THE INFLUENCE OF RETINAL SPEED AND RETINAL SIZE ON THE DURATION OF THE SPIRAL AFTEREFFECT

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CHAPTER I

INTRODUCTION AND REVIEW OF LITERATURE

The investigation of the phenomenon of apparent motion has concerned experimenters for many years. This phenomenon deals with movement sensations that correspond to the eliciting stimulus, yet are distinct from it. At least four different classes of apparent motion have received attention in visual research:

(1) Alpha Movement - A situation in which similar objects of different size are presented rapidly, causing the viewer to perceive one object as contracting or expanding.

(2) Beta Movement - A situation similar to alpha movement, except that the perceptual shift is in terms of the position of the object.

(3) Gamma Movement - A single object is perceived as contracting or expanding due to increasing or decreasing changes in illumination.

(4) Delta Movement - Two stimuli, presented in sequence, will cause a report of reversed movement, when the later stimulus is brighter than the former one.

The present investigation deals with one specific aspect of gamma movement, the negative aftereffect. The device commonly used to produce experimentally the negative aftereffect is a two-dimensional spiral, first introduced by Plateau (Holland, 1965). Centripetal and centrifugal presentation of the spiral causes a corresponding sensation of contraction and expansion. A negative aftereffect is produced when the spiral is stopped, giving a sensation of (apparent) movement in the direction opposite to that of the spiral. This sensation is familiar to those who have been on a moving train and observed passing rails and then quickly shifted their gaze to a stationary object. The new object appears to move in the opposite direction from the object of initial fixation. It is with the negative aftereffect of the previously discussed Plateau spiral that this paper is chiefly concerned.

The negative aftereffect phenomenon has been known since Aristotle made reference to it in his writings (Wohlgemuth, 1911). However, there was a dearth of interest in the aftereffect of apparent motion from that time until Purkinje's work in 1825. Wohlgemuth (1911) presents an excellent review of the early work done in this area, as well as his own ambitious and far-sighted experimentation. Between the years of 1825 and 1911, Wohlgemuth lists 34 references concerned with the aftereffect. While some authors merely described the phenomenon, others conducted experiments and some attempted an explanation of the aftereffect. Wohlgemuth grouped these explanations into three categories. One group based an explanation of the phenomenon on physical processes, which, in effect, emphasizes eye movements. A second group posited psychical factors as the cause of the aftereffect. The final group sought to assign physiological factors as the cause of the phenomenon.

Wohlgemuth rejected all of the explanations offered prior to his research, but presented a number of interesting hypotheses. He pointed out that the normal decay process of the illusion was inhibited by closing the eyes immediately after stimulation. This observation is similar to that of Spigel's (1960) and has relevance to Kohler's phenomenon of "self satiation" (Holland, 1965). One can also draw a comparison between Wohlgemuth's observation and Eysenck's (1955) theoretical formulations concerning individual differences and the magnitude of the aftereffect. Holland (1965) also points out that Costello's homeostatic theory of inhibition (1961) is based on Wohlgemuth's work relating magnitude and the expanding or contracting nature of the illusion. Anticipation of the practical utilization of the aftereffect is seen in Wohlgemuth's suggestion of its use with those having brain lesions.

Again the literature indicates a hiatus in published work on the aftereffect over the next thirty-eight years. There are, however, a few exceptions, and the paramount one is the work of Granit (1927, 1928). Granit, like Wohlgemuth, pursued issues which are still of considerable interest today. Granit centered his attention on the retina and particularly on the interaction between rods and cones. It was this interaction, in terms of rod inhibition of cone functioning, that Granit thought to be involved in the perception of the aftereffect. He had hypothesized that by increasing the retinal area stimulated and the retinal speed (speed of the stimulus across the retina), with the stimulus at a short distance from the eye, the duration of the aftereffect would be greater. Likewise, when the stimulus was moved farther from the eye, Granit anticipated a decrease in the duration, since the retinal area and retinal speed were also decreased. However, he found this not to be the case. He noted an increase in the duration up to an optimal point which was represented by a visual angle of two to four degrees. Hence duration increased up to this point, which is relatively rod-free, but decreased beyond this point according to Granit's hypothesis, because of rod inhibition. It is not the proposed rod inhibition hypothesis that makes Granit's work pertinent today, but rather his emphasis upon such variables as the visual angle, distance from the eye, and retinal speed. Grindley (1930), testing the rod inhibition hypothesis by means of stimulating rod and cone portions of the retina, found no basis to substantiate it and felt that the decrease in duration must be explained by other means, possibly changes in perceptual configuration.

A crucial point in the evolution of the spiral aftereffect (SAE) occurred in 1949. It represented a change in emphasis and an expansion of the use of the spiral. The spiral aftereffect was no longer only a psychophysical experiment designed to better understand perception; but was applied in clincial situations in an attempt to understand human behavior. Freeman and Josey (1949) utilized the spiral with hospitalized mental patients. They found that normal subjects reported the negative aftereffect when exposed to the spiral, but the hospitalized subjects failed to perceive it. These hospitalized subjects suffered from clinically-judged memory impairments. However, Stnadlee (1953) using normal and psychotic subjects reported all were capable of perceiving the SAE. He also tested the subjects with the Wechsler Memory Scale and found a great variation in ability. Hence Stnadlee concluded that the spiral aftereffect did not serve as a measure of memory impairment. Price and Deabler (1955), in support of Freeman and Josey, pointed out that Standlee referred to memory ability while Freeman and Josey dealt with memory impairment or true organic involvement. Price and Deabler further suggested that Standlee's subjects were functional psychotics with poor memories, but not patients with true organic impairment. In an experiment using 40 normal, 40 mixed psychiatric patients, and 120 organics with known cortical involvement, Price and Deabler were able to differentiate the organic and non-organic groups on the basis of the SAE. They used a six-inch diameter spiral of two-and-a-half turns which rotated at 100 rpm. The subjects were seated eight feet from the apparatus and the inspection period of real movement lasted for 30 seconds for each of four trials. The type A spiral, producing an expanding negative aftereffect, was presented first, followed by the type B spiral. This procedure was reversed for one-half of the subjects. Price and Deabler utilized a scoring system of 1 for a perception of the SAE and 0 for failure to perceive it. Hence the subjects were scored on the basis of a "see- no-see" system. Their results indicate that 98 per cent of the non-organic group were capable of perceiving the negative aftereffect. Depending upon the cutting score used, 2 - 10 per cent of the organics would have been misclassified.

These promising results immediately stimulated wide spread investigation of the SAE. Thus the importance of the Price and Deabler study cannot be overemphasized, since it became the reference point for all future clinical studies with the SAE. Although subsequent results proved less dramatic, it may be said that this study helped to secure, for the SAE, a place in the armamentarium of the clinical psychologist.

An example of the scientific interest in the spiral aftereffect can be gleaned from the remarks of Klebanoff, Singer, and Wilensky (1954).

> It is clear, nevertheless, that subtle perceptual impairments or reorganizations following cerebral injury are most clearly brought out by intensive laboratory examination rather than by widely used global clinic methods like the Rorschach, Bender Gestalt, Wechsler-Bellevue, Hunt-Minnesota, etc.

Yet scientific interest is never displayed unless it is done in a cautious mode. Hence these authors continue: "these methods do reveal promise, but one is not yet able to evaluate their ultimate significance as differentiating techniques". Yates (1954) also suggests:

> A satisfactory test of brain damage should be based on a reasonable theory that has been experimentally tested, has been supported by adequate statistical treatment, and has taken into account all relevant variables.

Gallese (1956), following the procedures of Price and Deabler, attempted independently to validate their results. His subject population consisted of normals (employees of a state hospital), schizophrenics, lobotomized schizophrenics, and organics with acute and chronic brain syndromes. Prior testing had indicated that those organics suffering from idiopathic convulsive disorders and alcoholism performed more like normals on the SAE. Thus he divided the organics into two groups; one group was characterized by these features, and the other group represented organicity due to other causes. None of the lobotomized schizophrenics were classified as organic by the SAE. This signified, for Gallese, that cortical involvement alone was apparently not sufficient for detection by the SAE. Yet he concluded that his results agreed with those of Price and Deabler in terms of differentiation of organics and non-organics. However, the value of the SAE in differentiation between the varieties of organicity was questioned. Sixty-six per cent of the organics (those not suffering from convulsions or alcoholism) were correctly identified, while only three per cent of the non-organics were misclassified. SAE scores were found to be unrelated to age, sex, or length of hospitalization. In an attempt to reconcile the differences between his results and those of Price and Deabler, Gallese indicated that comparability was made difficult due to varied methods of selection, statistical analysis, and procedure. Using a see- no-see scoring system, he remarked that, when a subject scores as an organic, he truly falls in that category, but the converse is not ture. Gallese did incorporate a verbal inquiry into the scoring technique which allowed greater confidence in the reported perceptions of the subject. Yet he had the impression that the duration of SAE for organics who scored like normals (though the durations were not measured), was considerably shorter than that of non-organics. Spivack and Levine (1957) found brain damaged adolescents to have a longer duration of aftereffect, and they related this to some significant aspect of cortical functioning. Thus, either Gallese's impression is in error or, as Spivack and Levine suggest, there is an important difference in the cortical functioning of adolescents and adults. The brain damaged adolescent group, in Spivack and Levine's study (1957), failed to perceive the SAE more often than a group of emotionally disturbed adolescents. However, the authors report that the discriminatory power of the technique is considerably poorer than that noted in the studies of Price and Deabler (1955), Gallese (1956), Garrett, Price, and Deabler (1957), and Page, Rakita, Kaplan, and Smith (1957). Only 40 per cent of the organic subjects in the Price and Deabler study saw the SAE on the first trial, while, in the Spivack and Levine study, 81 per cent of the brain-damaged group saw the SAE on the first trial. The explanation offered by the authors suggested that the age of onset of organicity causes a difference in psychophysiology. It should also be noted that Spivack and Levine utilized only the type A spiral while both types were used by Price and Deabler.

Spivack and Levine (1957) also extended the use of the SAE to include subjects as young as eleven years of age. Davids, Goldenberg, and Laufer (1957) combined the SAE and the Trail Making Test and found them to be applicable to the diagnosis of brain-damage in children. They felt that both tests, whose results were significantly related, possessed considerable potentiality as valid procedures for this purpose. Yet Harding, Glassman, and Helz (1957) were unable to obtain SAE results in children under a chronological age of 55 months or a mental age of 60 months. These authors felt that this age limit represented a perceptual threshold for the SAE. However, other authors (Gollin and Bradford, 1958; Berger, Everson, Rutledge, and Koskoff, 1958) felt that this limitation was more a verbal deficiency than a perceptual one. Following this line of reasoning, Gollin and Bradford were able to obtain SAE responses from subjects considerably younger and with lower mental ages than did Harding, Glassman, and Heltz. More recently, Snyder and Freud (1967) reported that the SAE could be used successfully with first graders as a means of testing their perceptual maturity.

Page, _et al_. (1957) attempted to duplicate the findings of Price and Deabler. However, a number of different techniques were employed in this study. Instead of a six-inch spiral, they tested both males and females with an eight-inch spiral and also used only the type B spiral. The findings of Page, _et al_. were in general agreement with those of Price and Deabler, but these were not as impressive. Forty per cent of the organic subjects were not identified and 15 per cent of the non-organics were mislabeled on a see- no-see basis. The differences between the organic and the non-organic subjects were significant, but the results caused the authors to question the effectiveness of the SAE as a diagnostic tool. Page, _et al_. recommended that the see- no-see scoring technique be abandoned in favor of a measure of the duration of the aftereffect. One point which had, heretofore, been overlooked was the base rate of organicity among hospitalized patients. What is the anticipated frequency above which any test must substantially function if it is to be of any use? Stilson, Gynther, and Gertz (1957) raised this question relative to the SAE and, on the basis of Price and Deabler's sample, estimated the base rate to be 16 per cent. The authors concluded that the results of Price and Deabler, and those of Page, *et al.* represented a substantial reduction of error over the use of mere base rates for diagnostic purposes. Hence, Stilson, *et al.* felt that the SAE was a sensitive technique in terms of identifying cases within a class, but a poor discriminatory technique in terms of identifying particular types of cases from the total population. The authors point out that it is this discriminatory power upon which the clinical psychologist depends in order to differentiate the organic from the functional case. Gilberstadt, Schein, and Rosen (1958) claim that the use of the SAE does not significantly improve diagnostic efficiency in determining cortical damage over the use of base rates. The evidence provided in this study demonstrates minimal effects of the SAE, while those of Gallese (1956) indicate intermediate results in comparison with the maximal results obtained by Price and Deabler (1955).

A summary of the research, to this point, would suggest that the SAE has some merit in differentiating organics from non-organics but its discriminatory powers within this nosological category are limited. Perhaps in order to overcome this difficulty, some researchers have attempted to validate externally the SAE with other tests.

Garrett, et al. (1957), for example, combined the SAE and the Kendall Memory-for-Designs Test. The external validity of the SAE was found to be high, but its ability to differentiate degrees of organicity was still poor. The authors classified the SAE as primarily a sensory phenomenon of a non-veridical nature. Those cases which were not properly identified by the SAE were picked up by the Kendall test. Hence, the reliability and validity of the diagnostic procedure were increased by the addition of the Memory-for-Designs tests. The following year, Price, Garrett, Hardy, and Hall (1958) added a third test, the binaural beat phenomenon. While there is a common factor among the three tests, each makes a unique contribution to the accuracy of the diagnosis. Thus, the reliability and validity of diagnosis were increased even further. In another type of comparison, Nilsson and Henriksson (1967) reported a high correlation between the SAE duration and the duration of the oculogyral illusion.

Blau and Schaffer (1960) indicated that the SAE had become an important and controversial technique and that the differences in reported results could be attributed to variations in equipment, sampling, and criteria. These authors tested 425 children between the ages of 5-16 in an outpatient clinic setting. They used a battery of four techniques, the SAE, the Bender Gestalt, the Draw-a-Person, and several sub-tests of the WISC, in order to predict EEG recordings. Previously, Berger, et al. (1958) reported that the SAE was not related to EEG findings, pneumonencephalograms, or skull X rays. Blau and Schaffer (1960) found the SAE was the best of the series in predicting EEG results, and was particularly effective as a discriminating technique. This led the authors to suggest that the SAE, in combination with other tests, was the best available screening technique for neurological referrals. Berger, et al. (1958) also were interested in determining the perceptual difficulty and duration of aftereffect for both type A and type B spirals. They found that the type A spiral, which gives an expanding aftereffect, was seen with greater ease and for a longer period of time than the type B spiral. Beyond this, the authors saw the SAE as a heuristic laboratory technique, but felt it was inadequate when used to differentiate ambiguous and difficult diagnostic cases. The inability of the SAE to identify accurately the borderline case was also noted by Johnson, Bauer, and Brown (1959).

Goldberg and Smith (1958) used the spiral to test general admissions to a medical and surgical hospital, hence a less chronic type of population than is found in state hospitals or in Veteran's Administration hospitals, where many of the earlier studies were conducted. Goldberg and Smith indicate that the SAE has little utility as a technique for differential diagnosis. The normal subjects in their study had no difficulty in reporting the SAE, but decreasing efficiency was noted among psychotics, post electric-shock patients, and organics. However, when these hospitalized groups were adjusted for age, there was no significant distinction between them. Thus, the SAE did discriminate normal from pathological subjects, but not organics from psychotic subjects. Goldberg and Smith did indicate that such variables as rate of rotation, spiral size, and level of illumination have some influence on the SAE. Philbrick (1959) examined admissions to a neurological ward of a general hospital. Subsequent to the SAE, the Weinstein sodium amytal test was administered to 53 of 72 organic subjects and they were reexamined with the SAE. The Weinstein test increases organic symptoms when diffuse pathology exists. Scoring the SAE on a see- no-see basis, Philbrick found that there was no differentiation between those admissions subsequently diagnosed as organics and those diagnosed as non-organics. Philbrick stated that the SAE was not a useful tool in determining brain pathology in a general hospital. Garner, Neuringer, and Goldstein (1968) also felt the SAE discriminated poorly between brain damaged and non-brain damaged subjects.

