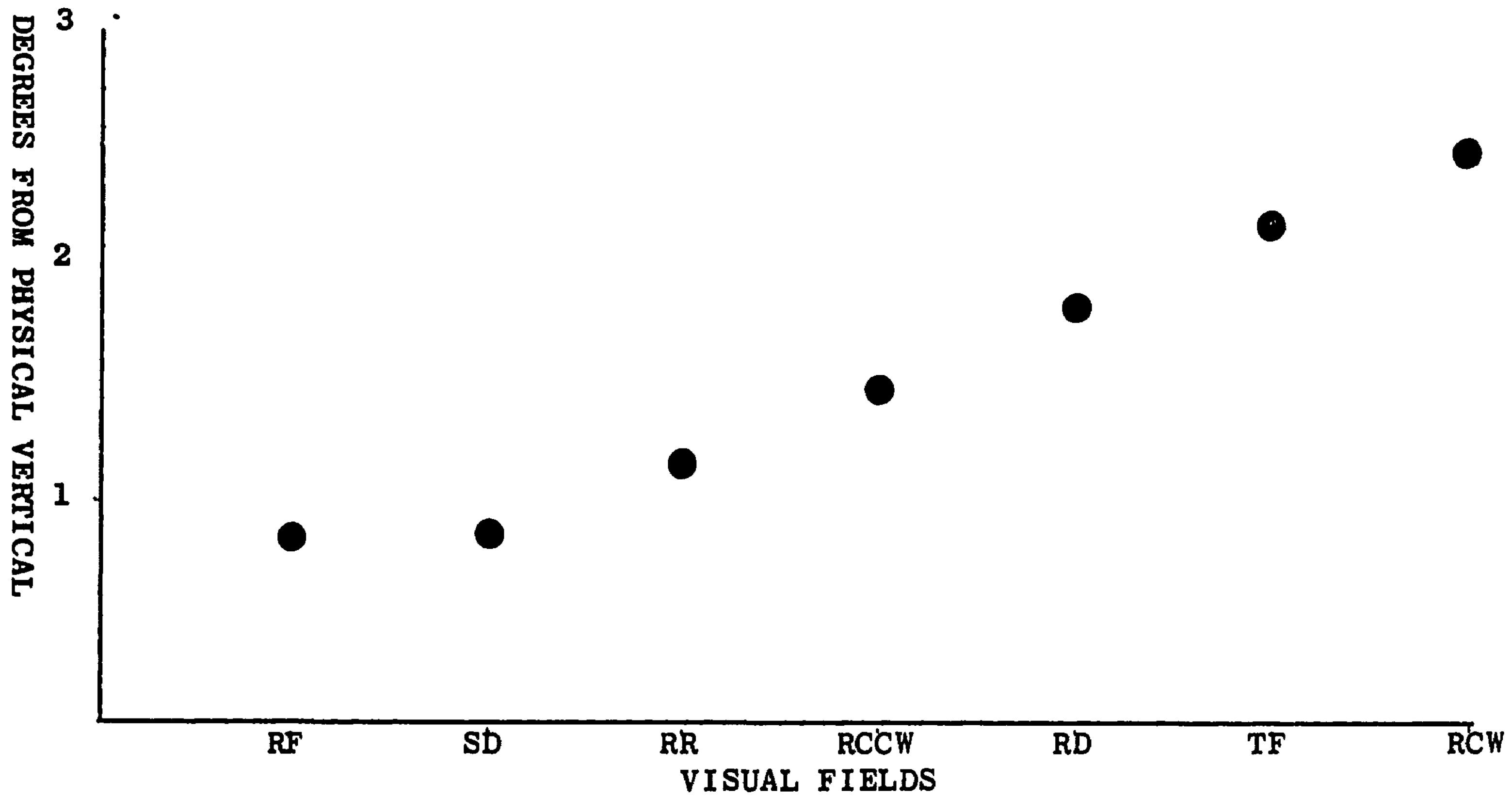

Figure 4. Mean maximum estimate (in degrees CW) of the apparent vertical from the physical vertical for the seven visual fields.

Inspection of the effects on vertical judgment of the different visual fields employed in the study suggests that the various degree of shifts in the perception of the apparent vertical are similar in nature. This raises the question of the degree of intercorrelation existing between perception of vertical in the seven visual fields. The intercorrelations among the seven fields based on mean estimates are summarized in Table 8. It can be observed that except for the two control fields (SD and RF) the intercorrelations are positive and significant, the highest correlations being between the TF, RCW, and RD fields (Hypotheses 2a,b). These are the same conditions which also resulted in the greatest shifts in the apparent vertical. It is noteworthy that with the exception of the control fields the RCCW and RR fields had the lowest intercorrelations with the other visual fields. This is what one would expect in view of the nature of these two visual fields, i.e., opposing frame and motion cues.

The RFT and the Apparent Vertical

In this section we are interested in how the subjects performed on the RFT and how their RFT performance relates to their perception of the apparent vertical in the other tasks. The mean deviation scores on the RFT had a range of 2.12 to 10.10. Only one subject or 5 per cent of the subjects could be classed as strictly field dependent, i.e., mean deviation score greater than 10. The average deviation score was 4.10 and the variance 4.40.

TABLE 8

INTERCORRELATIONS BETWEEN THE VISUAL FIELD CONDITIONS ON MEAN ESTIMATES OF THE APPARENT VERTICAL

Visual Field	SD	RF	RD	RCCW	RR	RCW	TF
Stationary Disc (SD)	1.00	0.12	0.15	0.04	0.15	0.20	0.13
Rectilinear Frame (RF)		1.00	0.11	-0.10	0.22	0.16	0.18
Rotating Disc (RD)			1.00	0.46^{c}	0.52^{b}	0.74^{a}	0.76^{a}
Rotating Disc with CCW Tilted Frame (RCCW)				1.00	0.42^{d}	0.39^{d}	0.26
Rotating Disc with Rectilinear Frame (RR)					1.00	0.48^{c}	0.38^{d}
Rotating Disc with CW Tilted Frame (RCW)						1.00	0.81^{a}
CW Tilted Frame (TF)							1.00

$^{a}p<.01$, $^{b}p<.02$, $^{c}p<.05$, $^{d}p<.10$

Hypotheses 3a-d state that certain visual fields will produce shifts in the vertical which will positively correlate with the average deviation from physical vertical on the RFT while other visual fields will correlate negatively, and some not at all. Table 9 summarizes these correlations between RFT and mean difference estimates on the vertical. Mean difference scores were obtained by computing the difference between the control field (RF) and each of the other six visual fields. These differences scores resemble more closely the deviation scores of the RFT. Inspection of Table 9 shows that the TF visual field results correlate highest with the RFT. This was predicted in hypothesis 3a and is to be expected with such similar visual fields. The fact that the RD field correlates highly with the RFT points again to the similar effect that rotating and tilted visual fields have upon vertical perception and suggests some overlap in the mechanisms involved in the alteration of apparent verticality in the two tasks. Thus as the tilted frame in the RFT produces greater shifts in the vertical, so too does the rotating disc.

The negative correlations found between the RCCW and RR fields with the RFT, even though of borderline significance, support tentatively the view that when the visual field is composed of conflicting or opposing visual stimuli, i.e., frame tilted in opposition to disc rotation, it is the particular mode of perception of the perceiver that determines which cues, frame or rotating disc, have greater relevance. Those perceivers that are closer to the field dependent side of the

TABLE 9

CORRELATIONS BETWEEN THE MEAN DIFFERENCE ESTIMATES ON THE VERTICAL FOR THE VISUAL FIELD CONDITIONS AND THE AVERAGE DEVIATION ON THE RFT

Visual Field	RFT
Stationary Disc	0.12
Rotating Disc	0.66[a]
Rotating Disc with CCW Tilted Frame	-0.43[b]
Rotating Disc with Rectilinear Frame	-0.35
Rotating Disc with CW Tilted Frame	0.58[a]
CW Tilted Frame	0.73[a]

[a] $p < .01$ [b] $p < .10$

continum, i.e., high RFT score, would be more global in their mode of perception taking into account cues produced by CCW tilted frame. These cues could serve to compete more with the rotating disc cues resulting in less of a shift in the apparent vertical. On the other hand those perceivers with low RFT scores, classified as field independent perceivers, are more analytical in their perception being less affected by external cues other than those which involuntarily induce ocular torsion. Since rotating discs induce ocular torsion to a greater extent than tilted frames, a finding to be presented later, one might expect greater shifts in the apparent vertical as a result of disc rotation. The negative correlations support this contention in that as the RFT score becomes higher indicating more field dependency, the shifts in the apparent vertical with the RCCW and RR fields become less.

In summary, perception of the vertical under various visual field conditions is directly related to mode of perception as defined by the RFT. A rotating visual field apparently influences one's perception of the vertical in a manner quite similar to that of the RFT even though the size of the correlations leaves room for other factors to enter in.

Ocular Torsion

As was previously discussed (pp. 39-40) 61 photographs per subject were taken of the right eye for use in measuring ocular torsion. Each condition had a control photograph taken while the subject was fixating on the center point of the RF visual field. The photographs for each condition were then compared with the control photograph by projecting them one at a time onto a specially prepared screen containing a polar coordinate grid. The grid was used to center the photograph and contained degree markings for determining changes in ocular torsion. The projection of the photograph served also to increase the size of the photograph by a factor of 8. By carefully marking down the position of 2 or 3 episcleral blood vessels from the control frame it was possible by use of the grid to determine any changes in the position of these vessels during testing. A new control photograph was used for each condition and the maximum and mean amount of ocular torsion, in degrees, determined. The experimenter had no knowledge of which condition the measures belonged to until after all measures had been completed. Of the 120 frames which were remeasured for ocular torsion only 7 had different measures for the degree of ocular torsion, six of one half a degree torsion and one of one degree torsion. Such consistency indicates a fairly reliable measuring technique.