A number of general theoretical explanations have been offered in an attempt to explain the spiral aftereffect. Most of these explanations were first introduced in terms of the figural aftereffects (FAE), and were then extrapolated to the SAE. A family of theories was generated around the basic Pavlovian concepts of cortical irradiation and inhibition. Shapiro (1954) offered an inhibition theory. According to this view, the brain damaged individual is unable to perceive the SAE because the irradiation, emanating from the cerebral focal point, is inhibited. Talland (1958) supported this theory when he explained the inability of his subjects, with Korsokoff's psychosis, to perceive apparent movement.

Another theory, using the same principles but emphasizing a different process, was presented by Kohler and Wallach (1944). Their satiation theory, which includes among its exponents Hans Eysenck (1952, 1955), posits cortical alteration of a given area due to prolonged stimulation by a particular figure. The area is sated, during the inspection period, by the contours of the figure. Simultaneously, there is an increase in the resistance of this area to accept other figural contours and this area of resistance spreads. When the test figure is presented, it cannot overcome the cortical resistance present, and its shape then is perceived as being similar to that of the inspection figure, thus decreasing the ability to perceive the actual test contour. Spivack and Levine (1957) found that results from the SAE and the Necker Cube test did not correlate significantly and this prompted them to suggest that either the SAE is not a satiation phenomenon or that the SAE and Necker Cube tap different cortical functions. Spitz (1958) felt that the Satiation Theory was an adequate explanation of the FAE but was less well applied to the case of the SAE. Both Smith (1952) and George (1953) noted great difficulty in applying the Satiation Theory to gamma movement.

Related theories are represented by the views of Klein and Krech (1952), who explain individual differences in the perception of FAE on the basis of cortical conductivity, and Wertheimer (1956) who suggests that cortical modifiability is the result of maximum metabolic efficiency. Thus Wertheimer predicts that the brain damaged are less capable of perceiving FAE because of decreased metabolic efficiency. Spivack and Levine (1959) find however, that adult organic subjects have a longer SAE duration than do control subjects and thus suggest that little is gained by applying the views of Klein and Krech, Wertheimer, and Eysenck to the SAE.

The question of whether the SAE is a peripheral or a central nervous system phenomenon is often discussed. Early theories stressed retinal factors such as the ocular musculature and its innervation, muscle fatigue, or eye movements. Little emphasis was given to central factors save for the influence of attention upon the SAE. More recent theories, such as those mentioned above, concentrate on the central nature of the phenomenon. Contralateral transfer of the aftereffect from the stimulated eye to the unstimulated eye is frequently pointed to in support of such a position. Walls (1953) demonstrated contralateral transfer of the illusion from one eye to the other, but Pickersgill and Jeeves (1958) found little evidence to support this transfer in their study. Freud (1964a), however, indicates that transfer effects are complete between homonymous hemiretinas. By this time Eysenck (1955) had stated that retinal factors play some part in the development of the SAE, and Holland (1958) demonstrated that only 60 to 70 per cent of the normal duration of the SAE is transferred. Thus, to strengthen the argument for central control and to test the generation and dissipation of inhibitory potentials, Eysenck, Holland, and Trouton (1957) administered drugs to their subjects prior to viewing the SAE. A central depressant drug shortened the duration of the SAE, but a central excitant did not significantly lengthen it beyond the effects of a placebo. Still Eysenck bases his explanation of individual differences on cerebral factors. Costello (1960a) also found that meprobamate caused a general decrease in SAE results. While Pickersgill and Jeeves (1962) reported that transfer was not universal, they were persuaded by their results to assign the more important role, in the SAE, to cerebral processes.

Statistical explanations of apparent motion have also appeared (Deutsch, 1956; Osgood and Heyer, 1952). The theory of Osgood and Heyer was derived from the work of Marshall and Talbot (1940) and emphasizes the functioning of the visual mechanisms, particularly the on-off responses of the retinal receptors. Gradients of stimulation are caused by the on-off firings of a varying number of cones, which come into play as a result of the eye movements. Hence, there are different rates of excitation and adaptation. The statistics apply to the differential rate of recovery, and as George (1953) points out, this rate depends on the time interval between inspection and the presentation of the test figure. George indicates that this theory is not a refutation of the Satiation Theory but is a more parsimonious explanation, if a neurophysiological base can be assumed.

Theories about the perceptions of brain damaged individuals of course suggest the work of Kurt Goldstein (1940). His basic premise is that the perceptual deficiencies are not due to specific tissue damage, but instead are due to the inability of organics to order (abstractly) and neutralize the resultant threatening aspects of the world. The organic avoids inexplicable phenomena by limiting his awareness or by not admitting his perceptions. The sum total of this behavior suggests a lowering of efficiency. Saucer and his associates (Saucer and Deabler, 1956; Saucer, 1958; Saucer and Coppinger, 1960) developed an isomorphic theory of motion perception based on Goldstein's work. They considered the cortex to be a single matrix such that damage to any part would result in a general loss of efficiency. Thus, perception was conceived of as a global cortical activity. Measurement of the organizational force, available to the individual for apparent motion, was tantamount to measuring the functional efficiency of the individual and hence the presence or absence of cortical pathology (Saucer and Deabler, 1956). Werner and Thuma (1942) reported that brain injured children were unable to perceive apparent motion tachistoscopically. They felt this to be a fundamental deficiency of neurophysiological organization, namely a perceptual difficulty in figure - ground relationships.

Mayer and Coons (1960) noted that there was no seeming relation between the locus of brain damage and inability to perceive the SAE, though some organics in all studies did see the aftereffect. Hence, they were of the opinion that lack of perceiving the SAE might be due to psychological factors. They hypothesized that organics fail to report the strangely appearing aftereffect because to do so would label them ill or queer. If this be the case, then assurance at the outset of the experiment should eliminate this failure in reporting. The authors utilized three sets of instructions. The neutral instructions merely explained that the spiral would turn and asked the subject what he saw when it stopped; the reassuring instructions indicated that most people see something strange happening to the spiral when it stops; while anxiety-provoking instructions stated that people in hospitals, due to their illness, see something strange when it stops. It was found that organics given reassuring instructions performed as well as schizophrenic subjects. London and Bryan (1960) did much the same thing in giving organics prior information as to what they might experience. They felt that the anticipatory set served to create excitatory effects which checked the inhibition, thus allowing the organic to perceive the SAE. The authors consider the SAE to be a useful instrument but call for the establishment of standardized procedures and norms for various clinical groups.

Controversy, regarding the SAE, is not limited to the clinical investigations of brain damage nor to the theoretical formulations of this phenomenon. There is decided discrepancy in the literature about the basic parameters underlying measures of the spiral aftereffect. While these variables have not been totally ignored in some of the previous studies, they have received only cursory attention. It seems logical, if we are to discuss the adequacy of a test of organicity, that the basic parameters of the test be well understood. That such is not the case today, is quite evident.

One might question whether there is any difference between the results produced by the type A spiral (real motion of contraction and aftereffect of expansion) and the type B spiral (real motion of expansion and aftereffect of contraction). Wohlgemuth first noted a difference in duration favoring the centrifugal aftereffect. Most of the evidence seems to favor this position (Berger, *et al*., 1958; Spitz and Lipman, 1959; Costello, 1960b, 1961; Eysenck, Willett, and Slater, 1962; Scott and Medline, 1962; Costello, 1966; Scott, Lavender, McWhirt, and Powell, 1966). However, Pickersgill and Jeeves (1958) were not able to find any asymmetry between the two types of spirals. Various explanations have been offered for this asymmetry, the earliest of which was the one put forth by Wohlgemuth (1911), who suggested that continued fixation brings about fatigue and blurring of the image. The resulting image is enlarged favoring centrifugal movement and counteracting centripetal movement. Scott, *et al*, (1966) discount this explanation.

Bakan and Mizusawa (1963) explain the asymmetry in terms of fixation. According to their position, fixation is facilitated by centripetal stimulation because the eyes are drawn towards the center by the movement of the spiral. Fixation is likewise impaired by centrifugal stimulation because the eyes are drawn away from the fixation point. Thus, a type B spiral (centrifugal stimulation) reduces the aftereffect. The importance of fixation had been mentioned by Freeman and Josey (1949) and ascribed as a possible cause of the organic's inability to perceive the SAE. However, they later rejected this idea when they found the subjects capable of reporting the direction of the spiral. What they seem not to have appreciated was the fact that being able to describe the direction of the spiral is not the equivalent of fixating its center. Holland (1957) likewise suggested that the lack of fixation might be responsible for the brain damaged subject's deficiency with the SAE. Yet in 1958 (Holland and Beech, 1958) it was indicated that this was only one of the possible causes. Day (1960) changed the emphasis slightly. He said that lack of fixation does adversely affect the SAE, but he did not ascribe this lack to the inattentiveness of the brain damaged. He felt that the voluntary control of fixation had been rendered ineffective due to frontal lobe damage. The control of fixation, he reasoned, was then replaced by occipital reflex activity which enabled the eye to follow the movements of the spiral rather than concentrate on the center. Thus, Bakan and Mizusawa's explanation of spiral asymmetry as due to lack of fixation on the center appears to have corroborating evidence. Peters (1967) on the other hand, found little correlation between eye-movements and the SAE duration.

Scott, _et al._ (1966) showed that the reversal of the spirals had an insignificant effect upon eye movements, which is contrary to the expectations of the Bakan and Mizusawa hypothesis. Hence, Scott, _et al._ rejected this hypothesis and conclude: "...(the) hypothesis cannot account for more than a very small fraction of the obtained asymmetry." Costello (1966) also questioned the Bakan and Mizusawa explanation. However, his point of view represents a position based on central processes, and explicitly his Homeostatic Excitation - Inhibition Theory (Costello, 1961, 1964). Deutsch (1956) proposed that a wave front of excitation is propogated in the direction of the moving stimulus. Therefore, excitation from a centripetal stimulus would remain within the cortical area (contour of the spiral) corresponding to the spiral. Excitation from a centrifugal stimulus, on the other hand, would spread beyond this area (contour) and thus accumulate less excitation. Hence, the theory provides, for an equal period of stimulation, that the stimulus, for which more excitation is accumulated, will result in a longer duration of aftereffect since the duration is proportional to the amount of excitation built up. Thus, Costello (1966) hoped to explain the asymmetry on this basis and not, as Bakan and Mizusawa suggest, on the basis of fixation.

In his study, Costello (1966) made use of the techniques utilized by Spigel (1960, 1964). Briefly, Spigel found that the termination of the aftereffect could be extended, or to use his terms - the rate of decay of the movement aftereffect is inhibited, by the interspersion of darkness or homogeneous illumination following stimulation. Hence, if the decay of the aftereffect were independent of illumination (and fixation), there should be no difference in SAE duration when the interspersed period of darkness, equivalent to the individual's mean duration time, had elapsed. But this was not the case. Thus, Costello argued if the asymmetry is due to the extent of fixation, then the delay of the normal decay function of the aftereffect for both types of spirals would be the same following an interval of darkness. This seems to be rather circuitous reasoning and there is little surprise to find that he obtained significant differences between the centrifugal and centripetal aftereffects. Thus, Costello managed to replicate the inhibitory effects of post-stimulation darkness but had little of consequence to add to the role of the fixation hypothesis in the problem of spiral asymmetry. It is interesting to note that Scott, et al. (1966) also reported that asymmetry is not peculiar to the spiral aftereffect and may well be due to some structural aspect of the retina and/or central nervous system. These investigators also studied the aftereffect over a four-day period and found that continued exposure brought about a marked reduction in asymmetry. This caused them to postulate an environmental adaptation hypothesis which attempted to explain the human's differential response to the spirals on the basis of massive centrifugal stimulation throughout his life.

The dependence of the aftereffect upon fixation is unequivocally stated in a paper by Morant and Efstathiou (1966). They say that the impairment of the SAE is directly related to the maintenance of fixation. The consequence of such a view is, of course, that the SAE would not discriminate between any groups in which the subjects were not able to attend or fixate on the stimulus. The same authors (Efstathiou and Morant, 1966) showed that when fixation is not required, such as in the waterfall illusion, brain damaged subjects function near normal levels.

The level of illumination of the spiral, or the brightness contrast between the spiral and the background, seem to have little effect upon the duration of the SAE. Day (1957, 1958) investigated this problem and his results are in agreement with those of Holland (1958) and of Pickersgill and Jeeves (1958). Griffith and Spitz (1959) were concerned with the surface needed to produce an aftereffect. It had generally been thought that any surface would suffice. However, Griffith and Spitz contended that the surface must be a textured one or else the aftereffect is not possible. They also found that the basic inspection time necessary to produce a spiral aftereffect was similar to that of the figural aftereffect. It was of the order of one to five seconds.

The duration of the aftereffect has received considerable attention. Freud (1963) reported that the duration was a reliable measure and would more profitably replace the see- no-see type of measure. He further stated that the duration measure was asymptotic and increased as a monotonic function of the exposure time. Taylor (1963) however indicates that it is an exponential function of the exposure time. Freud (1963) was also interested in determining the optimal stimulation time and this investigation led him to suggest 15 seconds. It has been shown that a significant differential in duration time does result when exposure times of 10 seconds and 30 seconds are used (Truss and Allen, 1959). The adaptation rate of the SAE also shows a differential in terms of the type of subjects used. When adaptation signifies shorter duration times and an increased frequency of not perceiving the aftereffect, both normal and emotionally disturbed subjects have a faster adaptation rate than do brain damaged subjects (Levine and Spivack, 1962). Maxwell (1968b) states that, as trials progress, the subject establishes an individual criterion of when the SAE stops. This, he feels, accounts for a progressive diminution of the SAE duration. Yet, Anderson (1966) and Smith, Fries, and Anderson (1969) considered visual aftereffects to represent a process rather than a non-sequential phenomenon. Thus, they have found the SAE response to stabilize over a number of trials.

Another question which has confronted the investigators of the spiral aftereffect is that of the order of presentation of the different types of spirals, that is, the expanding type spiral (B) and the contracting type spiral (A). The most common presentations have been ABAB, AABB, and AAAA. Roehrig and Rutschmann (1963) found that an alternating presentation (expanding followed by contracting spirals or vice versa) caused a reduction of the SAE duration. An inhibitory effect, which is most probably neural in nature, seems to persist over the intertrial interval. This disrupts the next aftereffect and the duration is lessened. Roehrig and Rutschmann identified three stages in the development of the aftereffect. Initially, there is a positive aftereffect which exists for a few moments and then dissipates rapidly. This is followed by a latency period in which the stimulus does not appear to change in size or distance. Finally, the negative aftereffect begins to appear. These authors report that the aftereffect did not commence until four seconds after the spiral had stopped. They point out that aftereffects of five to eight seconds duration are indeed weak and may not be reported by the subject. This is especially likely to occur with the type B spiral (contracting aftereffect) when the subject compares it with the usually strong aftereffects produced by the type A spiral. Thus, they do not recommend an alternating order of presentation and suggest that only one spiral be used in research, or at least only one spiral be used on a given day. Panagiotou and Roberts (1966) also found a reduction in duration with alternating presentation of spirals. The latency period was found to be shorter for both the type A spiral and the consistent type presentation. Duration, in addition, was found to increase as the intertrial interval increased. The results of this study led the authors to suggest that two types of inhibition are operating during the aftereffect. The first type is general in nature and has a deleterious effect upon the next afterimage no matter which type spiral is used. However, the inhibitory effect seems to dissipate within five minutes. The second type of inhibition is more specific and applies to situations in which the alternating method of presentation is used. This effect does not appear to dissipate within five minutes.

The visual angle is another basic variable in most visual research (Graham, 1951). The size of the stimulus and its distance from the subject determine the angle subtended by the stimulus at the eye. The closer the object is, the larger will be the visual angle and the retinal image. When, however, the appropriate cues obtain, objects maintain their apparent size even though the distance increases. This is known as the law of size constancy, of which the law of visual angle is a special case (Holway and Boring, 1941). Interestingly enough, Holland (1957) mentioned that the visual angle had little effect upon the SAE. He reiterated this opinion in 1958 and said the visual angle "... may justify further investigation ... but (it) plays a very small role, if any." As he indicated in his book (1965), he used visual angles of four and six degrees. McKenzie and Hartman (1961) were interested in investigating three variables, those of spiral size (hence visual angle), rotation speed, and inspection time; the measure used was SAE duration. The authors distinguished between the initial period in which the aftereffect blooms (alpha phase) and the second portion characterized by rapid alterations of expansion and contraction (beta phase). They used only the former as the duration measure. It might be noted that Maxwell (1968a) questions the existence of two SAE phases. He is disposed to view the SAE as one phenomenon which is interrupted by lack of attention and gross eye movements. This suggests that

McKenzie and Hartman's duration scores might not be directly comparable to the measures of other studies. Be that as it may, McKenzie and Hartman found no significant effect due to spiral size (visual angle), though significant results were obtained for the other two variables. The visual angles used in their study were $2^{\circ}8'$, $4^{\circ}14'$, and $6^{\circ}22'$. Thus, one might assume, on the basis of Holland's work and that of McKenzie and Hartman, that the visual angle does not have any significant influence upon the spiral aftereffect.

Granit (1927, 1928) suggested that the visual angle was of importance in the determination of apparent motion. Using the waterfall illusion, he obtained a peaking effect in durational responses between two and four degrees of visual angle. The duration measures increased up to this optimal point and thereafter decreased as the angle became larger. Supportive evidence of this view is found in the results of Pickersgill and Jeeves (1958). They found that the relationship between visual angle and duration is a non-linear one. Duration scores increased up to a point subtending an angle of $5^{\circ}44'$ and then decreased beyond that point. Costello (1960b), using the same visual angle at two different distances, found significantly shorter aftereffects for the shorter distance (smaller size spiral). Fozard, Fuchs, Palmer, and Smith (1965) investigated the effects of six variables, among them visual angle and rotation speed. They consistently found higher duration scores for visual angles of $2^{\circ}23''$ and $4^{\circ}46'$ than those obtained for an angle of $9^{\circ}23'$. Thus, the peaking effect mentioned by Granit receives some confirmation. Yet, Freud (1964b) found a linear relationship between duration and visual angle. He had the subjects fixate on different points of the spiral in order to stimulate foveal and peripheral areas of the retina. With visual angles of two, four, and eight degrees, he obtained a steady increase in the duration score.

In order to study visual angle, two methods are generally employed. One technique varies the size of the spiral (Pickersgill and Jeeves, 1958; McKenzie and Hartman, 1961; Fozard, et al., 1965); the other utilizes a variation in viewing distance (Freud, 1964b; Holland, 1958). Collins and Schroeder (1968) varied both spiral size and viewing distance by using several spirals with diameters between two and 16 inches and varying the visual angles between $1^{\circ}12'$ and $18^{\circ}56'$. Their results clearly showed a non-linear function between visual angle and duration. They obtained a peaking effect between two and four degrees which agrees essentially with the results of Granit, Pickersgill and Jeeves, and Fozard, et al. They suggested that the failure of Holland and of McKenzie and Hartman to obtain this peaking may in part be due to the fact that they used both too small a range of angles and angles which were too close to the optimal point (i.e., around 4°) to show statistical significance. Williams and Collins (1970) also investigated the effect of visual angle upon duration. However, they used three conditions, a "size constant" condition, a "visual angle constant" condition, and a "distance constant" condition. They obtained the anticipated peaking effect in the size constant condition. Duration scores increased up to an angle of two degrees and then decreased continually to an angle of 16 degrees. In the visual angle constant condition, several spiral sizes and distances were so manipulated as to maintain a visual angle of four degrees for the observer. An anticipated result was that duration scores would remain relatively constant; yet they increased significantly from the smallest size spiral (closest to the subject) to the largest size spiral (greatest distance from the subject). The authors explained this result on the probable basis of factors associated with perceived size which, because of the existing visual cues, probably increased as successively larger spirals were employed.

The physical speed of the rotating spiral has come under consideration, and once again conflicting results can be found. Holland (1958) reported no effects upon duration with rotating speeds of 50 and 150 rpm. Likewise, Fozard, et al. (1965) found no effect when rotating speeds of 25, 100, and 250 rpm were used. However, Pickersgill and Jeeves (1958) found a significant difference between a spiral rotated at 16 rpm (the SAE duration was shorter) and one rotated either at 45 or 78 rpm (there was no difference between the latter). McKenzie and Hartman (1961) also found significant differences for rotational speeds of 40, 80, and 120 rpm. Finally, Sindberg (1961) reported significant differences with spirals rotated at 18, 54, and 90 rpm. As important as the physical speed of the spiral may be, the retinal speed must be considered. Granit (1928) noted that the retinal speed and visual angle decrease together. The importance of the retinal speed was stressed by Scott and Noland (1965). Scott (1960, 1962) had presented a method of calculating the normal motion at the edge of a rotating spiral and in his article with Noland (1965) designated the measure as the Speed of Eliciting Motion (SEM). The measure assumes that the visual angle is a factor and the SEM is expressed in terms of minutes of arc per second (minarcs/sec). Scott and Noland had hoped, by this method, to account for the differences in duration that previously had been attributed to spiral size, distance, visual angle, and rotational speed. The SEM then gives a measure of the speed of the stimulus across the retina as determined by the distance of the spiral from the subject.

Scott and Noland (1965) re-evaluated the data of three prior spiral studies (Granit, 1928; Scott, 1962; Freud, 1964a) in terms of the SEM. This reworking indicated that the duration of the SAE increased for SEM speeds between 30 and 132 minarcs/sec, and decreased beyond that point. Stager and Burton (1964) found a maximum duration between 148 and 172 minarcs/sec. However, Stager (1966) indicated that the optimal rate of stimulation still remained to be determined. Collins and Schroeder (1968), using the SEM measure, found SAE duration to increase between 30 and 60 minarcs/sec. They also recalculated the data of Fozard, *et al.* (1965) in minarcs/sec and found a wide range of optimal points depending upon the variables manipulated. Williams and Collins (1970) found the SEM to have no effect upon SAE duration between 50 and 200 minarcs/sec. Thus, their results showed a considerable discrepancy from the previous reports of Scott and Noland, and of Stager and Burton. Yet, the data of Williams and Collins suggest that there might be an effect of SEM below approximately 50 minarcs/sec. The data for 20 minarcs/sec and 50 minarcs/sec for a visual angle of four degrees yielded differences which were considerable but were just short of statistical significance. Thus, the speed of eliciting motion, while ineffective above 50 minarcs/sec may be responsible for changes in SAE duration below that value. Williams and Collins offered another alternative, however. They suggested that if the SEM is not the cause of these differences, then the perceived speed might be responsible. These authors also were cognizant of the possible effects of perceived size when duration scores increased in their "angle constant" condition. So in this case, the perceptual element may play the deciding role.

Support for such a view is gained through the work of Gogel and his colleagues (Gogel and Mertens, 1967, 1968; Gogel and Mershon, 1969) who suggest that depth and brightness judgments may vary because of certain perceived characteristics rather than the physical characteristics of the stimulus. A similar example of the importance of perceived rather than physical factors may be found in the work of Hildt and Van Liere (1965).

Reviewing the findings on the spiral aftereffect, one is struck by the fact that two possible influences on SAE durations require clarification. The first of these deals with the importance and influence of perceptual phenomena on spiral aftereffect results. Unexpected increases in duration were obtained by Williams and Collins (1970) in a "visual angle constant" condition, while Costello (1960b) reported similar results in a like situation. Williams and Collins proposed that perceptual factors might be responsible for the durational increases, while Granit (1927) had earlier suggested possible effects produced by size constancy. Yet none of these studies obtained measures of perceived size, hence these views represent <u>post hoc</u> hypothesizing. However, by presenting a "visual angle constant" condition and obtaining measures of perceived size, one might be able to supply an answer to this proposition.

The second influence of note is contained in the recent theory offered by Scott and Noland (1965) in which retinal speed rather than the physical speed of the spiral is influential in producing increases in duration up to a limit or peak. The limit or peak suggested by Scott and Noland seems to be questionable in view of the results of Williams and Collins. Yet Scott and Noland may be correct for stimulus values below 50 minarcs/sec. Hence, presentation of varying SEM speeds over a wide range of angles may provide the final answer for this theory.

The purpose of the present study is to investigate, with normal subjects, the effects of retinal speed and retinal size upon the SAE duration. This study includes the utilization of two conditions; a size constant condition and an angle constant condition. In the size constant condition a spiral, four inches in diameter, was presented at varying distances from the observer. These distances caused five different visual angles to be subtended at the eye. For each visual angle, seven different speeds (SEM) were presented and the duration of the spiral aftereffect, as well as measures of perceived size, distance, and speed, were obtained. This allowed an evaluation of the effect of visual angle, retinal speed (SEM), and perceptual factors upon the SAE duration. Failure to obtain an effect of SEM upon the SAE duration partially refuted the Scott and Noland theory. Moreover, in place of retinal speed it was found that perceived speed was the determining factor.

The angle constant condition contains two sessions; a rpm constant session (in which the actual speed of the spiral is held constant), and a minarcs/sec constant session (in which the retinal speed is held constant). Within each session three different visual angles were used (2°, 4°, and 8°). Within each visual angle, three different settings were used (varying size of spiral and distance from the observer). This allowed an evaluation of the effects of retinal size, as well as perceived size, upon the duration of the spiral aftereffect. Since SAE duration increased as perceived size increased, the effects of retinal size was not viewed as the determining factor under most conditions.

The hypotheses of this study are:

(1) SEM measures will have an effect on the duration, over a range of angles, below 50 minarcs/sec. Duration will increase as SEM increases.

(2) SEM measures have no effect on duration between 50 and 100 minarcs/sec.

(3) Peaking effects between 2° and 4° of visual angle will be evidenced in SAE duration scores in spite of maintaining a constant SEM.

(4) The duration of SAE will increase in the "angle constant" condition with increases in the diameter of the spiral (greater distances from the subject).

(5) Perceived size measures will increase, in the same condition, under the same circumstances.

(6) Increases in SAE duration can be attributed to increases in perceived size.

CHAPTER II

APPARATUS AND PROCEDURE

The methods used in this investigation will be outlined under three headings: subjects, apparatus, and procedure.

Subjects

(1) The subjects (Ss) were 14 paid volunteer males between the ages of 18 and 29, recruited from the University of Oklahoma.

(2) All prospective Ss were questioned about head injuries, high fevers, and hospitalizations prior to acceptance in the experiment. Two prospective Ss (foreign students) were eliminated because of language problems.

(3) All Ss qualified on the Ortho-rater according to the following criteria:

- (a) uncorrected distance acuity of at least 20/30
- (b) near acuity of 20/25
- (c) normal muscle balance
- (d) normal depth perception.

(4) After qualifying on the Ortho-rater, each prospective S was given two preliminary trials in which he was asked to describe his sensation while the spiral was rotating (8-inch spiral at 12 feet, rotating at 100 rpm for 15 seconds) and when it had stopped. This was done to assure the Ss ability to perceive the aftereffect, and it also

served as a demonstration. No Ss were eliminated as a result of this selection process.

(5) Then, each prospective S was asked to estimate the size of the spiral, the distance between him and the spiral, and the rotational speed of the spiral. No Ss were eliminated as a result of this selection process.

Apparatus

(1) Bausch and Lomb Ortho-rater - This is a specialized Brewster Stereoscope which produces slides optically at two settings. It tests monocular and binocular muscle balance, near acuity, and stereopsis or depth perception.

(2) Brenet No. 5 Stop Watch - This was used to time the interval between trials.

(3) Hunter Decade Interval Time (Model 111C) - This timer controlled the duration of the stimulus presentation. It was connected to the motor and the speed control (see Figure 1).

(4) Hewlett-Packard Electronic Counter (Model 521 AR) - The counter was used to give a numerical readout which, by calibration procedures, corresponded to the precisely desired speed of the motor (see Figure 2). It was connected to the motor and the power source.

(5) DC Interval Timer - This was used to obtain the duration of the aftereffect and could be read in hundredths of seconds (see Figure 2). It was activated by a microswitch which the subject depressed at the beginning of the aftereffect and was stopped when the subject released the microswitch. It was connected to the junction box and the microswitch.

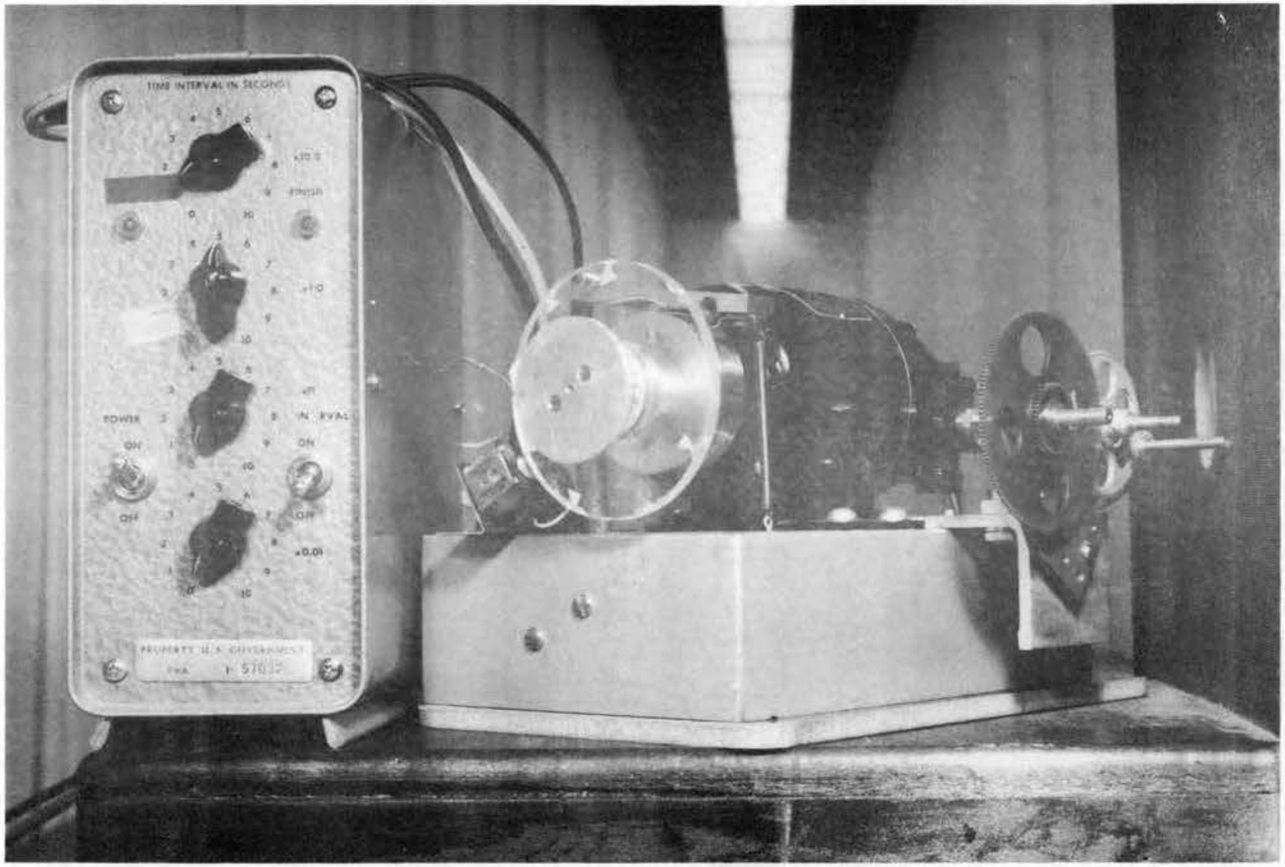

Figure 1. The Hunter Decade Interval Timer (Model 111C) and the Bodine Reducer Motor (Type NSH-12R) Viewed From the Side of the Wheeled Cart, Showing the Four Separate Gears of the Motor and the Slot Through Which the Gears Were Projected