The means and variances for the amount of ocular torsion per visual field are presented in Table 10. Cochran's C test was computed and it was observed that the variances for the mean ocular torsion were homogeneously distributed ($C = 0.273$, df 7/19, ns). Therefore a one way analysis of variance was computed on the mean ocular torsion for the seven visual field conditions. The analysis of variance is summarized in

TABLE 10

MEANS AND VARIANCES FOR THE MEAN OCULAR TORSION (DEGREES)

	SD	RF	RD	RCCW	RR	RCW	TF
$\overline{X}$	0.01	0.01	0.94	0.66	0.53	0.97	0.51
S^2	0.001	0.001	0.243	0.139	0.117	0.22[illegible]	[illegible]

Table 11. Inspection of the table reveals a highly significant F, and thus supports hypothesis 4 that the various visual fields will induce different amounts of ocular torsion.

Hypotheses 4a through 4e predicted that there would be specific ordering of the amount of ocular torsion induced by a specific visual field. The RCW field and then the RD field were to produce the maximum mean amount of ocular torsion (4a,d). The RF and SD fields were expected to produce no significant ocular torsion (4c) and the TF field was expected to produce significantly less torsion than RD field. The RCCW and RR fields were also expected to produce intermediate effects below that induced by the RD visual field. Inspection of figure 5 which plots the means for mean amount of ocular torsion per visual field supports these hypotheses. Computation of the conservative Tukey (a) test, summarized in Table 12, gives some statistical support for these hypotheses. Inspection of the table indicates that every visual field containing a tilted frame, rotating disc or both had associated with it an amount of ocular torsion significantly greater than when the visual field contained only a stationary disc or only a rectilinear frame. This is rather strong support for at least the occurrence of ocular torsion under visual conditions which lead to shifts in the perception of the vertical. The fact that the TF visual field has a significant amount of torsion associated with it also supports the prediction that rotatory motion is not a necessary condition for ocular torsion.

TABLE 11

SUMMARY OF ANALYSES OF VARIANCE ON MEASURES OF MEAN OCULAR TORSION

Source	SS	df	MS	F[a]
Between Subjects	9.91	19		
Within Subjects	25.09	120		
Visual fields	18.18	6	3.03	55.57[a]
Residual error	6.91	114	0.061	
TOTAL	35.00	139.00		

[a]$F_{.99}(1,19) = 8.18$, conservative probability estimate for within-subject effects, derived by assigning one degree of freedom to the replicated measure, i.e., visual fields and 19 degrees of freedom for the residual error (Winer, 1962, pp. 305-306).

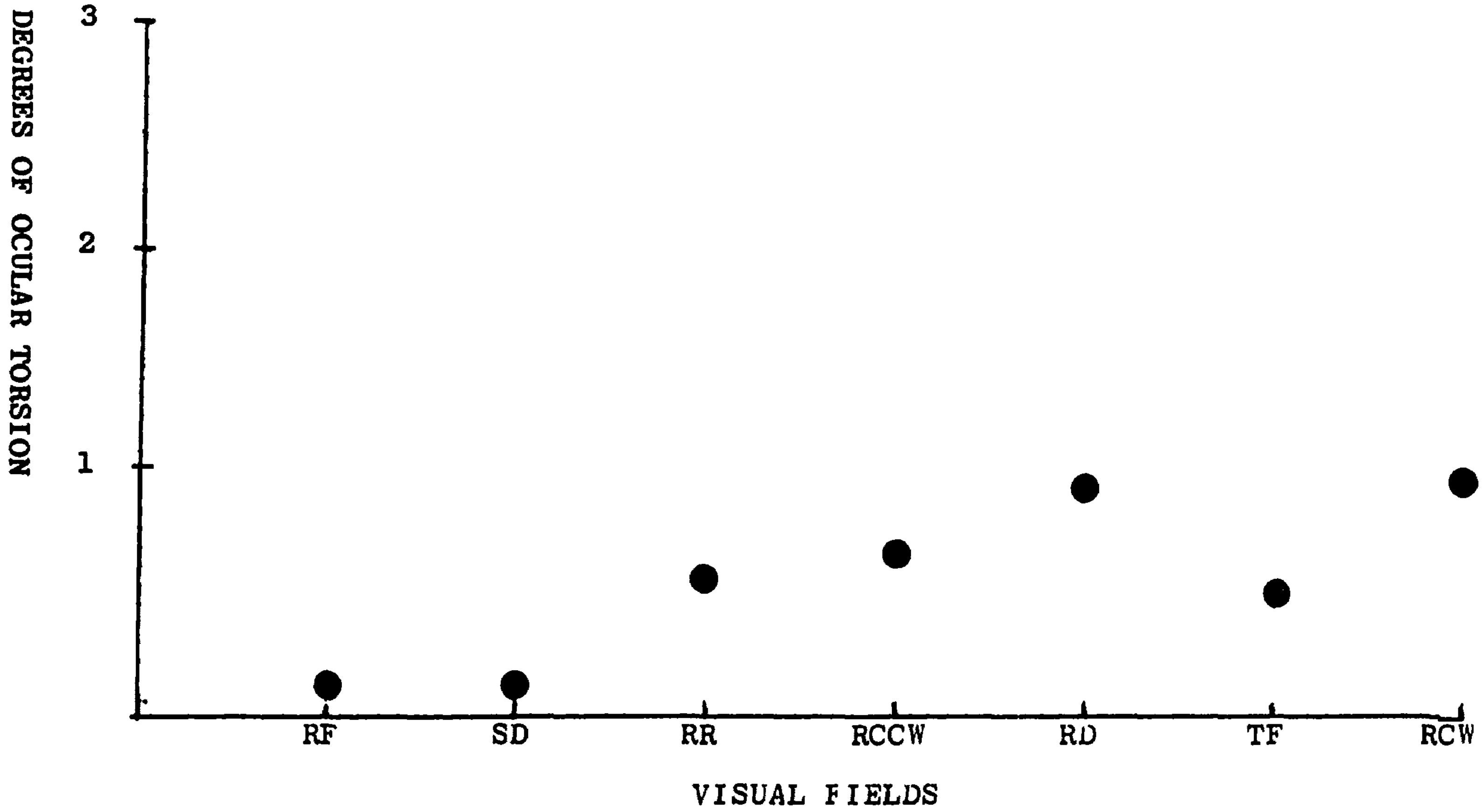

Figure 5. Mean amount of ocular torsion for the seven visual fields.

TABLE 12

GROUP DIFFERENCES ON OCULAR TORSION FOR THE SEVEN VISUAL FIELDS

Visual Field	SD	TF	RR	RCCW	RD	RCW
RF	0.09	10.08[a]	10.44[a]	13.02[a]	18.52[a]	19.16[a]
SD		9.99[a]	10.35[a]	12.93[a]	18.43[a]	19.07[a]
TF			0.36	2.94	8.44[a]	9.08[a]
RR				2.58	8.08[a]	8.72[a]
RCCW					5.50	6.14
RD						0.64
RCW						

[a]Tukey (a) test significant at 0.01 level.

The hypothesis that the TF field would not induce as great amount of torsion as the RD visual field (4b) is also supported by the Tukey (a) test as is the hypothesis (4e) that the RR field would have significantly less torsion than the RD visual field. However, the RCCW field's ocular torsion was not significantly less than the RD amount, as predicted.

On the basis of the prediction that either tilted frame or a rotating disc could induce significant amounts of ocular torsion it was hypothesized (4d) that the simultaneous use of both the CW tilted frame and rotating disc (RD), as in the RCW visual field, would lead to a significant increase in the mean amount of ocular torsion for the RCW field over the RD field. Tukey (a) test did not find these two groups significantly different, but the computation of a dependent $\underline{t}$ test found the two means to be significantly different ($\underline{t}$=4.49, df 18, $p < .01$).

To examine the hypotheses concerning whether the ocular torsion is large enough and of the correct amount to account for the apparent verticality data and the shifts observed, the mean maximum amount of ocular torsion for each condition was determined. It was felt that this score would be a much better indicator in that the mean ocular torsion included many instances of zero amount of torsion, due no doubt to problems of lack of fixation and improper timing of optimal point for photographing the ocular torsion.

An analysis of variance was also computed for these maximum scores to ensure that overall differences were significant and further analyses warranted. Table 13 summarizes the analysis and figure 6 depicts the curve for the means. The order of magnitude for ocular torsion with respect to the seven visual fields is similar to the order of magnitude of the shift in the apparent vertical, except for the TF field producing much less maximum ocular torsion than the other test fields.

If ocular torsion were systematically accounting for at least part of the shift occuring in the vertical then one would expect at least high positive correlations between the difference scores on the vertical perception and the respective maximum amount of ocular torsion. Difference scores were computed by taking the mean difference between the control field, RF, and each of the other six visual fields for each subject. These differences were then correlated with the maximum ocular torsions for the respective fields. Table 14 summarizes these correlations. Inspection of this table gives strong support for hypothesis 5b that positive correlations would be obtained for the RCW, RD, and TF fields. The correlation for the TF is much lower but still significant. This lower correlation might suggest that one or more other components beside the torsion is responsible for the resulting perception of the vertical, i.e., external frame cues.