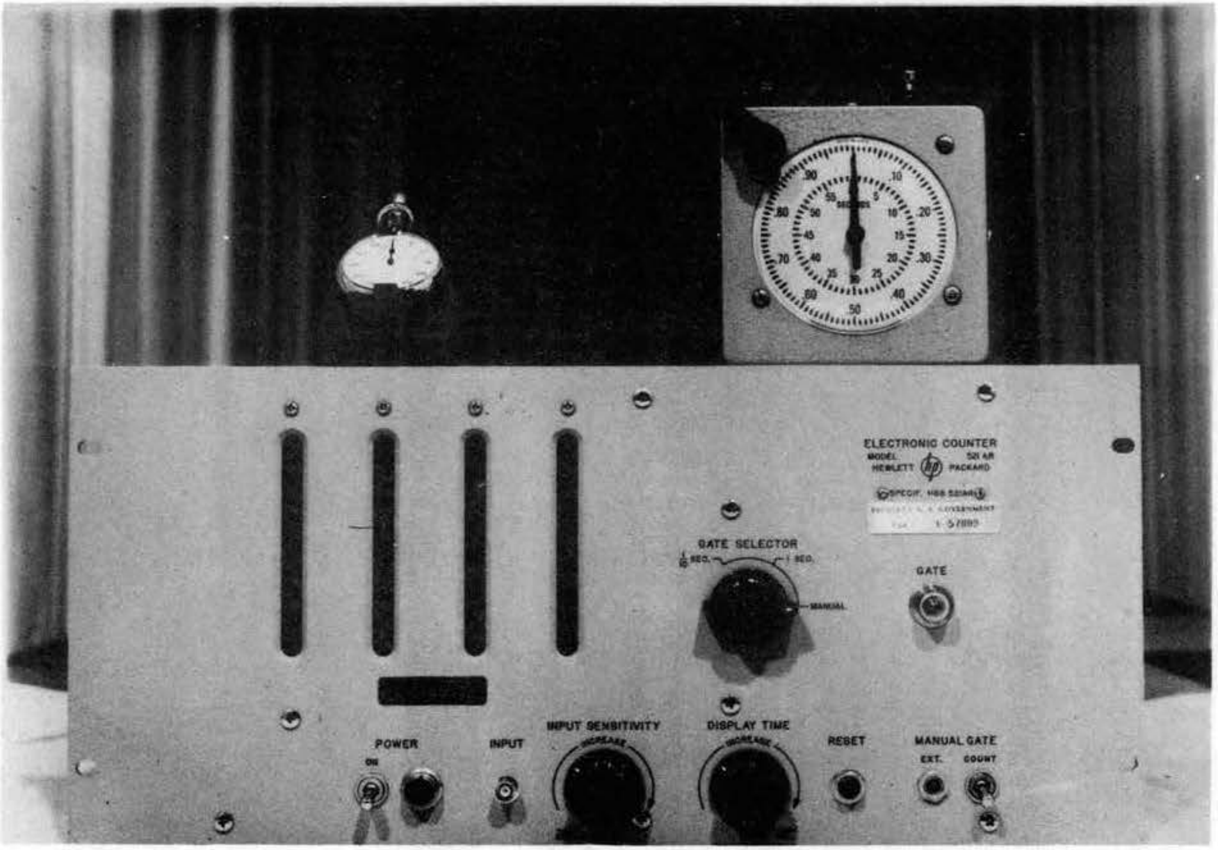

Figure 2. The Hewlett-Packard Electronic Counter (Model 521 AR), the DC Interval Timer, and the Brenet no. 5 Stopwatch

(6) Bodine Speed Reducer Motor (Type NSH-12R) - The motor was modified so as to provide four separate gears which permitted a wide range of shaft speeds (see Figure 1). The motor was connected to the junction box.

(7) La Pine 5-in-1 Control (Junction Box) - The junction box received connections from the interval timer and the motor and was connected to the source of electricity.

(8) Speed Control MSL (Model SM 100) - The speed control was directly connected to the power source and received a connection from the electronic counter. It allowed full torque and adjustment to a range of speeds.

(9) Spirals -

(a) All spirals were three throw arithmetic spirals which were photographically reproduced with equal portions of white and black. Three diameters were used: 4, 10, and 16 inches. Only type A stimuli (real motion of contraction and aftereffect of expansion) were presented.

(b) The spirals were attached to a shaft-driven variable speed motor.

(c) A timing system started the rotation, determined the stimulus duration (15 seconds), and stopped the rotation.

(d) The motor was set on a wheeled cart, one side of which had a mounted flat-white plyboard screen (17" x 18") which faced the observer and served as a viewing background. Spirals were attached to a drive shaft of the motor which projected through a hole in the screen (see Figure 3).

Figure 3. A 4-Inch Spiral set at a Distance of 9.5 Feet in the Visual Alley, Subtending a Visual Angle of 2°

(10) Visual Alley -

(a) The visual alley was 48 feet in length. The sides and end were draped in white cloth. The floor was tiled in white and gray checkerboard pattern (see Figure 4).

(b) The stimulus was viewed from a head and chin rest secured at one end of the alley. This allowed a straight line of visual sight for S to fixate the center of the spiral.

(c) Overhead fluorescent lighting was recessed in the ceiling and allowed a constant level of illumination along the length of the alley (see Figure 4).

(d) Duration of the aftereffect was measured with timing equipment activated by the depression of a microswitch located at the subject's position. Timing began when the spiral stopped rotating.

Procedure

(1) Each S was tested on each of seven days after being selected for the study. Each test period lasted from one and one-half to two hours, and was conducted at the Civil Aeromedical Institute of the Federal Aviation Administration, Oklahoma City, Oklahoma.

(2) Two stimulus conditions were used: (spiral) size constant (first five days of experimentation) and (visual) angle constant (last two days of experimentation).

(3) On the initial day of experimentation, the S was reminded of his experience during the selection period, in which he saw the spiral contract while it was rotating and expand when it stopped. He was now instructed to depress the red button (microswitch) when the spiral

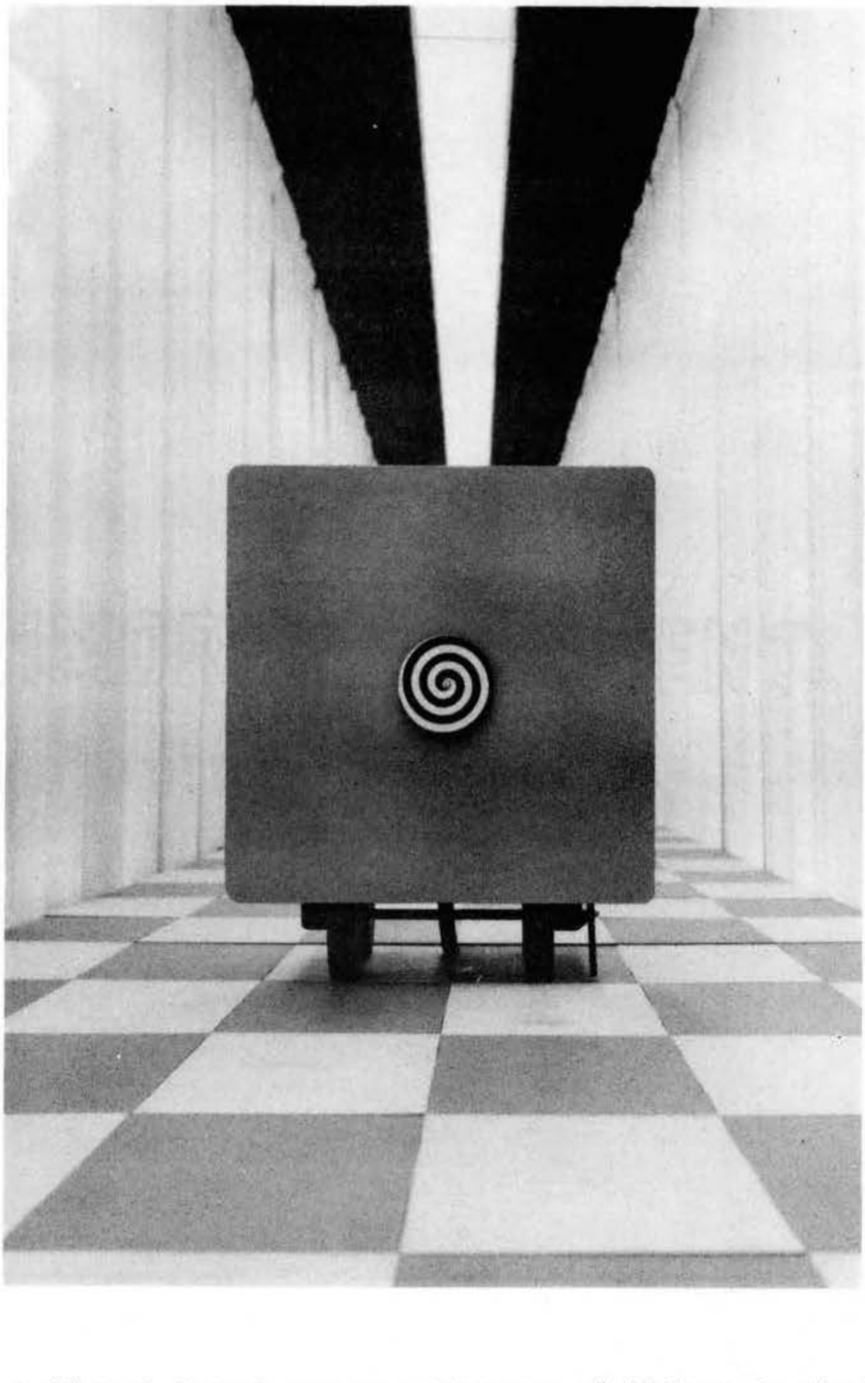

Figure 4. A 16-Inch Spiral set at a Distance of 38 Feet in the Visual Alley, Subtending a Visual Angle of 2°

stopped rotating and keep it depressed as long as the expansion sensation lasted.

(4) S was also told that he would be asked to estimate (in percentage values) the speed of the spiral. In order to provide him with a frame of reference, he was shown (this procedure was followed on each day):

(a) A spiral rotated at eight rpm for 15 seconds. He was told this represented "10 per cent" speed.

(b) After a two-minute rest period, he was shown a spiral rotating at 1280 rpm and was told that this represented "100 per cent" speed.

Size Constant Condition

(1) After the daily instructional period about speed, there was a three minute rest period.

(2) Following this each S received two preliminary (Pre) and two post (Post) session trials each day. Both Pre and Post session trials were identical for all seven days of experimentation. The presentation was a four-inch spiral, rotated at 75 rpm, at a distance of 4.77 feet, subtending a visual angle of four degrees (a sample calculation of a visual angle appears in the Appendix, Table XXIII). This provided a standard for comparison of possible changes in perceptual functions from the start to the end of each days' experimental trials. The S gave durational responses and responses of perceived size (spiral diameter in inches), perceived speed (spiral rotational speed in percentages), and perceived distance (distance in feet between S and the spiral).

(3) In the size constant condition, a four-inch spiral was presented at each of five distances to subtend selected visual angles. These were

(a) $\frac{1}{2}^{\circ}$ visual angle	38 feet
(b) 1° visual angle	19 feet
(c) 2° visual angle	9.5 feet
(d) 4° visual angle	4.7 feet
(e) 8° visual angle	2.4 feet.

(4) A single visual angle was presented on a given day. The presentation of angles was determined by random order from a table of random numbers (see Table I).

(5) For each angle, seven speeds of eliciting motion were presented (a sample SEM calculation appears in the Appendix, Table XXIV). The counterbalanced order of presentation appears in Table II.

(6) For each SEM setting, three durational responses and one judgment each of perceived size, distance, and speed was obtained. Each durational response followed a 15-second exposure to the spiral. A three-minute rest period followed each presentation of the stimulus.

(7) *Ss* were instructed during the preliminary trials and the experimental trials to fixate on the center of the spiral. They were also reminded to press the button as soon as the spiral stopped rotating.

(8) After each trial, during the rest period, *S* was instructed to face away from the alley. Reading material was made available. No smoking was allowed.

(9) The motor speeds necessary to produce each SEM at each angle are presented in Table III.

TABLE I

ORDER OF PRESENTATION OF VISUAL ANGLES IN THE SIZE CONSTANT CONDITION

	Days				
Subject	1	2	3	4	5
1	2°	4°	1°	½°	8°
2	4°	1°	½°	2°	8°
3	1°	½°	2°	8°	4°
4	½°	2°	4°	8°	1°
5	2°	4°	½°	8°	1°
6	4°	8°	1°	2°	½°
7	8°	½°	4°	1°	2°
8	2°	8°	1°	4°	½°
9	½°	4°	1°	8°	2°
10	½°	8°	1°	4°	2°
11	1°	4°	2°	½°	8°
12	2°	8°	½°	1°	4°
13	8°	2°	4°	1°	½°
14	8°	1°	½°	4°	2°

TABLE II

ORDER OF STIMULUS PRESENTATION IN THE SIZE CONSTANT CONDITION

		Minarcs/sec[1]				
Subjects		½°	1°	2°	4°	8°
1	Forward sequence	100	50	40	10	80
2		80	60	50	20	100
3		60	80	60	40	10
4		50	100	80	50	20
5		40	10	100	60	50
6		20	20	10	80	40
7		10	40	20	100	60
8	Backward sequence	10	40	20	100	60
9		20	20	10	80	40
10		40	10	100	60	50
11		50	100	80	50	20
12		60	80	60	40	10
13		80	60	50	20	100
14		100	50	40	10	80

[1] The value specified in the table indicates the first stimulus speed (in minarcs/sec) used for a given visual angle; the remaining six speed-presentations for that same angle followed in numerical progression either forward (e.g., 10, 20, 40, 50, 60, 80, 100 for subject 1 at 4°; or 80, 100, 10, 20, 40, 50, 60 for subject 1 at 8°) or backward (e.g., 100, 80, 60, 50, 40, 20, 10 for subject 8 at 4°; or 60, 50, 40, 20, 10, 100, 80 for subject 8 at 8°).

TABLE III

MOTOR SPEEDS (RPM) REQUIRED TO PRODUCE THE SPECIFIED RETINAL SPEEDS (SEM) FOR EACH OF THE FIVE VISUAL ANGLES

	Motor Speed (RPM)				
SEM	½°	1°	2°	4°	8°
10	128	64	32	16	8
20	256	128	64	32	16
40	512	256	128	64	32
50	640	320	160	80	40
60	768	384	192	96	48
80	1024	512	256	128	64
100	1280	640	320	160	80

Angle Constant Condition

(1) On the sixth and seventh days of experimentation, the angle constant conditions (rpm constant and minarcs/sec constant) were presented by alternating their order of presentation among Ss (see Table IV).

(2) Presentation of visual angles within conditions were counterbalanced as indicated in Table IV. The order of presenting the three spiral sizes (4, 10, and 16 inches) for each visual angle in the rpm constant and in the minarcs/sec constant sessions were also counterbalanced as indicated in Table V.

(3) Again both preliminary and post session trials with the standard stimulus were given each day.

(4) For each of the nine settings in the rpm constant and in the SEM constant conditions, three durational responses and one estimate of perceived size, speed, and distance were obtained.

TABLE IV

ORDER OF PRESENTATION OF VISUAL ANGLES IN THE VISUAL ANGLE CONSTANT (VAC) CONDITION

	Session VAC-I		Session VAC-II	
Subject	Condition	Visual Angle (°)	Condition	Visual Angle (°)
1	R[1]	2° - 4° - 8°	S[2]	8° - 4° - 2°
2	S	4° - 8° - 2°	R	2° - 8° - 4°
3	R	8° - 2° - 4°	S	4° - 2° - 8°
4	S	8° - 4° - 2°	R	2° - 4° - 8°
5	R	4° - 2° - 8°	S	8° - 2° - 4°
6	R	2° - 8° - 4°	S	4° - 8° - 2°
7	S	2° - 4° - 8°	R	8° - 4° - 2°
8	R	4° - 8° - 2°	S	2° - 8° - 4°
9	S	8° - 2° - 4°	R	4° - 2° - 8°
10	S	8° - 4° - 2°	R	2° - 4° - 8°
11	R	4° - 2° - 8°	S	8° - 2° - 4°
12	S	2° - 8° - 4°	R	4° - 8° - 2°
13	R	2° - 4° - 8°	S	8° - 4° - 2°
14	S	8° - 4° - 2°	R	2° - 4° - 8°

[1] R = RPM Constant.

[2] S = SEM Constant.

TABLE V

ORDER OF PRESENTATION OF SPIRAL DIAMETERS WITHIN VISUAL ANGLES FOR THE ANGLE CONSTANT CONDITION

	Spiral Diameter in Inches					
	2° Visual Angle		4° Visual Angle		8° Visual Angle	
Subject	Session VAC-I	Session VAC-II	Session VAC-I	Session VAC-II	Session VAC-I	Session VAC-II
1	10-16-4	4-16-10	4-10-16	16-10-4	16-4-10	10-4-16
2	16-4-10	10-4-16	10-16-4	4-16-10	4-16-10	10-16-4
3	4-16-10	10-16-4	16-4-10	10-4-16	10-4-16	16-4-10
4	4-10-16	16-10-4	16-10-4	4-10-16	10-16-4	4-16-10
5	16-10-4	4-10-16	10-4-16	16-4-10	4-10-16	16-10-4
6	10-4-16	16-4-10	4-16-10	10-16-4	16-10-4	4-10-16
7	10-16-4	4-16-10	4-10-16	16-10-4	16-4-10	10-4-16
8	16-4-10	10-4-16	10-16-4	4-16-10	4-16-10	10-16-4
9	4-16-10	10-16-4	16-4-10	10-4-16	10-4-16	16-4-10
10	4-10-16	16-10-4	16-10-4	4-10-16	10-16-4	4-16-10
11	16-10-4	4-10-16	10-4-16	16-4-10	4-10-16	16-10-4
12	10-4-16	16-4-10	4-16-10	10-16-4	16-10-4	4-10-16
13	10-16-4	4-16-10	4-10-16	16-10-4	16-4-10	10-4-16
14	4-16-10	10-16-4	16-10-4	4-10-16	10-4-16	16-4-10

CHAPTER III

RESULTS

The results will be discussed in four sections. The Pre and Post experimental data will be reviewed initially. Consideration will be given next to the duration of the spiral aftereffect for both the size constant condition and the angle constant condition. Following the section dealing with SAE duration, the visual perception data (speed, distance, and size) will be presented, again for both conditions. Finally, the relationships between data from the last two sections will be examined to permit an evaluation of the influence of the perceptual variables upon the SAE duration.

Pre and Post Experimental Data

Group means and standard deviations for the Pre and Post trials of SAE duration, perceived speed, perceived distance, and perceived size are presented in Table VI. It can be seen that the duration measures do not show any pattern of decline within test days or over the course of seven days of experimentation. Likewise, the Pre and Post data for the three perceptual phenomena are relatively consistent within and across days. There is a tendency for the perceived speed measures to increase slightly from the first to the last day of experimentation; as is also true of the perceived distance estimates. The perceived size judgments tend to rise slightly during the middle portion of the

TABLE VI

MEANS AND STANDARD DEVIATIONS FOR THE DURATION (IN SECONDS), PERCEIVED SPEED (IN PERCENTAGES), PERCEIVED DISTANCE (IN FEET), AND PERCEIVED SIZE (IN INCHES) OF THE STANDARD SPIRAL (4-INCH DIAMETER, 4.77 FEET FROM THE OBSERVER, ROTATED AT 75 RPM) USED PRIOR TO AND FOLLOWING THE EXPERIMENTAL TRIALS ON EACH OF THE SEVEN DAYS OF EXPERIMENTATION

		Duration[1] (seconds)		Speed (%age)		Size (inches)		Distance (feet)	
Day		Pre	Post	Pre	Post	Pre	Post	Pre	Post
I	M	18.16	15.92	26.07	27.14	4.71	4.79	3.86	3.96
	SD	5.32	6.81	7.64	9.75	0.91	0.96	0.46	0.50
II	M	17.66	18.41	27.14	35.71	4.61	4.71	3.96	3.96
	SD	6.30	8.98	7.26	9.38	1.04	1.19	0.50	0.50
III	M	15.07	15.79	28.21	32.86	5.07	5.11	4.07	4.04
	SD	5.02	6.35	6.96	12.97	1.27	1.27	0.58	0.69
IV	M	15.69	17.89	28.57	31.43	5.18	5.07	4.11	4.07
	SD	5.24	7.59	5.69	8.86	1.27	1.14	0.56	0.55
V	M	17.37	16.54	28.93	33.93	5.14	5.07	4.04	4.04
	SD	8.80	8.47	7.39	13.47	1.23	1.14	0.57	0.57
VI	M	14.76	18.51	29.29	38.57	5.07	4.57	4.04	4.36
	SD	7.46	8.87	7.81	14.34	1.07	1.07	0.57	1.18
VII	M	17.21	18.45	32.14	36.79	4.79	4.71	4.14	4.14
	SD	8.77	7.46	8.02	15.14	0.98	0.99	0.60	0.60

[1] Duration data represent an average of two judgements for each of 14 subjects; all other data are based on a single score for each of the same subjects.

experiment, but return to the original level of estimate at the end. It can be seen that there is no striking change among these measures nor are they affected by a progressive decline (habituation) either within or across the experimental period. Therefore, no effects of habituation or fatigue appear to have contaminated the experimental data. The individual means and standard deviations for the Pre and Post data appear in the Appendix, Tables XXV through XXVIII.

SAE Duration

Size Constant Condition

Group means and standard deviations for the SAE duration scores appear in Table VII. Data for individual subjects are in the Appendix, Tables XXIX through XXXIII. The group data are graphically presented in Figures 5 and 6. Figure 5 shows the effects of visual angle on SAE duration for each of the seven rates of SEM used in this condition. It may be noted that a peaking effect occurs, between angles of 2° and 4°, for SEM values ranging from 40 through 100 minarcs/sec; the duration scores decline at both the shorter and longer visual angles. However, there is no peaking evident for the two lowest speeds. There is more of a flattening effect in the 20 minarcs/sec plot, while the plot for the 10 minarcs/sec rate indicates a general decline from the smallest to the largest visual angle. In a series of seven speeds, the 10 and 20 minarcs/sec presentations are considerably slower than the remainder of the series for any of the angles. This may well account for the different functions obtained with these rates, as seen in Figure 5. Attention may also be drawn to the fact that the SAE value for the 100 minarcs/sec rate at the $\frac{1}{2}^{\circ}$ angle is significantly lower than any other

TABLE VII

MEANS[1] AND STANDARD DEVIATIONS FOR THE DURATION (IN SECONDS) OF THE SPIRAL AFTEREFFECT IN THE SIZE CONSTANT CONDITION

		Visual Angle				
Minarcs/sec		½°	1°	2°	4°	8°
10	M	15.25	12.49	12.92	11.49	10.51
	SD	6.96	5.29	5.50	5.25	5.79
20	M	16.35	16.82	16.88	16.38	11.53
	SD	5.36	5.56	5.86	6.92	5.91
40	M	17.12	19.46	20.51	20.07	14.92
	SD	6.00	6.06	6.08	8.74	8.21
50	M	17.68	19.63	19.87	20.36	15.63
	SD	7.96	4.93	4.87	8.01	7.25
60	M	16.52	17.99	20.52	20.01	15.84
	SD	5.99	4.93	4.04	7.71	7.28
80	M	15.83	16.81	19.62	20.30	15.88
	SD	5.95	5.67	4.85	7.38	7.54
100	M	12.25	15.82	21.24	20.19	17.56
	SD	5.43	6.64	5.69	7.41	8.50

[1] Each mean is based on an average of three judgments for each of 14 subjects.

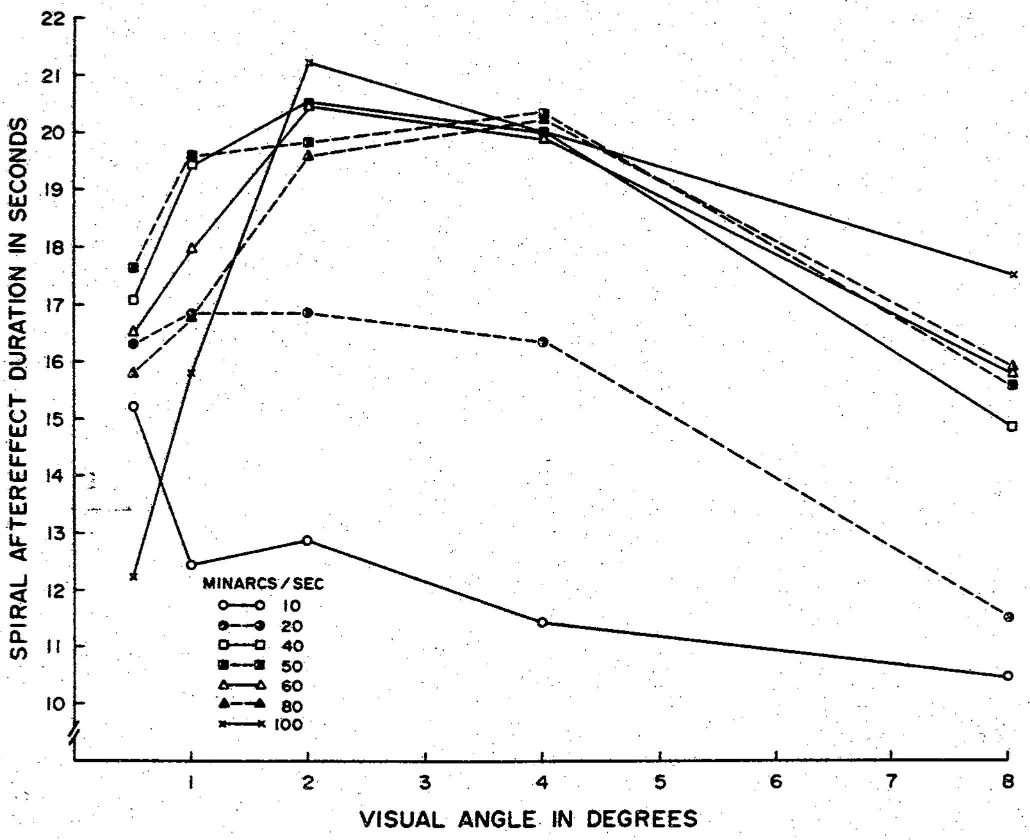

Figure 5. Duration of the Spiral Aftereffect (in Seconds) as a Function of Visual Angle for Seven Speeds of Eliciting Motion (in Minarcs/sec) in the Size Constant Condition

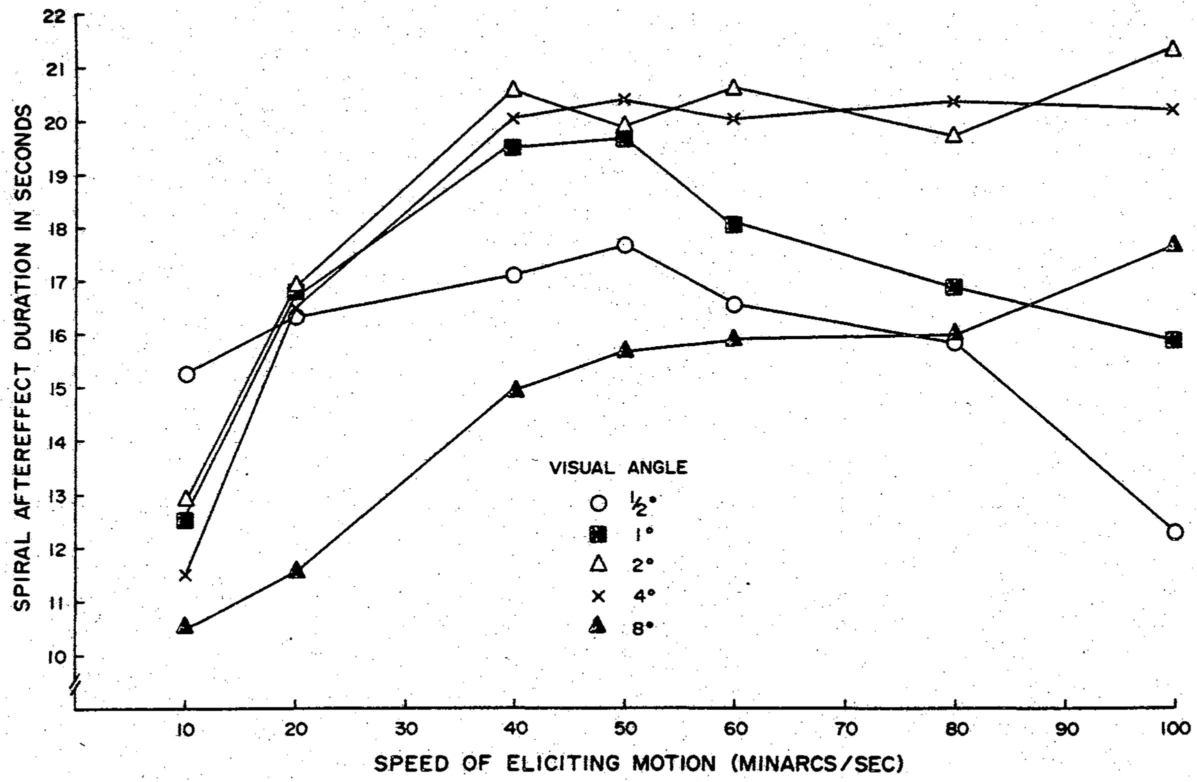

Figure 6. Duration of the Spiral Aftereffect (in Seconds) as a Function of the Speed of Eliciting Motion (in Minarcs/sec) for Five Visual Angles in the Size Constant Condition

duration score at this angle.

Figure 6 presents the same data depicted in Figure 5 except that the SAE scores are plotted to show the effects of variations in SEM on duration measures for each of the five visual angles. It can be seen that, for every angle, SAE durations increase from 10 through 40 minarcs/sec. Also, while the 2^{o}, 4^{o}, and 8^{o} angles show no essential change in SAE duration scores between 40 and 100 minarcs/sec, the $\frac{1}{2}^{o}$ and 1^{o} angles show peaks at 50 minarcs/sec and then decline.