TABLE 13

SUMMARY OF ANALYSES OF VARIANCE ON MEASURES OF THE MAXIMUM OCULAR TORSION

Source	SS	df	MS	F[a]
Between Subjects	38.33	19		
Within Subjects	87.14	120		
Visual fields	67.28	6	11.21	64.43[a]
Residual error	19.86	114	0.174	
Total	125.47	139		

[a] $F_{.99}(1,19) = 8.18$, conservative probability estimate for within-subject effects, derived by assigning one degree of freedom to the replicated measure, i.e., visual fields and 19 degrees of freedom for the residual error (Winer, 1962, pp. 305-306).

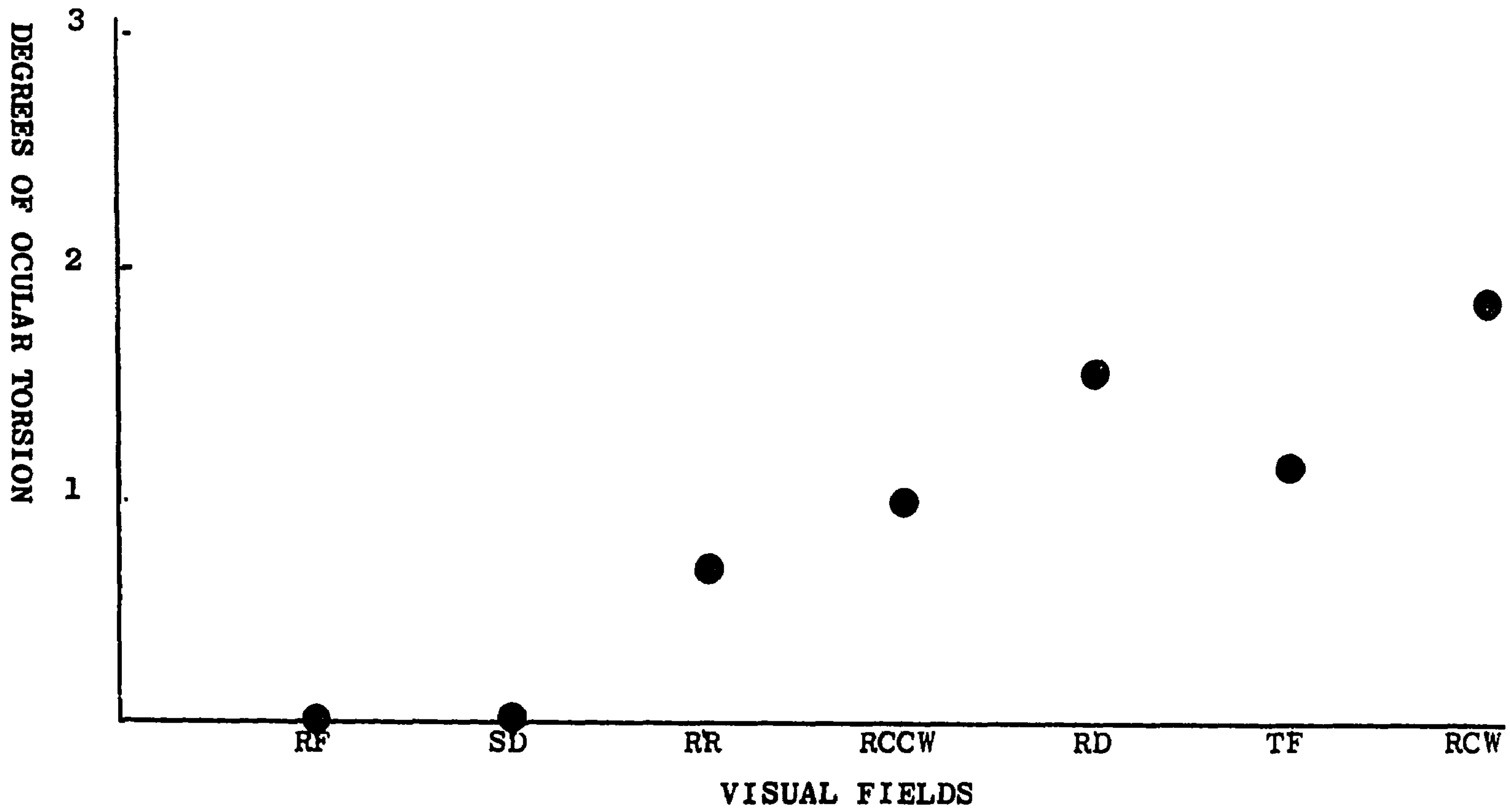

Figure 6. Mean amount of maximum ocular torsion for the seven visual fields.

TABLE 14

CORRELATIONS BETWEEN THE DIFFERENCE ESTIMATES ON THE VERTICAL JUDGMENTS AND THE MAXIMUM OCULAR TORSION

Visual Field	Ocular Torsion
Stationary Disc	0.06
Rotating Disc	0.84[a]
Rotating Disc with CCW Tilted Frame	0.33
Rotating Disc with Rectilinear Frame	0.36
Rotating Disc with CW Tilted Frame	0.67[a]
CW Tilted Frame	0.49[b]

[a] $p < .01$ [b] $p < .05$

This possibility can be tested by computing the magnitude of shift in the vertical for the TF field which is not accounted for by ocular torsion, i.e., the TF difference score minus the ocular torsion, and correlating these scores with the RFT (hypothesis 5d). When this is computed the obtained correlation is 0.58. Thus one's position on the field dependent-field independent continuum apparently accounts for part of the verticality shift.

However, with respect to the visual field containing only a rotating disc, it was hypothesized that ocular torsion would explain all of the observed shift in the vertical. This is supported by the extremely high correlation of 0.84 and the fact that there was no significant difference between means ($\overline{X}_{diff}$=0.25) for the verticality scores and maximum ocular torsion under the RD field ($\underline{t}$=1.95, df 18, ns).

In summary, the results provide support for the contention that ocular torsion occurs during conditions of a rotating disc and/or a tilted frame, but that the amount of torsion is only of sufficient amounts to explain the total variability for shifts in the vertical under the rotating disc condition. However, it was demonstrated that ocular torsion varies with changes in vertical estimates for the TF condition and also that the simultaneous use of both the tilted frame and the rotating disc, as in the RCW field, increases both the amount of torsion and vertical shift above the values occuring when they are used separately (TF and RD conditions).

If the means for the ocular torsion per visual field are ordered in the same manner as was done for the verticality estimates, figure 4, inspection reveals change in the order with the TF field having a lower amount of torsion, figure 6. Assuming the order of the verticality data, the testing for the best-fitting curve for the ocular torsion data shows that the linear relationship is significant and accounts for most of the variance. Of the total of 18.18 units of variation due to difference in complexity of visual field, 13.07 or 72 per cent were predictable from the linear component. However, the quadratic, cubic, and quartic components were also significant but explain only 28 per cent of the variation.

Part of the reason for the low TF scores on ocular torsion can be explained by analyzing the number of occurrences of measureable ocular torsion for each visual field condition. When this is done one finds that of the eight photographs taken per visual field for each subject only an average of 2.35 of them had instances of ocular torsion of one half a degree or more as compared to 5.15 for RCW, 4.7 for RD, 3.9 for RCCW, and 3.6 for RR. Computation of an analysis of variance, summarized in Table 15, demonstrates highly significant differences. Some of the possible explanations for these findings will be dealt with in the next chapter.

Supporting the consistency of the visual fields in

TABLE 15

SUMMARY OF ANALYSES OF VARIANCE ON THE MEAN NUMBER OF OCULAR TORSIONS PER VISUAL FIELD CONDITIONS

Source	SS	df	MS	F[a]
Between Subjects	95.22	19		
Within Subjects	585.71	120		
Number of OT	488.09	6	81.35	95.04[a]
Residual	97.62	114	0.856	
Total	680.93	139		

[a] $F_{.99}(1,19) = 8.18$, conservative probability estimate for within-subject effects, derived by assigning one degree of freedom to the replicated measure, i.e., visual fields and 19 degrees of freedom for the residual error (Wincer, 1962, pp. [illegible]05-306).

inducing ocular torsion for each subject in related amounts is the high positive intercorrelations obtained between the maximum ocular torsions for each visual field condition. Table 16 presents these intercorrelations. The highest intercorrelations are between the RD, RCW, and TF visual field conditions. Insignificant correlations were obtained for the two control groups, RF and SF, with all other conditions, as would be expected.

TABLE 16

INTERCORRELATIONS BETWEEN THE VISUAL FIELD CONDITIONS ON MEASURES OF THE MAXIMUM OCULAR TORSION

Visual Field	SD	RF	RD	RCCW	RR	RCW	TF
Stationary Disc (SD)		0.16	0.20	-0.11	0.16	-0.14	0.10
Rectilinear Frame (RF)			0.13	-0.08	0.09	0.19	0.22
Rotating Disc (RD)				0.61[a]	0.67[a]	0.95[a]	0.85[a]
Rotating Disc with CCW Tilted Frame (RCCW)					0.80[a]	0.78[a]	0.56[a]
Rotating Disc with Rectilinear Frame (RR)						0.67[a]	0.51[b]
Rotating Disc with CW Tilted Frame (RCW)							0.82[a]
CW Tilted Frame (TF)							

[a]$p < .01$ [b]$p < .05$

CHAPTER IV

DISCUSSION

Before presenting a detailed interpretation and discussion of the results, a brief reveiw of the results will be presented. The results of this experiment generally confirmed the hypotheses and expectations set out in the introduction. First with regard to the findings on the perception of the apparent vertical it was demonstrated that the apparent vertical is shifted away from the physical vertical when a rotating disc and/or tilted frame (28^{o}CW) is part of the visual field. The use of both visual fields simultaneously (RD and TF) produced an effect on the apparent vertical greater than when either one was used alone. Less effect on the apparent vertical occurs when the frame and disc oppose one another, i.e., frame tilted CCW or rectilinear with disc rotating CW.