Table VIII contains the results of an analysis of variance which yielded statistical significance for SAE duration differences among the five visual angles and among the seven speeds of eliciting motion, as well as for the visual angle by retinal speed interaction (see also Figures 5 and 6). To evaluate the hypothesis regarding the effects on SAE durations of speeds below 40 minarcs/sec, t tests were conducted between SAE values at 40 minarcs/sec with those at 10, at 20, and at 100 minarcs/sec for each of the five visual angles (Table IX). The t tests show that, in all but one case (20 vs 40 minarcs/sec for the $\frac{1}{2}^{o}$ angle), the lower SEM rates produce significantly shorter (.05 to .001 levels) SAE durations than those obtained at 40 minarcs/sec; in the case of the exception, the difference, though not significant, was in the anticipated direction. The comparisons between the 40 and 100 minarcs/sec data indicate no change in duration scores for visual angles of 2^{o}, 4^{o}, and 8^{o}. However, declines in SAE duration from 40 to 100 minarcs/sec for the two smallest visual angles ($\frac{1}{2}^{o}$ and 1^{o}) are significant (.01 and .001 levels).

TABLE VIII

RESULTS OF THE ANALYSIS OF VARIANCE OF THE SPIRAL AFTEREFFECT DURATION SCORES OBTAINED IN THE SIZE CONSTANT CONDITION

Source	df	Mean Square	F
Subject (Su)	13	957.30544	
Angle (A)	4	305.20849	4.45[1]
(A x Su)	52	68.57446	
Speed (SEM)	6	333.72119	33.02[2]
SEM x Su	78	10.10753	
A x SEM	24	41.35955	6.28[2]
A x SEM x Su	312	6.58778	

[1] $p < .01$.

[2] $p < .001$.

TABLE IX

RESULTS OF t TESTS FOR CORRELATED DATA COMPARING SPIRAL AFTEREFFECT DURATION SCORES OBTAINED AT 40 MINARCS/SEC WITH THOSE OBTAINED AT 10, 20, AND 100 MINARCS/SEC AT EACH VISUAL ANGLE IN THE SIZE CONSTANT CONDITION (df=13)

	Minarcs/Sec		
Visual Angle	10 vs 40	20 vs 40	40 vs 100
$\frac{1}{2}^{\circ}$	-2.444^{1}	-1.195	4.848^{4}
1°	-6.562^{4}	-2.612^{1}	3.091^{3}
2°	-9.241^{4}	-3.491^{3}	-0.890
4°	-6.616^{4}	-3.082^{3}	-0.127
8°	-4.273^{4}	-2.575^{1}	-1.866

[1] $p < .05$.

[2] $p < .02$.

[3] $p < .01$.

[4] $p < .001$.

Angle Constant Condition

Table X presents the group means and standard deviations for the SAE duration data. Data for individual subjects appear in the Appendix, Tables XXXIV and XXXV. The group results are displayed in Figure 7. It can be seen in every case, for sessions with either rpm constant or minarcs/sec constant, that there is a steady increase in SAE duration as the spiral diameter increases in size from 4 to 10 to 16 inches within each visual angle. It would be anticipated, with the visual angle remaining constant over these three stimulus sizes, that the duration would be constant, if either visual angle or retinal speed were the major factor influencing the SAE duration. In the rpm constant session, SAE durations, for the three spiral sizes subtending the 4° angle, have consistently higher values than those at either 2° or 8°. With minarcs/sec constant, the three spiral sizes subtending the 8° angle yield significantly lower SAE duration scores than those for the 2° and 4° angles. It should be remembered that, in order to maintain a constant minarcs/sec rate (retinal speed), a considerably lower motor speed was required at 8°.

Table XI shows the results of an analysis of variance in which the visual angle, the spiral diameter, and the session (rpm constant and minarcs/sec constant) by visual angle interaction have significant influences on the SAE duration. Table XII presents the t test results in which the duration data for each spiral size are compared with the other two sizes within a given visual angle. In Table XIII, t tests of the SAE scores were conducted among the three angles which were subtended by each spiral size. Those analyses were conducted separately for the rpm constant and the minarcs/sec constant sessions. In each

TABLE X

MEANS[1] AND STANDARD DEVIATIONS FOR THE DURATION (IN SECONDS) OF THE SPIRAL AFTEREFFECT IN THE ANGLE CONSTANT CONDITION

Visual Angle		Spiral Diameter (inches)					
		RPM Constant			Minarcs/Sec Constant		
		4	10	16	4	10	16
2°	M	16.65	18.18	19.00	18.90	19.95	21.62
	SD	6.29	5.74	6.50	6.77	6.68	7.30
4°	M	17.16	19.92	20.26	16.94	20.13	20.87
	SD	8.65	8.51	8.84	7.19	7.94	6.95
8°	M	16.55	18.80	19.17	13.84	16.47	18.36
	SD	9.00	7.71	8.58	8.54	8.39	7.06

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[1] Each mean is based on an average of three judgments for each of 14 subjects.

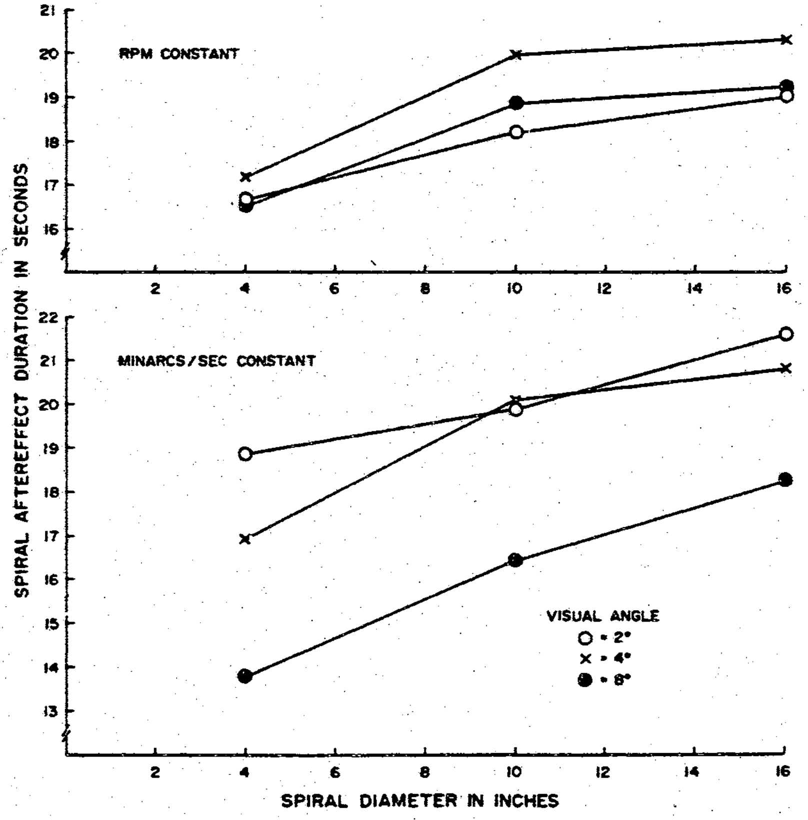

Figure 7. Duration of the Spiral Aftereffect (in Seconds) as a Function of Three Spiral Sizes (4, 10, and 16-Inch Diameters) for the Three Visual Angles (2°, 4°, and 8°) in the RPM Constant Session and in the Minarcs/sec Constant Session of the Angle Constant Condition

TABLE XI

RESULTS OF ANALYSIS OF VARIANCE OF THE SPIRAL AFTEREFFECT DURATION SCORES OBTAINED IN THE ANGLE CONSTANT CONDITION

Source	df	Mean Square	F
Subject (su)	13	880.81792	
Session (Ses)	1	1.50893	0.18
Su x Ses	13	8.31334	
Angle (A)	2	105.12615	4.46[1]
A x Su	26	23.57406	
Diameter (D)	2	227.30270	17.65[2]
D x Su	26	12.87527	
Ses x A	2	91.17475	5.36[1]
Ses x A x Su	26	17.01342	
Ses x D	2	6.76381	0.92
Ses x D x Su	26	7.37076	
A x D	4	5.72207	1.30
A x D x Su	52	4.41699	
Ses x A x D	4	1.38268	0.22
Ses x A x D x Su	52	6.38350	

[1] $p < .05$.

[2] $p < .001$.

TABLE XII

RESULTS OF t TESTS FOR CORRELATED DATA COMPARING SPIRAL AFTEREFFECT DURATION SCORES FOR THREE SPIRAL SIZES AT EACH VISUAL ANGLE IN THE ANGLE CONSTANT CONDITION

Comparison (Spiral Diameter)	RPM Constant Session		
	Visual Angle		
	2°	4°	8°
4- vs 10-inch	-1.859	-3.758[3]	-1.850
10- vs 16-inch	-0.927	-0.308	-0.344
4- vs 16-inch	-1.850	-2.380[1]	-1.520
	Minarcs/Sec Constant Session		
	2°	4°	8°
4- vs 10-inch	-1.534	-3.297[3]	-4.119[3]
10- vs 16-inch	-2.974[2]	-0.886	-2.584[1]
4- vs 16-inch	-3.526[3]	-3.772[3]	-5.303[4]

[1] $p < .05$.

[2] $p < .02$.

[3] $p < .01$.

[4] $p < .001$.

TABLE XIII

RESULTS OF t TESTS FOR CORRELATED DATA COMPARING SPIRAL AFTEREFFECT DURATION SCORES AT THREE VISUAL ANGLES SUBTENDED BY EACH SIZE OF SPIRAL IN THE ANGLE CONSTANT CONDITION

Comparisons (Visual Angle)	RPM Constant Session		
	Spiral Diameter (inches)		
	4	10	16
2° vs 4°	-0.387	-1.242	-0.885
4° vs 8°	0.424	1.493	1.110
2° vs 8°	0.063	-0.450	-0.103
	Minarcs/Sec Constant Session		
	4	10	16
2° vs 4°	2.176[1]	-0.196	0.610
4° vs 8°	2.729[2]	4.110[4]	3.368[3]
2° vs 8°	3.760[3]	3.067[3]	2.943[2]

[1] $p < .05$.

[2] $p < .02$.

[3] $p < .01$.

[4] $p < .001$.

case, with minarcs/sec constant, the 4-inch spiral yielded a significantly lower duration score than did the 16-inch spiral (.01 and .001 levels); although always intermediate, scores for the 10-inch spiral did not always differ significantly from the 4-inch and the 16-inch stimuli (Table XII). The 4-inch spiral, in the rpm constant session, yielded significantly lower (.05 and .01 levels) duration scores than both the 10-inch and 16-inch spirals only within the 4^o visual angle (Table XII); however, the same comparisons for the 2^o and the 8^o angle were in the anticipated direction (Table XII). With minarcs/sec constant, the 8^o angle for each spiral size yielded significantly lower duration scores than the 2^o and 4^o angles (.02 to .001 levels), but the latter two did not differ from each other except for the 4-inch spiral size (Table XIII). With rpm constant, the 4^o visual angle consistently produced higher (but not significantly so) SAE duration scores for all three spiral sizes; data for the 2^o and 8^o angles did not differ significantly for any of the spiral sizes.

Visual Perception Data

Size Constant Condition

Perceived Speed. The group mean perceived speed responses and their standard deviations appear in Table XIV. Data for individual subjects appear in the Appendix, Tables XXXVI through XL. Table XV compares the perceived speed, represented as a percentage of a standard, with the actual speed in terms of rpm. It can be seen that, as the angle increases (stimulus closer to the subject) the estimate of spiral speed consistently decreases. Moreover, for the same visual angle, increases in rpm (and, therefore, in retinal speed) result in increases

TABLE XIV

MEANS[1] AND STANDARD DEVIATIONS FOR THE PERCEIVED SPEED (IN PERCENTAGES) OF THE SPIRAL STIMULUS IN THE SIZE CONSTANT CONDITION

		Visual Angle				
Minarcs/Sec		½°	1°	2°	4°	8°
10	M	31.21	20.71	19.07	11.93	8.93
	SD	10.30	7.56	6.49	3.12	2.13
20	M	47.14	39.29	26.79	20.00	13.57
	SD	18.78	11.07	7.99	5.88	4.01
40	M	72.86	47.50	42.50	27.50	25.00
	SD	23.76	18.68	14.11	6.43	10.19
50	M	83.57	66.07	53.57	36.43	29.29
	SD	15.98	19.73	15.25	13.65	11.07
60	M	78.57	66.79	48.21	42.86	30.00
	SD	19.16	18.67	15.76	15.53	12.25
80	M	87.50	80.57	58.21	52.50	36.07
	SD	18.27	17.23	16.83	16.84	13.61
100	M	101.07	90.00	64.64	61.43	43.57
	SD	15.71	11.27	18.76	13.79	12.47

[1] Each mean is based on a single score for each of 14 subjects.

TABLE XV

THE RELATIONSHIP BETWEEN CHANGES IN VISUAL ANGLE AND IN PHYSICAL SPEED OF THE SPIRAL DISC ON JUDGMENTS OF PERCEIVED SPEED (IN PERCENTAGE VALUES)

Spiral Speed (RPM)	Visual Angle				
	½°	1°	2°	4°	8°
8					8.93
16				11.93	13.57
32			19.07	20.00	25.00
40					29.29
48					30.00
64		20.71	26.79	27.50	36.07
80				36.43	43.57
96				42.86	
128	31.21	39.29	42.50	52.50	
160			53.57	61.43	
192			48.21		
256	47.14	47.50	58.21		
320		66.07	64.64		
384		66.79			
512	72.86	80.57			
640	83.57	90.00			
768	78.57				
1024	87.50				
1280	101.07				

in perceived speed. The data are graphically represented in Figure 8. It might be noted that there is no peaking effect between visual angles 2° and 4°.

Perceived Distance. The group mean perceived distance responses and their standard deviations are presented in Table XVI and the data are plotted against physical distance in Figure 9 for the five visual angles used. Since these estimates showed little variability within a given angle (Table XVI), they were averaged (i.e., treated as replications) and the mean for each angle was then plotted. The five points, then, represent the five visual angles used; reading from left to right; 8° to $\frac{1}{2}^{\circ}$. Obviously, the 8° stimulus is perceived as closest to the observer and the $\frac{1}{2}^{\circ}$ stimulus as farthest from him. The function in Figure 9 represents a line of best fit drawn by eye. However, there is clearly a proportional and linear relationship between perceived and physical distance. Individual subjects' data appear in the Appendix, Tables XLI through XLV.

Perceived Size. The group means and standard deviations are presented in Table XVII. Individual data are located in the Appendix, Tables XLVI through L. Again, the means, within a given angle, were treated as replications and averaged, as with the perceived distance data. It can be seen in Figure 10 that the size of the 4-inch spiral is slightly but consistently over-estimated at each of the five visual angles. There is also a slight peaking effect at 4°, although the range of size judgments is quite small.