A second general finding concerned the relationship between perception of the vertical on the RFT and of the apparent vertical in the other tasks used in the present experiment. A definite relationship was demonstrated between RFT performance and estimates of the apparent vertical under a number of visual field conditions.

The third general conclusion is that ocular torsion occurs either during conditions of a rotating disc or a tilted frame. The amount of ocular torsion is also definitely related to the perceivers perception of the apparent vertical, with ocular torsion accounting for the magnitude of the observed changes in the apparent vertical in the rotating disc condition. In the tilted frame condition, however ocular torsion did not account for the total magnitude of observed change in the apparent vertical.

The results of the experiment are interpreted as supporting a dual mechanism approach to the perception of the visual vertical. Ocular torsion and external framework cues interact with each other to determine the perceiver's perception of the apparent vertical.

In the discussion that follows the results will first be treated by discussing them in terms of the three categories and the sequence presented in the preceding chapter. A more general discussion will follow.

Apparent Verticality

It is apparent that rather systematic changes occur in the perceived orientation of a rod when viewed under various visual field conditions. Even when vestibulo-kinesthetic cues are held constant these changes occur. These changes in perceived orientation represent increases in the non-veridical perception of the vertical and thus represent a shift of the apparent vertical away from the physical vertical. The Witkin group (Witkin, *et.al.*, 1954) has for many years examined the influence of tilted frames on vertical perception, demonstrating changes in perception of the vertical very similar to those found in this study.

The fact that in this study a tilted frame was associated with shifts in the apparent vertical similar to those found by Witkin and others is not surprising. However, it is of interest that rotating discs also produced such changes and of a magnitude statistically equivalent to that of a tilted frame. Such findings suggest overlap of the mechanism(s) accounting for the shifts of the apparent vertical in the two conditions.

When the rotating disc and frame are introduced into the visual field simultaneously, further changes in the apparent vertical occur. In the RCW condition the visual field contains stimuli which maximize the shift in the apparent vertical away from the physical vertical. The RCW visual field actually contains two very different types of stimulus elements. However, they produce quite similar perceptions of the vertical. One stimulus element (RD) emphasizes motion of the visual field and de-emphasizes specific lines of orientation. The other stimulus element (frame) introduces specific lines into the visual field. If either the lines (i.e., frame) are tilted or rotating motion is introduced into the visual field an instability develops in the normal orientation system represented by the gravitational or retinal vertical meridian. The result of this change in the orientation system is that a stationary object, i.e., rod, viewed in the visual field appears vertical when it is actually tilted in the direction of the tilted frame or rotation. Yet, a random patterned disc is not a sufficient or necessary condition for producing such changes in verticality. If the disc remains stationary no change is observed; if a spoked disc is rotated instead of a randomly patterned disc shifts in the apparent vertical still occur but to a lesser extent (Hughes et.al., 1972). All that is needed to produce the shift is a rotating field and/or tilted lines.

If stability is introduced into a rotating visual field by subscribing it in a rectilinear oriented frame, the rotating disc still produces the shift in the vertical. However, the presence of the rectilinear oriented frame decreases the magnitude of the shift. If a conflict between stimulus cues is introduced by tilting the frame in the direction opposite disc rotation (28°CCW) the result is not as might be predicted. One might predict that the two effects should cancel each other or that the resulting effect would at least be less than that observed for the rectilinear frame and rotating disc. This is not the case; the resulting effect is nearly that obtained for the rotating disc by itself. A possible explanation of this finding is that the perceiver attempts to resolve the conflict by phenomenally perceiving the frame as tilted in the other direction, i.e., 62° CW. This is entirely possible in that any square object (equal sides) tilted in one direction is also tilted in the other direction by 90^{o} minus the smaller angle, i.e., $90^{o} - 28^{o} = 62^{o}$. It is also possible that the rotating disc would phenomenally emphasize this particular perception of the tilted frame. Ocular torsion is also greater under rotating disc conditions than tilted frame conditions thus increasing the possibility of viewing the tilt in this direction. Attneave (1972) in a recent paper entitled "Multistability in Perception" has noted that the square is a tristable geometric figure. Prolonged inspection of the tilted square leads to perceiving it in three ways or orientations: diamond CW tilted square and CCW tilted square. The addition of the rotating disc may increase perceptive stability in the direction of the CW rotation, serving to minimize complexity as in the principle of Prägnanz.

If the above explanation is tenable there must be some satisfactory answer to why the shift in the apparent vertical for the RCCW condition is not actually larger than that for the RD condition, for what is really perceived should be a visual field similar to the RCW. First a tilt of 62^{o} CW is far from optimum for producing changes in the apparent vertical. Such a tilt probably adds little shift to the apparent vertical for even under optimal conditions (28^{o} CW) the added effect is small (0.46^{o}). Second, it had been predicted that the subject's position on the field dependent, field independent dimension would affect the shift. The higher the RFT score of the perceiver the more the frame serves as an external framework. This was observed to be the case. Possibly the more field dependent a perceiver the more the conflict was resolved by perceiving the frame tilted 28° CCW rather than 62° CW. That the three subjects with the highest RFT scores had the smallest shifts in the apparent vertical under the RCCW condition and that 5 of the 20 subjects, all in the lower 50 per cent on the RFT, had larger shifts in the apparent vertical for the RCCW condition than for the RD condition, supports the tenability of such an explanation. Unfortunately, the possibility of one perceiving the tilt as a larger tilt in the opposite direction did not occur to the experimenter during the actual study and therefore its presence was not measured.

While the possible mechanisms accounting for the shift in the apparent vertical will be discussed in greater detail later in this chapter, it is noted that the dual mechanism approach of ocular torsion and external cues helps explain the results of the RR and RCCW conditions. It was hypothesized that under rotating disc conditions without frame the major mechanism accounting for the shift in the vertical would be ocular torsion (see pp. 17-22). When definite lines of orientation, as in the frame, are added to the visual field the other mechanism of external framework cues takes on added importance, especially for the more field dependent perceiver. Thus in the RR and RCCW conditions the second mechanism of the external framework cues is producing a decrease in the resulting shift, especially for the three subjects with the highest RFT scores.

This approach can also explain the larger shift obtained for the TF field than for the RD field. In the RD condition the shift is mainly a function of ocular torsion while in the TF condition both ocular torsion and external frame cues interact with each other to produce greater shift (see pp 17 and 21).

In that the ordering or sequence of effects on the estimates of the apparent vertical for the seven visual fields is generally as predicted, it is relevant to determine the association among the 20 subjects' ordering on the apparent vertical for the seven visual fields by calculating the Kendall coefficient of concordance (W). Kendall's W, a nonparametric analog of multivarate analysis, besides measuring the extent of the association or agreement among the subjects' estimates of the vertical for the seven conditions also serves as a measure of the intersubject reliability. It answers the question of whether the perceivers are applying basically the same perceptual technique in judging the position of the vertical under the seven viewing conditions. Kendall's W was calculated by converting the data to ranks. Only six ranks were used instead of the seven because both the SD and RF conditions were controls and essentially no difference existed between them on the verticality estimates. The average subject score was computed between these two conditions and the resulting average then used in determining the rank order for this average score with the remaining five conditions. Kendall's W was calculated for both the mean apparent vertical data and for the maximum apparent vertical data" W_{mean} =0.58 and W_{max} =0.67. Both are significant at the 0.01 level. These W values indicate significant reliability or intersubject agreement on the ordering of these values; however, the degree of agreement is not very high due, most likely, to subject differences on field dependency, field independency.

Some caution must therefore be taken in specifying the exact order of effect, due to the existing degree of subject variability. Of course, a high degree of agreement would not be expected due to the predicted and demonstrated differences in the perceivers mode of perception and the differences in the degree of the operation of the two proposed mechanisms, i.e., ocular torsion and external framework cues. Not only do the subjects demonstrate differences in mode of perception and degree of the operation of the two mechanisms, but also the different tasks elicit different amounts of the two mechanisms. Yet, the subjects do show high intercorrelations on their mean estimates of the apparent vertical under the various visual field conditions, especially between the RD, RCW, and TF conditions ($r's \geq .74$). Such high intercorrelations point again to a common underlying mechanism or mode of perceiving objects for vertical judgment. Whether the visual field is one of a rotating, random patterned disc or a tilted frame the subject appears to respond to the judging of the orientation of a stationary rod in much the same way, i.e., r=.76, for RD versus TF.

The RFT and the Apparent Vertical

Performance on the RFT for the 20 subjects were similar to the results obtained by other investigators; only 5 per cent of the population are classified as field dependent (Vaught, 1971). While the one subject found to be field dependent in the present study supports the larger population samples of 5 per cent (i.e., mean shift of 10^{o} or more), the lack of a large number of field dependent perceivers limited the conclusions that were made.

It had been predicted that if one's mode of perception, i.e., field dependency vs. field independency, were important for how one perceived the vertical, then one's perception of the vertical on the RFT should be related to how one perceives the vertical on other tasks.

The data presented in the results chapter, Table 9, reveal that the mean difference estimates of the apparent vertical for the various visual field conditions group into three categories on the basis of their correlation with RFT performance: no correlation, positive correlation, and negative correlation. As was predicted no significant correlation occured between the estimates under the stationary disc (SD) condition and the RFT. It is only when motion and/or a tilted frame is introduced that any significant correlation develops between the two tasks. Thus there is nothing inherent in the stationary pattern of the disc that is related to the shift in the vertical or RFT.

The second group of correlations are those that are positive and represent the RD, RCW, and TF conditions. One would expect that the highest positive correlation with the RFT would be with the visual field most similar to the RFT. Of course, this is the TF condition which as predicted correlated most highly with the RFT, r= .73. Eut there is also high correlation between the RD and RFT and between the RCW and RTF, r= .66 and r= .58 respectively. These latter correlations again point to the close similarity between frame conditions and rotating conditions in producing shifts in the apparent vertical and in their relation to the RFT. Thus one's mode of perception, i.e., one's degree of field dependency or field independency, has a definite relationship with how one perceives the vertical under rotating disc conditions.

Caution must be observed, however, for the correlation between RD and RFT is far from unity, r=.66. Two reasons may account for this lack of a higher correlation. First, the procedure employed to measure the apparent vertical is different for the two tasks. In the RFT the rod is gradually moved toward the physical vertical in a method of limits procedure. For the RD and TF conditions the rod is viewed in only the stationary condition; a double random staircase procedure is employed. Also a center fixation point is used for the seven visual field conditions. These procedural differences could easily account for the observed variability between the RFT and other tasks. Hughes et.al. (1972) found that the direction of rod movement in the method of limits procedure interacted with the type of visual field used. They also noted greater shifts in the apparent vertical than were observed under the condition of the present study.

The second factor that probably helps account for the lack of a higher correlation is that while the 20 subjects represent a normal sample of the population on RFT performance it is rather restricted with regards to subjects which are highly field dependent. Except for three subjects the range of RFT mean deviation scores is very restricted, 2.12 to 5.00, and highly field in[illegible] such a small spread of scores the RFT i[illegible]nd it is actually surprising that th[illegible]gh as they are. If the correlatio[illegible] the data for the three highest subject[illegible]of correlation is greatly reduced. Tab[illegible]relations for all 20 subjects with the corr[illegible]d without the three subjects with the highest RFT scores. Inspection of these correlations clearly demonstrates that without those subjects who demonstrate some field dependency the relationship between one's perception of the vertical on the RFT and the other tasks is greatly decreased. Only between the quite similar conditions of the RFT and TF did any modest correlation remain, $r = .59$ vs. $r = .73$. The rotating disc correlation with the RFT ($r = .44$) was low and of borderline significance, indicating that its relationship with RFT perception exists only when the two types of perceivers are represented. Thus with very restricted samples, i.e., high field dependent or high field independent,

TABLE 17

CORRELATIONS BETWEEN THE MEAN DIFFERENCE ESTIMATES ON THE VERTICAL FOR THE VISUAL FIELD CONDITIONS AND THE AVERAGE DEVIATION ON THE RFT FOR ALL SUBJECTS (20) AND FOR FIELD INDEPENDENT SUBJECTS (17)

Visual Field	RFT	
	All Subjects	Field Independent
Stationary Disc	0.12	0.09
Rotating Disc	0.66[a]	0.44[b]
Rotating Disc with CCW Tilted Frame	-0.43[a]	-0.19
Rotating Disc with Rectilinear Frame	-0.35	-0.14
Rotating Disc with CW Tilted Frame	0.58[a]	0.43[b]
CW Tilted Frame	0.73[a]	0.59[a]

[a] $p < .01$ [b] $p < .10$

interacted with the type of visual field used. They also noted greater shifts in the apparent vertical than were observed under the condition of the present study.

The second factor that probably helps account for the lack of a higher correlation is that while the 20 subjects represent a normal sample of the population on RFT performance it is rather restricted with regards to subjects which are highly field dependent. Except for three subjects the range of RFT mean deviation scores is very restricted, 2.12 to 5.00, and highly field independent. For such a small spread of scores the RFT is not very sensitive and it is actually surprising that the correlations are as high as they are. If the correlations are recomputed without the data for the three highest subjects on the RFT the degree of correlation is greatly reduced. Table 17 compares the correlations for all 20 subjects with the correlations computed without the three subjects with the highest RFT scores. Inspection of these correlations clearly demonstrates that without those subjects who demonstrate some field dependency the relationship between one's perception of the vertical on the RFT and the other tasks is greatly decreased. Only between the quite similar conditions of the RFT and TF did any modest correlation remain, $r = .59$ vs. $r = .73$. The rotating disc correlation with the RFT ($r = .44$) was low and of borderline significance, indicating that its relationship with RFT perception exists only when the two types of perceivers are represented. Thus with very restricted samples, i.e., high field dependent or high field independent,

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CW Tilted Frame	0.73[a]	0.59[a]

[a] $p < .01$ [b] $p < .10$

the relationship of the RCW and RD conditions with the RFT on vertical perception is quite limited.

The third group of correlations are the negative correlations represented by the RCCW and RR conditions. As previously discussed, in these two conditions a conflict or opposing of the two mechanisms is brought about by having both frame and rotating disc presented in the visual field simultaneously in such a way that they do not induce a shift of the apparent vertical in the same direction. In the RCCW visual field the frame is tilted in the direction opposite disc rotation. If one's mode of perception is important in determining how one perceives the vertical rod when the frame and rotating disc are in opposition, then a specific relationship should exist between this task and perception of the vertical on the RFT. The observed negative correlation demonstrates the proposed relationship. The more field dependent a perceiver is the more the frame's counter-clockwise orientation appears to influence the vertical judgment above the influence of the clockwise rotating disc. The external lines of the frame become more important even though the result is such that a compromise is made between the ocular torsion produced by the rotating disc and the ocular torsion and external cues produced by the frame. For the field dependent perceiver the rotating disc still has an effect on the apparent vertical as evidenced by a small mean CW shift of the apparent vertical for the three subjects having the largest RFT deviation scores, i.e., $\overline{X}=0.18^{\circ}$ CW for the apparent vertical. However, as the negative correlation demonstrates, those subjects with low RFT scores had much larger shifts in the apparent vertical for the RCCW condition, i.e., $\overline{X}=0.97$. This higher shift in the apparent vertical for the more field independent perceiver supports the theory that the two mechanisms are working to different degrees in the two types of perceivers. The larger shifts of the field independent perceiver are the result of the CCW tilted frame either having little effect on the perceiver or being phenomenally viewed as tilted in the CW rather than CCW direction. Ocular torsion which is produced maximumly by a rotating disc appears to have a greater influence than effects due to external cues. Phenomenally the conflict between frame and rotating disc is resolved in favor of the rotation for the field independent perceiver and in favor of the frame for the field dependent perceiver, although both exert their effect.

Ocular Torsion

The findings with regard to ocular torsion emphasize the importance of the orientation of the retinal elements, especially the retinal vertical meridian, in the perception of vertical orientation. A nearly invariant correspondence exists between the receptor elements and the orientation of the external rod for a given eye position. Thus the external rod stimulates a rather specific line of retinal elements with the result that the orientation of the external rod is mapped in nearly the same orientation on the retina. If the position of the eye in its orbit changes, i.e., ocular torsion, then there is a corresponding change in the orientation of the retinal receptors. This change in eye position results in changes in the apparent orientation of objects in space, with greater ocular torsion in the clockwise direction corresponding to greater clockwise shifts in the apparent vertical.

The results of the present study confirmed the earlier observations of Noji (1929) and Brecher (1934), and the recent findings of Howard and Templeton (1964) and Kertesz and Jones (1969, 1970) that ocular torsion can be induced by a rotating field and occurs in the direction of disc rotation.

Unlike the previous studies it was shown that the rotating field need not contain any definite lines of orientation, i.e., spoked disc, to produce ocular torsion. Discs containing a random pattern of small triangles elicited ocular torsion when rotated. This supported the contention of Hughes et. al. (1972) that observed changes in the perception of the apparent vertical for a sandpaper disc were the result of changes in ocular torsion. On the basis of the Hughes et. al. study and the present findings, there is strong support for the claim that random pattern discs induce greater shifts in the apparent vertical and greater amounts of ocular torsion than result from discs with non-random patterns, i.e., spiral or spoke discs.

Rather systematic changes were obtained in the amount of ocular torsion when the rod was viewed under the various visual field conditions. As expected both the SD and RF conditions did not elicit any ocular torsion. Either rotary motion or a tilted frame was necessary for the occurrence of ocular torsion, as was also true for changes in the perception of the apparent vertical. The rectilinear frame and the stationary disc produce stability in the orientation and thus involuntary ocular torsion is rare with these conditions. But when the stability of the spatial field is disrupted by introducing rotation or by tilting the frame ocular torsion occurs. Howard and Templeton (1964) observed ocular torsion when only a thin rod was rotated in an otherwise homogenous visual field.

The fact that a non-moving visual field represented by a tilted frame elicited ocular torsion confirmed the earlier finding of Greenberg (1960) that the RFT was associated with ocular torsion as measured by an after-image technique. Thus motion does not appear to be a necessary condition for the occurrence of ocular torsion when vestibulo-kinesthetic stimuli are held constant.

The amount of ocular torsion for the TF condition was systematically related to the other test conditions as evidenced by the high intercorrelations (see Table 16). Subjects with high amounts of ocular torsion for the RD condition also had high amounts for the TF and RCW conditions, i.e., r=.85 and r=.82 respectively. Such high intercorrelations point to a common element of the visual field in its ability to elicit ocular torsion. The common element is not lines or motion, but an instability of the visual field toward the CW direction. For when the instability is decreased without the changing or stopping of the rotating disc by adding a rectilinear frame (RR) the amount of ocular torsion is greatly reduced.