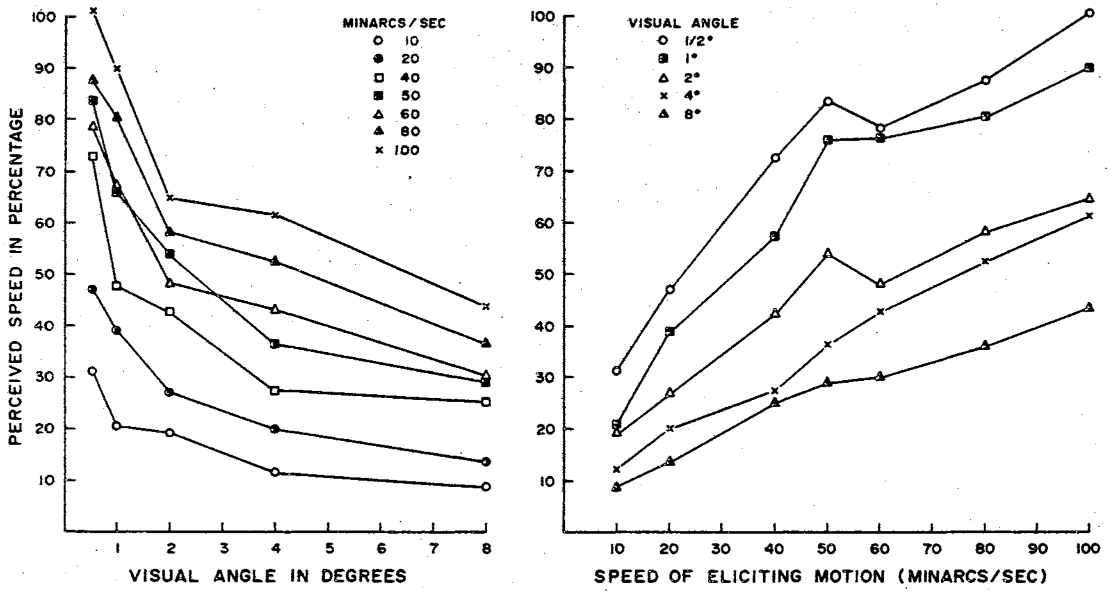

Figure 8. Perceived Speed (in Percentage) as a Function of Visual Angle and Speed of Eliciting Motion (in Minarcs/sec) in the Size Constant Condition

TABLE XVI

MEANS[1] AND STANDARD DEVIATIONS FOR THE PERCEIVED DISTANCE (IN INCHES) OF THE SPIRAL STIMULI USED IN THE SIZE CONSTANT CONDITION

		Visual Angle				
Minarcs/Sec		$\frac{1}{2}^{\circ}$	1°	2°	4°	8°
10	M	409.68	229.68	107.16	48.48	24.48
	SD	111.72	72.60	26.40	6.84	2.88
20	M	414.84	231.48	103.68	49.68	24.48
	SD	114.48	71.40	20.28	7.20	2.88
40	M	419.16	227.16	103.68	49.32	25.32
	SD	118.20	72.72	16.68	7.56	2.52
50	M	410.52	228.00	103.68	49.32	24.24
	SD	97.20	71.28	17.40	7.56	3.00
60	M	408.84	225.48	106.32	48.48	23.40
	SD	131.52	56.76	27.00	6.84	3.72
80	M	416.52	233.16	104.52	48.48	23.76
	SD	126.72	61.56	25.08	6.84	4.20
100	M	414.84	224.52	105.48	48.48	24.48
	SD	112.08	49.68	24.60	6.84	2.88
	M	413.49	228.50	104.93	48.89	24.31
	SD	3.87	3.14	1.42	0.53	0.61
Actual Distance		458.40	229.20	114.00	57.24	28.80

[1] Each mean is based on a single score for each of 14 subjects.

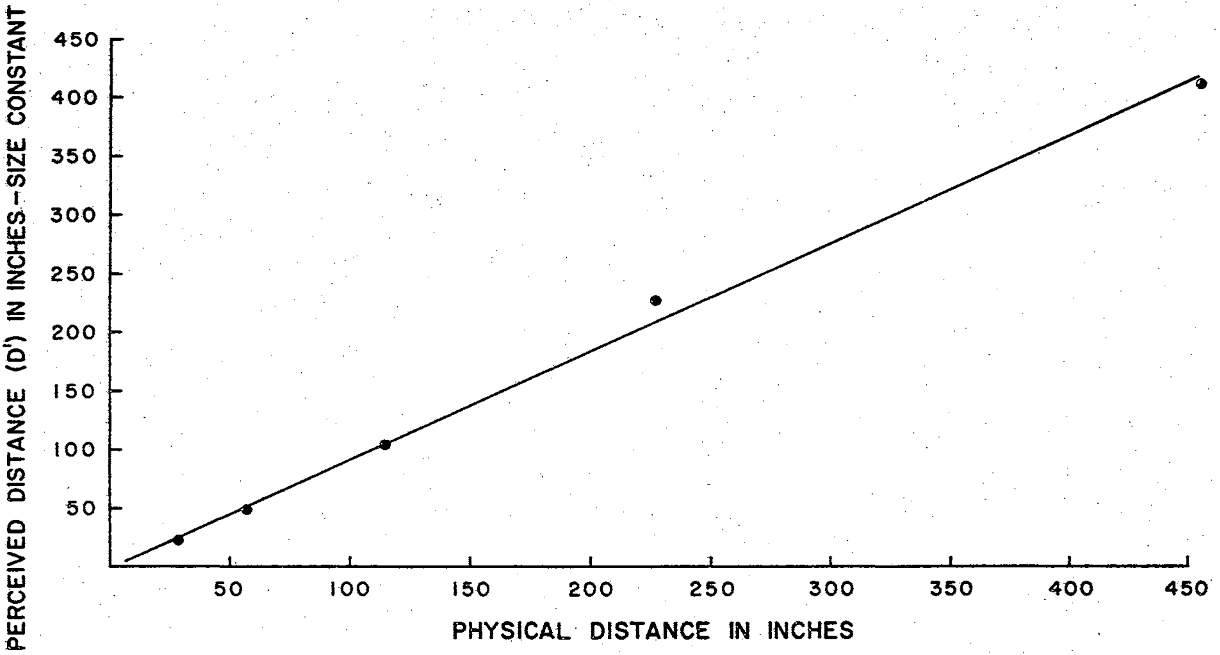

Figure 9. Perceived Distance (D') in Inches as a Function of Physical Distance (D) in Inches in the Size Constant Condition

TABLE XVII

MEANS[1] AND STANDARD DEVIATIONS FOR THE PERCEIVED SIZE (IN INCHES) OF THE 4-INCH SPIRAL USED TO SUBTEND DIFFERENT VISUAL ANGLES IN THE SIZE CONSTANT CONDITION

		Visual Angle				
Minarcs/Sec		½°	1°	2°	4°	8°
10	M	4.71	4.82	4.93	5.21	4.86
	SD	1.59	1.38	1.33	1.31	1.29
20	M	5.04	4.75	5.04	4.96	4.96
	SD	1.69	1.34	1.45	1.08	1.18
40	M	4.79	4.75	4.82	4.86	5.00
	SD	1.59	1.45	1.32	1.03	1.19
50	M	4.68	4.68	5.04	4.96	4.82
	SD	1.59	1.30	1.50	1.12	1.03
60	M	4.82	4.86	4.75	5.07	4.82
	SD	1.51	1.34	1.16	1.12	1.10
80	M	4.86	4.79	4.79	5.07	4.68
	SD	1.67	1.30	1.24	1.14	1.14
100	M	4.79	4.75	4.96	5.00	4.93
	SD	1.44	1.40	1.34	1.11	1.43
	M	4.81	4.77	4.90	5.02	4.87
	SD	0.12	0.06	0.12	0.11	0.11

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[1] Each mean is based on a single score for each of 14 subjects.

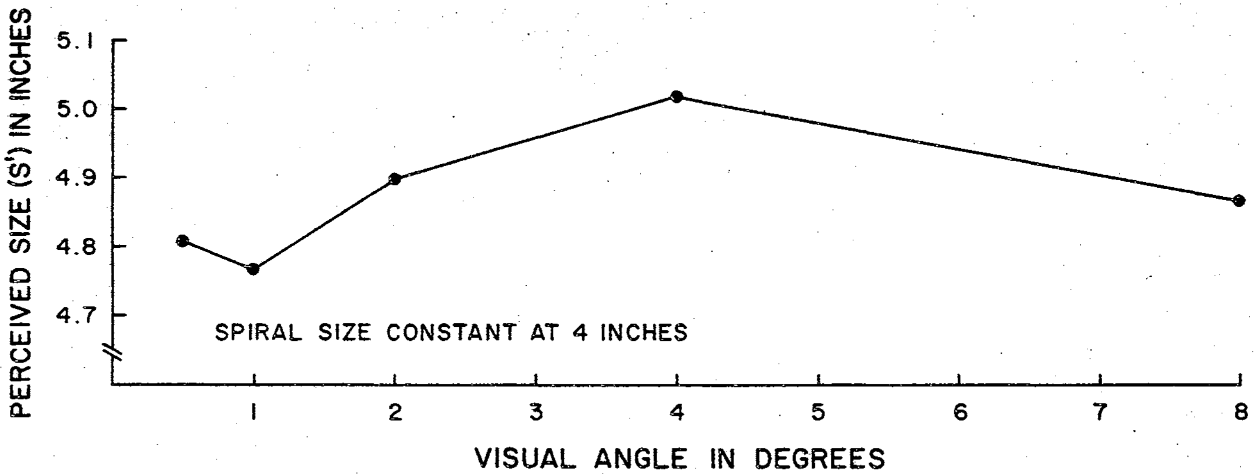

Figure 10. Perceived Size (S') in Inches as a Function of Five Visual Angles in the Size Constant Condition

Angle Constant Condition

Perceived Speed. Table XVIII presents group means and standard deviations for perceived speed. The individual data appear in the Appendix, Tables LI and LII. Figure 11 shows a tendency for perceived speed to increase with increases in visual angle (and retinal speed) in the rpm constant sessions. However, across angles (for the different spiral sizes) the perceived speed is essentially a straight line function. Again, in the minarcs/sec constant session, the perceived speed is rated essentially the same for the three spiral sizes within a given angle. However, here the retinal speed is held constant and the actual speed of the spiral disc increases as the visual angle becomes smaller. Thus, the perceived speeds for the 2° angle (a four-fold increase in actual speed over the 8° angle) are significantly faster. The effect, therefore, must be primarily one of motor speed. Table XIX presents the results of an analysis of variance in which the session, angle, and session by angle interaction are seen significantly to affect the perceived speed judgments. The results of t tests, presented in Table XX, indicate, that for the minarcs/sec constant session, every angle comparison yields a significant difference at each spiral diameter. In the rpm constant session, there is no significant difference, at any of the three spiral diameters, between the 2° and 4° angles. All other comparisons yield significant differences except the 4° and 8° comparison with the four-inch spiral diameter.

Perceived Distance. Table XXI presents the mean data for perceived distance. Individual data are in the Appendix, Tables LIII and LIV. Figure 12 combines the judgments for corresponding points in the rpm constant and minarcs/sec constant sessions. For example, the values

TABLE XVIII

MEANS[1] AND STANDARD DEVIATIONS FOR THE PERCEIVED SPEED (IN PERCENTAGES) OF THE SPIRAL STIMULI IN THE ANGLE CONSTANT CONDITION

Visual Angle		Spiral Diameter (inches)					
		RPM Constant			Minarcs/Sec Constant		
		4	10	16	4	10	16
2°	M	30.36	30.71	32.50	48.57	48.93	49.29
	SD	12.63	9.58	12.82	11.84	13.75	14.12
4°	M	32.14	30.71	33.21	32.50	36.07	37.14
	SD	10.69	8.96	11.03	10.52	13.47	13.11
8°	M	35.00	37.14	39.64	27.14	27.50	27.86
	SD	11.09	11.72	13.37	7.77	8.72	8.93

[1] Each mean is based on a single score for each of 14 subjects.

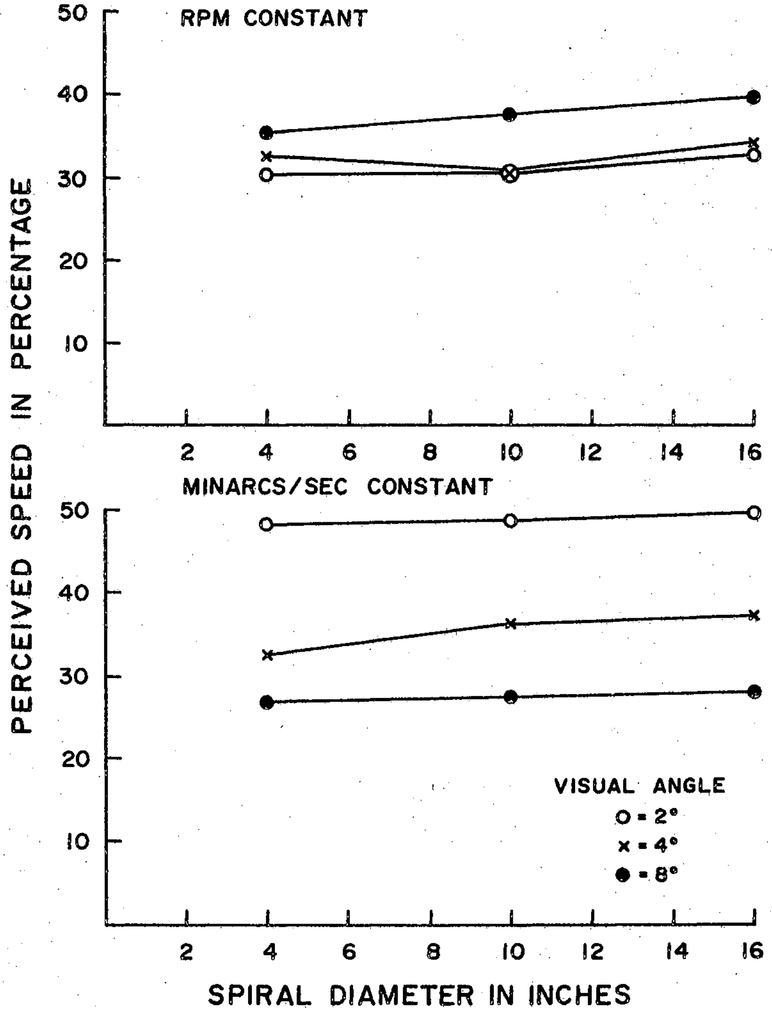

Figure 11. Perceived Speed (in Percentage) as a Function of Three Spiral Sizes (4, 10, 16 Inch Diameters) for Three Visual Angles (2°, 4°, and 8°) in the RPM Constant Session and in the Minarcs/sec Constant Session of the Angle Constant Condition

TABLE XIX

RESULTS OF THE ANALYSIS OF VARIANCE OF PERCEIVED SPEED MEASURES FOR RPM AND FOR MINARCS/SEC CONSTANT SESSIONS FOR THREE VISUAL ANGLES (2°, 4°, and 8°) AT THREE SPIRAL SIZES (4-, 10-, AND 16-INCH DIAMETERS)

Source	df	Mean Square	F
Subject (Su)	13	1562.05722	
Angle (A)	2	1425.89264	17.44[3]
Su x A	26	81.76890	
Session (Ses)	1	876.58535	6.90[1]
Ses x Su	13	127.01478	
Diameter (D)	2	115.17850	3.00
D x Su	26	38.36232	
A x Ses	2	3974.50378	38.42[3]
A x Ses x Su	26	103.45682	
A x D	4	4.46439	0.02
A x D x Su	52	22.35948	
Ses x D	2	14.98101	0.44
Ses x D x Su	26	34.31759	
A x Ses x D	4	31.64673	1.48
A x Ses x D x Su	52	21.33672	

[1] $p < .05$.

[2] $p < .01$.

[3] $p < .001$.