It would be interesting to determine if under an unrestrained head situation, i.e., no biting board, subjects viewing the rod for the TF and RD conditions tilt the head CW to increase the stability of the visual field. Such head tilts could serve to stabilize the environment and via vestibulo-kinesthetic feedback actually elicit compensating countertorsion of the eye, thus correcting for CW ocular torsion. Recent neurophysiological findings to be discussed in the next section, support the tenability of such a suggestion.

In the RCW condition the largest amount of ocular torsion occurs and is significantly greater than that for the RD and TF conditions. Thus the combination of tilted frame and rotating disc elicit increases in the amount of ocular torsion above that elicited for each condition separately. This combining of effects was obtained also for the shift of the apparent vertical.

The ordering of effects, with the RCW producing the greatest ocular torsion followed by the RD, RCCW, RR, TF, and SD, was generally the order predicted. It was felt that the TF condition would elicit less ocular torsion than it did shift in the apparent vertical. The mean ocular torsion for the TF and RR conditions was nearly identical, i.e., $\overline{X}_{diff} = 0.02^{o}$.

The degree of association among the 20 subjects' ordering on the amount of ocular torsion for the seven visual field conditions was determined by calculating the Kendall coefficient of concordance (W). Kendall's W was calculated for both the mean and maximum ocular torsion: $W_{mean} = 0.76$ and $W_{max} = 0.82$. Both are significant at the .01 level. These W values indicate rather high reliability or intersubject agreement on the ordering of these values. The reliability is much higher than that obtained for the apparent verticality measures. This indicates that the sequence of magnitudes of ocular torsion for the various conditions is consistent across subjects. This is what one should expect if only one mechanism is involved in the measure taken. In the case where the apparent vertical was the measure there was at least two components involved in the effect, i.e., ocular torsion and external cues. But with ocular torsion itself being the measure, no other component is involved and the RCW condition is nearly always associated with the greatest amount of ocular torsion, followed by the RD and the other conditions.

Therefore ocular torsion does occur in a systematic way, but ocular torsion must also correspond closely with changes in the perceived vertical if it is to be considered a mechanism which can account for changes in the perception of the apparent vertical. A dual mechanism approach to the perception of the apparent vertical stressing the importance of both ocular torsion and external reference cues must predict that under certain visual field conditions ocular torsion will not be of a sufficient amount to account for all of the shift in the apparent vertical. Both these predictions were supported by the previously presented results.

For the RD condition one finds an extremely close relationship existing between the amount of ocular torsion and vertical estimate, i.e., r= .84. However, for the TF condition this relationship is greatly reduced, i.e., r=.49, indicating that most likely more than just ocular torsion is accounting for the changes in the perception of the vertical.

A clearer picture of the extent of the fit between the amount of ocular torsion per condition and the amount of shift in the apparent vertical per condition can be achieved by plotting the two curves. Since the amount of ocular torsion is always with respect to the eye position during the control condition (RF), it thus represents a difference, i.e., X degrees more or less than the control; the same must and can be done with respect to the apparent vertical scores by subtracting them from the apparent vertical scores for the control condition (RF). These difference scores were determined for the mean maximum scores and are shown in figure 7.

Before discussing the differences between the two curves, the rationale for the use of the mean maximum scores rather than mean scores will be stated. First, the interest was mainly in the maximum or greatest effect produceable under each condition. Second, the mean values are greatly increased and reduced due to the fact that under some conditions ocular torsion could be photographed on the average 5 out of 8 times (RCW, RD) while for other conditions only 3 out of 8 times (TF, RR). By using the maximum value for each condition this was avoided. Third, the use of maximum scores treats each condition the same and does not overemphasize high chance scores for the control conditions. Both control conditions (SD and RF) had associated with them neglible shifts and no ocular torsion as evidenced by practically zero variance.

Inspection of figure 7 reveals that the fit between the two curves is very close with the ocular torsion not being of sufficient amount to account for vertical differences in only two cases: RCCW and TF. To test whether these differences are significant *t*-tests on the differences scores were computed, i.e., maximum verticality difference minus maximum ocular torsion. The difference was significant for the TF difference but only of borderline significance for the RCCW difference (t_{TF}=3.11, df 18, p<.01; t_{RCCW}=1.86, df 18, ns).

If a percentage of the difference between the vertical estimate and ocular torsion is determined it is found that ocular torsion can explain at least 80% of the vertical shift for the RCCW condition but only 60% for the TF condition. It should be emphasized that while the ocular torsion does not account for the full shift or change in the vertical, for these conditions, it does systematically change with changes in the vertical shift.

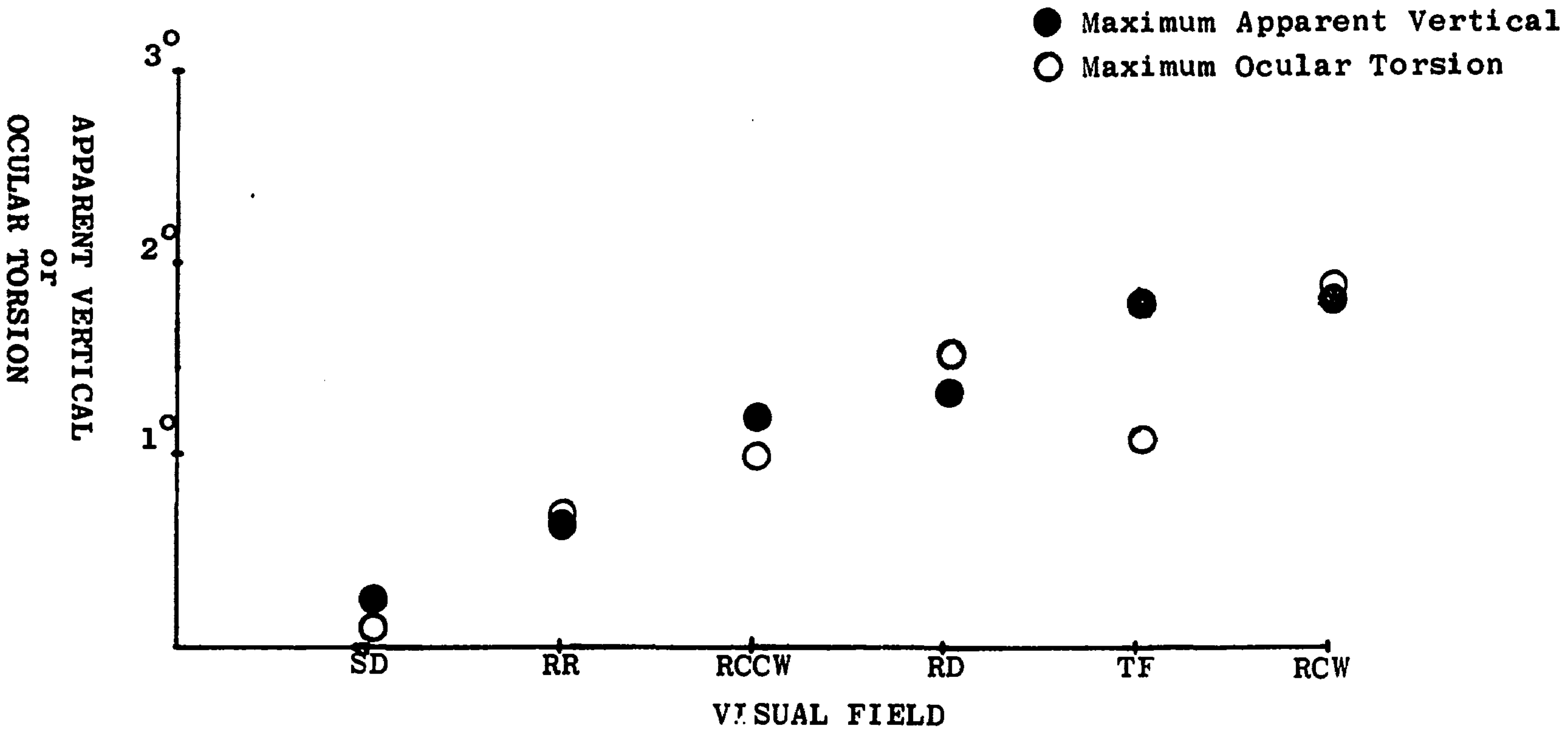

Figure 7. Mean amount of maximum ocular torsion and maximum difference in apparent vertical from control for the seven visual fields.

These findings offer strong support for a dual mechanism approach to the perception of the visual vertical with ocular torsion accounting for most of the vertical changes brought about by rotating visual fields and external reference cues taking on more importance as definite lines of orientation are introduced into the visual field. Thus a reference theory of the perception of the vertical is still of importance, especially when definite lines of orientation exist in the visual field and when the perceivers' mode of perception emphasizes such cues, i.e., field dependent perception. A question that still needs to be considered is how such visual fields, as used in the present study, induce ocular torsion. It is to this question that the next section is directed.

Related Neurophysiology: a possible solution

One is faced with difficulty when attempting to account for the observed phenomena and the accompanying ocular torsion in terms of neurophysiological mechanisms. Almost nothing is known about the neural mechanisms or pathways involved in ocular torsion, especially under conditions where vestibulo-kinesthetic stimulation is held constant. Any attempt to answer the question of how a rotating disc or tilted frame triggers ocular torsion must therefore be limited to empirical findings which are often far removed from the present question.

The first question that might be asked is why a rotating random pattern disc induces the greatest effects in vertical displacement and ocular torsion. A strong possibility is that "directional satiation" (Mackay, 1961) is held to a minimum by the random organization. Spatially repetitive patterns may decrease the firing of stimulus detection neurons in the visual cortex. It has been known that inspection of a grid for prolonged periods elevates the detection threshold for any grid with similar orientation and spatial frequency (Blakemore and Campbell, 1969; Campbell and Maffei, 1970). Stimulus evoked cortical potentials are also decreased along with the elevated threshold (Campbell, 1972). Pantle and Sekular (1969) have demonstrated that such adaptation also occurs for the direction of grating movement.

From these data it is very plausible to predict that the visual system will not easily satiate or adapt to random patterned discs. The disc also has the added advantage of being composed of many differently oriented triangles. Such stimuli with their many edges and orientations are capable of firing a greater number higher order visual cells, (i.e., the complex and hypercomplex cells of Hubel & Wiesel) than a spiral or a spoked disc.

The superior colliculi are also of importance in that a small number of neuron of the upper layers have been recently found to respond only to certain directions of stimulus motion, but not to others (Wurtz and Goldberg, 1972). Wurtz and Goldberg report that many of the neurons in the superior colliculi of the monkey have a fixed relation to eye movements. Some neurons increased their spike discharge whenever the visual stimulus was related to saccadic eye movements; others in the intermediate gray layers discharged prior to an eye movement made to fixate a certain area of the visual field. These intermediate gray layer neurons also have an increased rate of firing associated with a specific direction of eye movement made to fixate a certain area of the visual field. While these findings are not directly related to ocular torsion they do point to the possibility that ocular torsion is also coded. To this can be added the recent work of Noda, Freeman and Creutzfeldt (1972). They found that about ten percent of the cells in the visual cortex of the awake cat have neuronal correlates of eye movements. They did not respond to stationary parallel stripes in any orientation nor to stripes moving at moderate speeds across the visual field in any direction. But the cells were related to eye movements when the cat faced a patterned visual field. They also reported that approximately twenty percent of the 300 neurons sampled could be driven only by undefinable movements. Such cells might be an example of cells in the human brain particularly sensitive to the rotary movement of random patterns.

It is hard to make little more than tentative conclusions about the above findings, as the central mechanisms controlling eye movements are quite complex. Yet, it is clear that cortical areas are important for eye movements. The frontal cortex and frontal eye fields have been implicated in saccadic movements for many years for many species (Smith, 1949). Other known structures important in eye movements are the cerebellum, vestibular system, lateral geniculate nuclei, motor nuclei of extra-ocular muscles and reticular formation (Whitteridge, 1960; Bach-Y-Rita & Collins, 1971). It is even thought that, at least for the invertebrate organism, the directionally sensitive movement detector units of the retina may drive the oculomotor neurons to induce ocular movements (Wiersma, 1967). At the vertebrate level such data might be related to the belief that the interstitial nucleus of Cajal serves as a coordinating center for the control of ocular torsion and rotatory movements of the head in the frontal plane (Szentágothai, 1943, 1952; Hyde and Toczek, 1962; Carpenter, 1971).

Electrical stimulation of the nucleus of Cajal by means of implanted electrodes or in encephale isole preparations has evoked ocular torsion and rotation of the head to the stimulated side. Hyde and Eason (1959) report that they obtained an average of 20 degrees of ocular torsion in the cat when so stimulated. While these findings appear to be quite promising, it should be noted that the nucleus of Cajal apparently does not discharge to visual stimuli. The nucleus is closely related to vestibular unit activity with stimulation of the nucleus leading to ipsilateral inhibition of type I vestibular neurons and ipsilateral activation of type II vestibular neurons (Markham, Precht & Shimazu, 1966). Angular acceleration in the direction of the recording site increases the discharge rate of type I neurons while inhibiting type II. This relationship between vestibular activity and the nucleus of Cajal is further supported by the anatomical studies of Pompeiano and Walberg (1957). They have demonstrated that the nucleus of Cajal in the cat projects fibers via the medial longitudinal fasiculus (MLF) to portions of the medial vestibular nucleus. This is the only midbrain structure known to project fibers to the vestibular nuclei (Carpenter, 1971). The MLF also contains ascending fibers from the superior vestibular nuclei to the nucleus of Cajal. The investigations of Szentagothal (1950) stress that the most important impulses mediating ocular movements in response to stimulation of the semicircular canals ascend in the MLF to the nuclei of the extraocular muscles and accessary oculomotor nuclei.

There are a number of nonvestibular afferent projections to the interstitial nucleus of Cajal, although the connections and functions are poorly understood. Fibers from the frontal cortex (Szentágothai and Rajkovits, 1958; Kuypers and Lawrence, 1967) and striate cortex (Mettler, 1935; Woodburne, Crosby and McCotter, 1946) have been reported projecting to the nucleus of Cajal in a number of primates.

It is apparent that the nucleus of Cajal is involved in ocular torsion and also vestibular functions. What is important for the present discussion is that even though no definite connection has been demonstrated between the nucleus of Cajal and visual stimulation it is very possible that such a relationship exists. The superior colliculus which has a direct tie up with retinal and occipital fibers is known to have connections with the nucleus of Cajal. Altman and Carpenter (1961) have demonstrated that lesions restricted to the superior colliculus of the cat produce bilateral degeneration in the Cajal nucleus. This fact together with rather strong support for interconnections between areas 17 and 18 of the visual cortex with the superior colliculus (Altman, 1962; Garey, Jones and Powell, 1968) provides some evidence for the tentative view that ocular torsion induced by pure visual stimulation occurs via these above pathways in the cat or at least similar ones for the primate. The same cells of the superior colliculus appear to receive two related imputs, one from the cortical cells of the visual cortex, and another from the ganglion cells of the retina. Also there is evidence in the primate that the superior colliculus receives cortical and peripheral impulses related to non-visual systems (Kuypers and Lawrence, 1967).

The fact that the nucleus of Cajal, the vestibular nuclei and the nuclei of the extraocular muscles are closely related with each other anatomically and physiologically raises the question of whether the ocular torsion induced by the rotating disc and tilted frame is the result of activation of the vestibular system. While vestibulo-kinesthetic stimuli were held constant in the present study, it is possible that rotating visual stimuli and to some extent tilting of the visual field induce activation of the vestibular system eliciting ocular torsion. This is what most likely takes place with head and/or body tilt and the perception of the apparent vertical.

Visual influence on the vestibular system is not as impossible as it might at first appear. Recently, Klinke and Schmidt (1970) demonstrated that a direction specific modulation of the resting discharge in the vestibular nerve of the goldfish is elicited by the motion of a large visual display. This has also been recently shown in the vestibular nuclei of the rabit (Dichgans and Brandt, 1972). That vestibular involvement occurs and can be extended to the human subject is strengthened by the recent findings of Dichgans, Held, Young, and Brandt (1972). They have shown that moving visual fields induce in human subjects not only a shift in the apparent vertical but also a displacing of the apparent direction of gravity in the direction of rotation. The effect is greatly pronounced when the visual field stimulates only the peripheral area of the retina. Subjects reported that they felt their body rolled laterally. These reports fit well the observations of Brandt, Dichgans and Koenig (1972) that subjects experience exocentric motion, i.e., illusion of self motion rather than external object motion, when the peripheral visual field is stimulated by a rotating cyclindrical drum containing vertical stripes. Egocentric motion perception results when peripheral vision is precluded and only the central visual field stimulated. Such behavioral findings of interaction between pure visual stimuli and the vestibular system support the feasibility of the anatomical connections presented for the cat and non-primates, existing also for the human brain.

Some of the effects observed by Dichgans _et_. _al_. (1972) were not noted in the present study because the visual stimuli employed emphasized central visual field stimulation rather than peripheral. Larger effects would be induced by peripheral stimulation and it would be interesting to measure whether ocular torsion under peripheral stimulation can account for the larger shifts in the vertical. Oscular torsion might account for the results up to a certain level of shift but it will be necessary to measure ocular torsion under both central and peripheral conditions to determine its exact relationship.

CHAPTER V

SUMMARY

The present investigation examined subjects' estimates of whether a line was vertical or not vertical when viewed in conjunction with a visual field composed of a rotating or stationary disc and/or surrounding frame. Ocular torsion of the right eye was measured photographically to ascertain if changes in eye rotation were systematically related to subjects' estimates of the vertical.

The results of the investigation generally confirmed the hypotheses and expectations of the experimenter. The perception of the apparent vertical was displaced away from physical vertical when a rotating disc and/or tilted frame (28^{o} CW) is part of the visual field. The use of both visual fields simultaneously (RD and TF) produced an effect on the apparent vertical greater than when either one was used alone. Less effect on the apparent vertical occured when the frame and disc were opposing one another, i.e., frame tilted CCW or rectilinear with disc rotating CW.

It was also concluded that one's pereception on the RFT was related to one's perception of the apparent vertical in the other tasks used in the present experiment. Those subjects with high RFT scores also tended to have high displacement of the apparent vertical from the physical vertical when the visual field contain a CW rotating random patterned disc and/or CW tilted frame. If the disc remained stationary or the frame rectilinear then the relationship with the RFT performance did not hold.

The findings also supported the hypothesis that ocular torsion occurs during conditions of a rotating disc and/or a tilted frame, but that the amount of torsion is only of sufficient magnitude to explain the total variability for shifts in the apparent vertical under the rotating disc condition. However, it was demonstrated that ocular torsion varies with changes in vertical estimates for the tilted frame (TF) condition. Further it was demonstrated that the simultaneous use of both the TF and rotating disc increased both the amount of torsion and the vertical shift above the values occurring when they are used separately.

The results were discussed in terms of a dual mechanism approach which can account for most of the observed differences in the perceived apparent vertical: 1. ocular torsion which changes the orientation of the retinal elements, and 2. external reference cues which stablize the orientation in the direction of the orientation of the cues (lines). The involvement of the vestibular system in the observed ocular torsion was also discussed as a possible underlying mechanism responsible for the activation of the ocular torsion.

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APPENDIX

MEAN RAW SCORE DATA FOR INDIVIDUAL SUBJECTS ON THE MEAN APPARENT VERTICALITY OF THE ROD

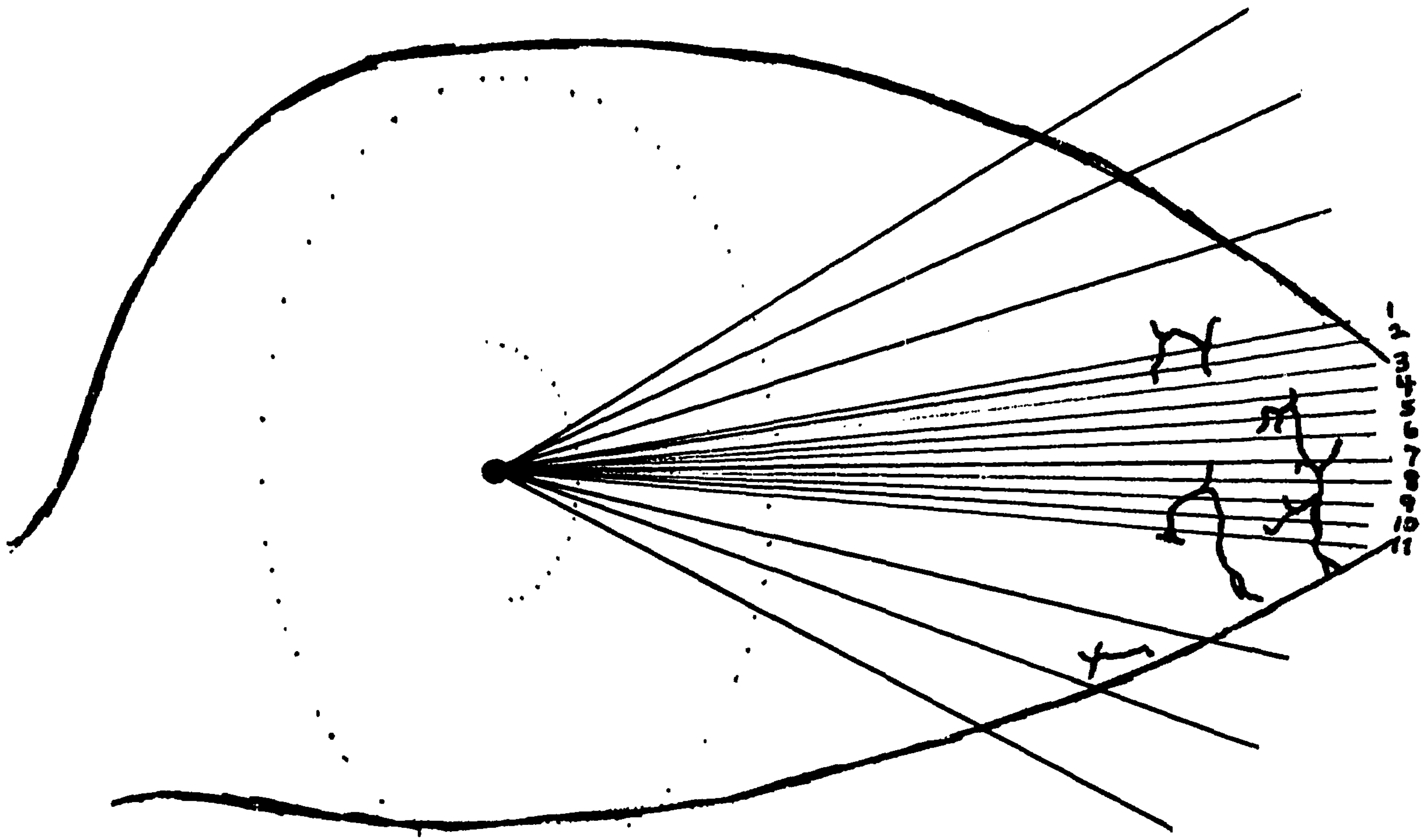
Sub-jects	Visual Fields						
	SD	RF	RD	RCCW	RR	RCW	TF
1	0	-0.28	0.50	1.75	0.33	1.75	2.00
2	-0.25	0.30	0.56	1.12	-1.10	1.27	0.15
3	0	0.41	0.87	0.08	0.50	1.25	1.41
4	0.12	0.40	1.00	1.26	0.75	2.66	2.41
5	0.12	1.56	2.37	0.70	-0.34	1.90	2.32
6	0.29	1.23	0.92	0.73	0.17	0.75	1.12
7	-0.35	-0.09	0.95	1.45	0.17	2.59	1.05
8	-0.50	0.87	1.00	1.33	0.36	2.30	2.25
9	0.50	0.41	0.50	0.16	1.33	0.33	1.08
10	1.66	0.83	2.00	2.00	1.50	2.20	1.60
11	1.50	1.66	1.87	1.17	0.54	2.62	1.75
12	0.50	0.50	1.00	1.83	1.67	2.00	2.50
13	1.33	0	-0.38	-0.55	1.57	-0.27	-0.54
14	1.25	-0.04	1.27	0.37	1.27	2.76	0.67
15	1.12	1.21	2.40	1.25	1.35	2.17	3.26
16	0.83	0.58	1.16	0.48	0.58	2.34	1.35
17	-0.25	-0.83	0.25	0.32	0.41	0.39	0.30
18	0.25	0.25	0.30	0.25	0.27	0.35	0.31
19	0.50	0.53	1.25	0.85	0.60	1.70	1.35
20	0.20	0.40	1.23	0.83	0.55	1.90	1.33

MEAN RAW SCORE DATA FOR INDIVIDUAL SUBJECTS ON THE MAXIMUM APPARENT VERTICALITY OF THE ROD

Sub-	Visual Fields						
jects	SD	RF	RD	RCCW	RR	RCW	TF
1	0.50	0.50	1.00	2.00	0.50	2.00	2.50
2	0.50	0.50	2.00	2.50	-0.50	1.50	1.00
3	0	1.00	1.00	2.00	0.50	1.50	2.00
4	0.50	1.00	1.50	1.50	1.00	3.00	3.00
5	0.50	1.50	2.50	1.50	0.50	2.50	2.50
6	1.00	1.50	2.00	1.00	1.50	3.00	2.50
7	0	0.50	1.50	2.00	0.50	3.00	2.00
8	0	1.00	1.50	1.50	1.00	2.50	2.50
9	0.50	0.50	1.00	0.50	1.50	0.50	1.50
10	2.00	1.00	2.00	2.50	1.50	2.50	2.00
11	1.50	1.50	2.00	1.50	1.00	3.00	2.50
12	0.50	1.00	1.50	2.50	2.50	2.50	3.00
13	1.50	0.50	0.50	0.50	2.00	0	-1.00
14	1.50	0.50	1.50	1.00	1.50	4.00	2.00
15	2.00	2.00	3.00	2.50	2.00	2.50	4.00
16	1.00	1.00	1.50	1.00	1.00	2.50	2.00
17	0.50	0	0.50	1.00	0	1.50	2.00
18	0.50	0.50	1.00	0.50	0.50	1.50	1.00
19	1.00	1.00	2.50	2.00	1.50	3.50	3.00
20	1.00	1.00	2.50	1.50	2.00	3.50	2.50

MEAN RAW SCORE DATA FOR INDIVIDUAL SUBJECTS ON THE MEAN OCULAR TORSION

Sub-jects	Visual Fields RF	SD	RD	TF	RCCW	RR	RCW
1	0	0	0.50	0.38	0.44	0.44	0.56
2	0	0	0.70	0.56	0.56	0.56	0.75
3	0	0	0.94	0.87	0.69	0.63	1.00
4	0.07	0.07	0.87	0.78	0.69	0.63	0.94
5	0	0	1.87	1.00	0.87	0.69	1.94
6	0.07	0	0.44	0.38	0.38	0.25	0.50
7	0	0	1.44	0.94	0.87	0.70	1.38
8	0.12	0	1.38	1.00	1.00	0.87	1.19
9	0	0.07	0.87	0.44	0.56	0.56	0.94
10	0	0	0.38	0.13	0.25	0.25	0.38
11	0	0	0.87	0.78	0.69	0.69	0.94
12	0	0.07	1.44	0.69	0.70	0.56	1.38
13	0	0	0.94	0	0.78	0.68	0.87
14	0	0	0.44	0	0.38	0	0.56
15	-0.07	0	2.13	1.38	1.56	1.44	2.00
16	0	0.07	0.87	0.25	0.44	0.38	0.94
17	0	0	0.69	0	0.44	0.44	0.87
18	0	0	0	0	0	0	0.08
19	0	0	0.94	0.69	0.87	0.87	1.00
20	0	0	1.00	0	0.94	0	1.13



Picture of a subject's eye with a number of prominent vessels used for measuring ocular torsion. Size of picture is appropriate size of projection picture used in study. Picture was projected onto angled markings as shown.