TABLE XX

RESULTS OF t TESTS FOR CORRELATED DATA COMPARING PERCEIVED SPEED SCORES AT THREE VISUAL ANGLES SUBTENDED BY EACH SIZE OF SPIRAL IN THE ANGLE CONSTANT CONDITION

Comparisons (Visual Angle)	RPM Constant Session		
	Spiral Diameter (inches)		
	4	10	16
2° vs 4°	-1.161	0.000	-0.285
4° vs 8°	-1.963	-2.386[1]	-4.500[4]
2° vs 8°	-2.509[1]	-3.628[3]	-3.069[3]
	Minarcs/Sec Constant Session		
	4	10	16
2° vs 4°	6.511[4]	3.379[3]	3.427[3]
4° vs 8°	3.741[3]	3.309[3]	4.192[3]
2° vs 8°	7.412[4]	6.430[4]	5.646[4]

[1] $p < .05$.

[2] $p < .02$.

[3] $p < .01$.

[4] $p < .001$.

TABLE XXI

MEANS[1] AND STANDARD DEVIATIONS FOR THE PERCEIVED DISTANCE (IN INCHES) OF THE SPIRAL STIMULI USED IN THE ANGLE CONSTANT CONDITION

Visual Angle		Spiral Diameter (inches)					
		RPM Constant			Minarcs/Sec Constant		
		4	10	16	4	10	16
2°	M	105.84	262.32	414.00	108.00	252.00	402.84
	SD	17.88	54.48	105.10	22.08	40.44	72.84
4°	M	48.48	136.32	208.32	48.84	133.68	217.68
	SD	6.84	31.90	33.84	8.16	23.04	38.52
8°	M	24.00	63.84	114.00	22.92	66.00	110.16
	SD	2.40	8.40	32.52	3.24	16.20	22.08

[1] Each mean is based on a single score for each of 14 subjects.

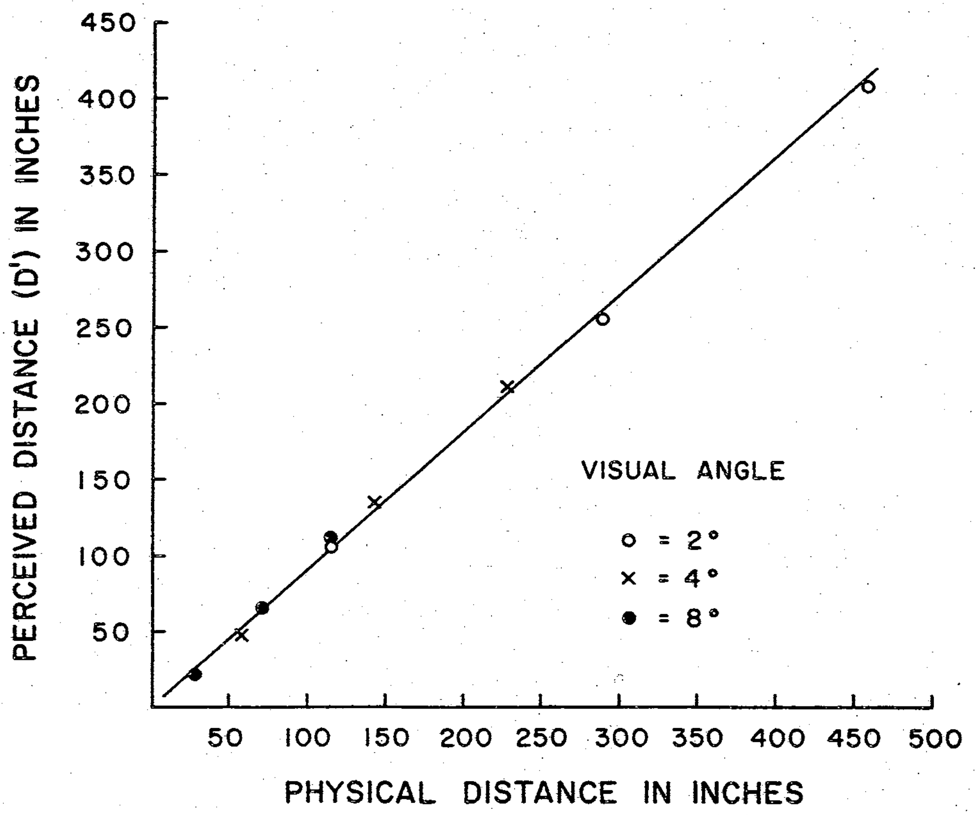

Figure 12. Perceived Distance (D') in Inches as a Function of Physical Distance in Inches for Three Spiral Sizes (4-, 10-, 16-Inch Diameters) for Three Visual Angles (2°, 4°, and 8°) in the Angle Constant Condition

for the 4-inch spiral subtending a 2° visual angle in both sessions were treated as replications, averaged, and plotted. Hence, Figure 12 compares the average perceived distance, for the three stimulus sizes within a given angle, with the physical distance. The function depicted in this figure is a visually determined line of best fit and indicates that the relationship between perceived distance and physical distance is linear and proportional.

Perceived Size. Table XXII presents the group mean data for perceived size. The individual data appear in the Appendix, Tables LV and LVI. Figure 13 presents a combination of perceived size judgments for corresponding points in the rpm and minarcs/sec constant sessions. This procedure (i.e., treating the data as replications) is the same as the one utilized above. It is seen that the judgments for a particular spiral diameter all cluster closely about a single point. It is also important to note that the function depicted is essentially linear.

Relationships Among Perceptual Events

The perceived size measures were converted into ratios of the perceived size (S') per unit of retinal size (θ). This $\frac{S'}{\theta}$ ratio was then plotted against perceived distance for both the size constant (Figure 14) and the angle constant conditions (Figure 15). From both figures, it is clear that $\frac{S'}{\theta}$ is equivalent to perceived distance as would be expected from the "Size-Distance Invariance Hypothesis".

The relationship between the perceptual variables and the SAE duration is seen in Figures 16 and 17. The effect of $\frac{S'}{\theta}$ can be demonstrated more aptly in Figure 17. In the angle constant condition, SAE increases with increases in $\frac{S'}{\theta}$ in every case. However, there is a

TABLE XXII

MEANS[1] AND STANDARD DEVIATIONS FOR THE PERCEIVED SIZE (IN INCHES) OF THE SPIRAL STIMULI USED IN THE ANGLE CONSTANT CONDITION

Visual Angle		Spiral Diameter (inches)					
		RPM Constant			Minarcs/Sec Constant		
		4	10	16	4	10	16
2°	M	4.82	12.43	18.21	4.86	12.00	18.86
	SD	1.14	3.13	3.70	1.03	2.32	3.44
4°	M	4.64	12.21	19.14	4.71	12.79	19.07
	SD	1.01	3.04	4.17	0.99	3.42	3.91
8°	M	4.75	11.64	18.07	4.50	12.43	19.29
	SD	1.01	2.37	3.22	1.07	2.82	3.63

[1] Each mean is based on a single score for each of 14 subjects.

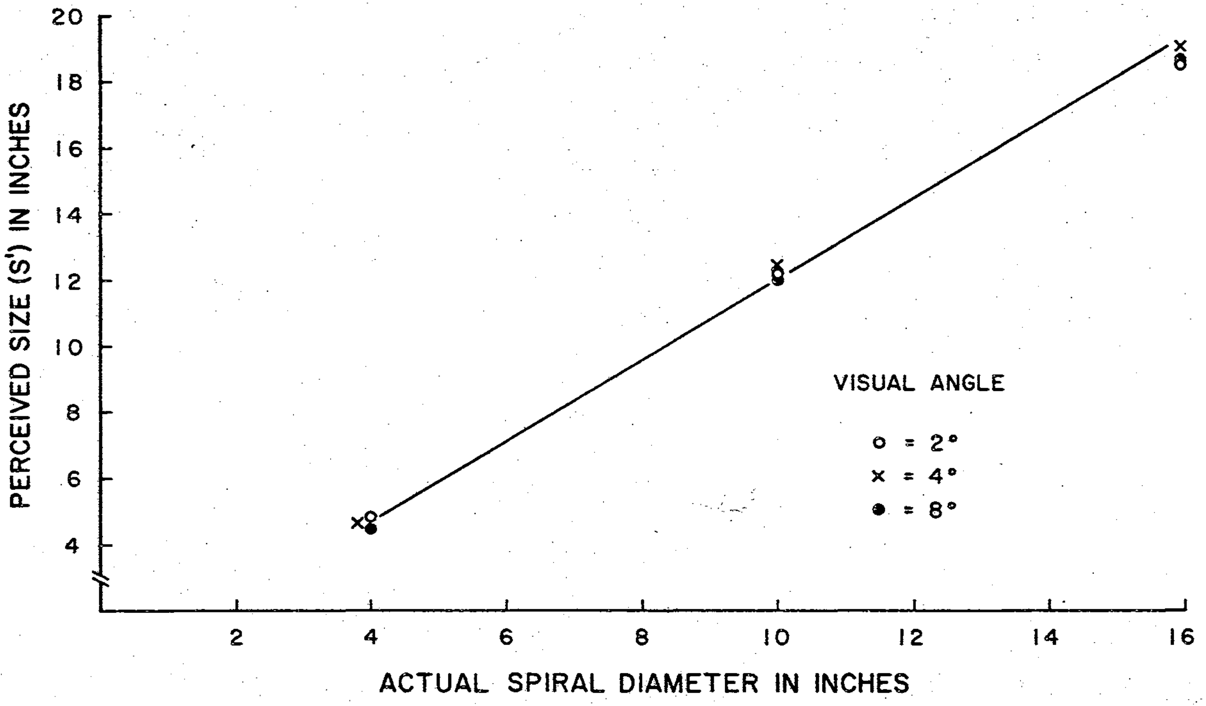

Figure 13. Perceived Size (S') in Inches as a Function of Actual Spiral Diameter (S) in Inches for Three Spiral Sizes (4-, 10-, and 16-Inch Diameters) for Three Visual Angles (2°, 4°, and 8°) in the Angle Constant Condition

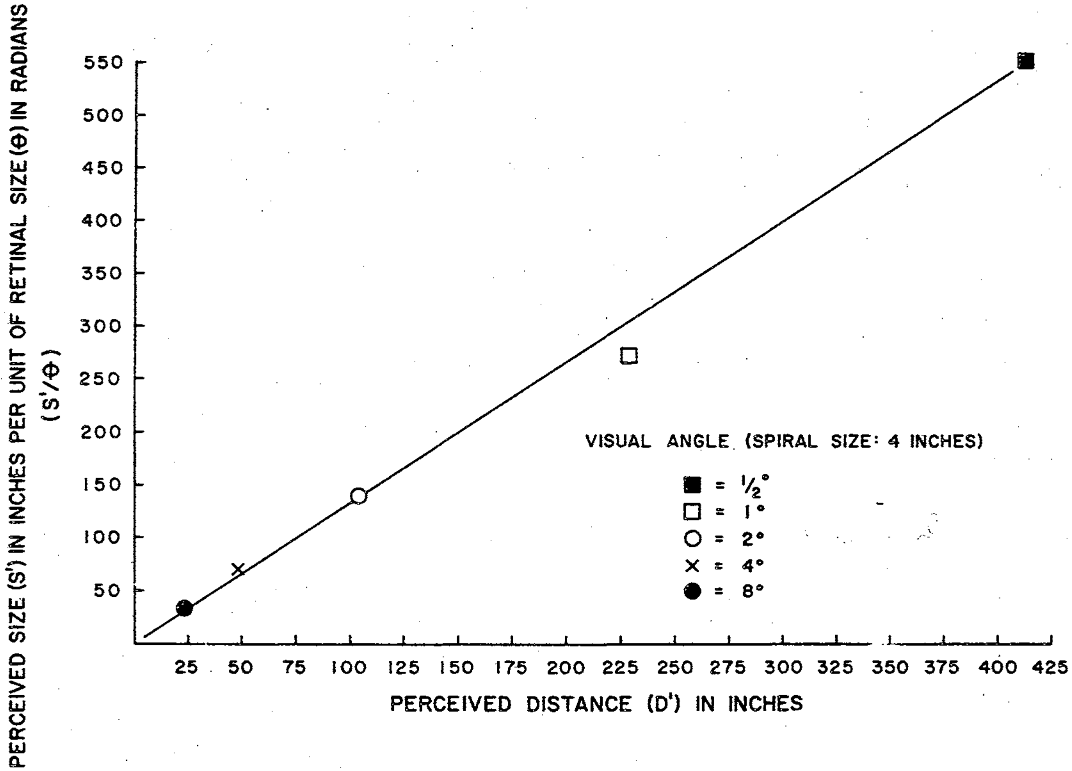

Figure 14. The Ratio (S'/θ) of Perceived Size (in Inches) per Unit of Retinal Size (in Radians) as a Function of Perceived Distance (D') in Inches for Five Visual Angles in the Size Constant Condition

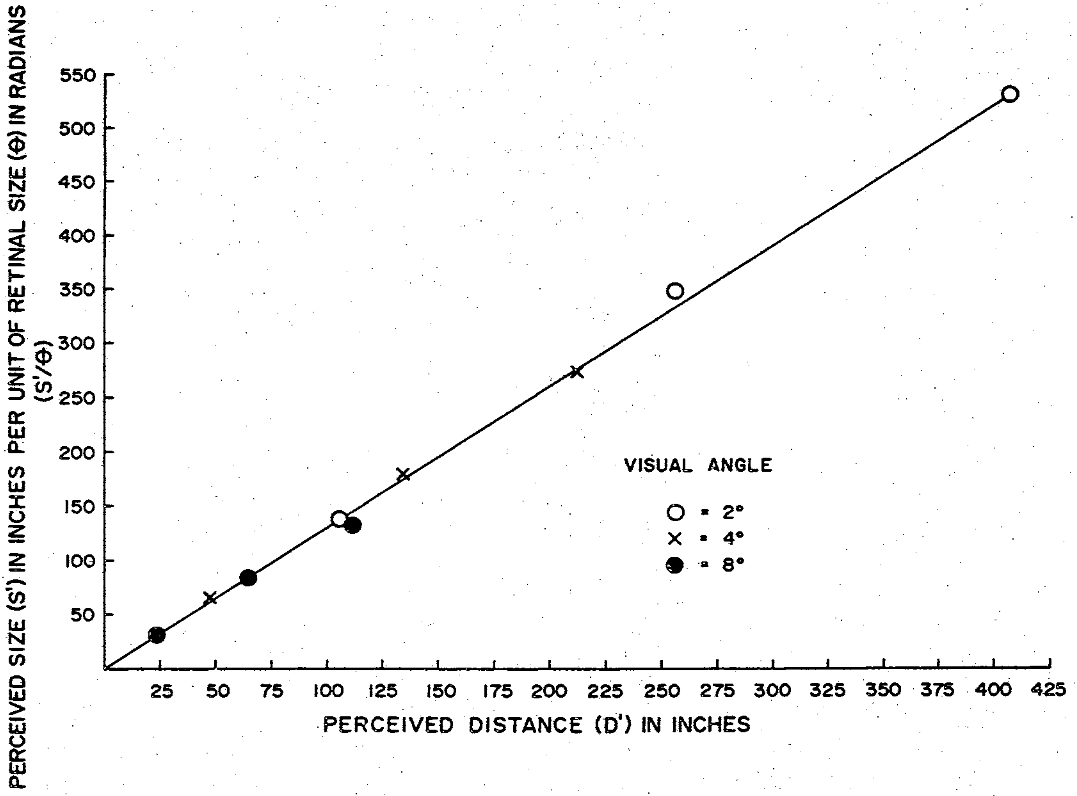

Figure 15. The Ratio (S'/θ) of Perceived Size (in Inches) per Unit of Retinal Size (in Radians) as a Function of Perceived Distance (D') in Inches for Three Spiral Sizes (4-, 10-, 16-Inch Diameters) for Each of Three Visual Angles (2°, 4°, and 8°) in the Angle Constant Condition

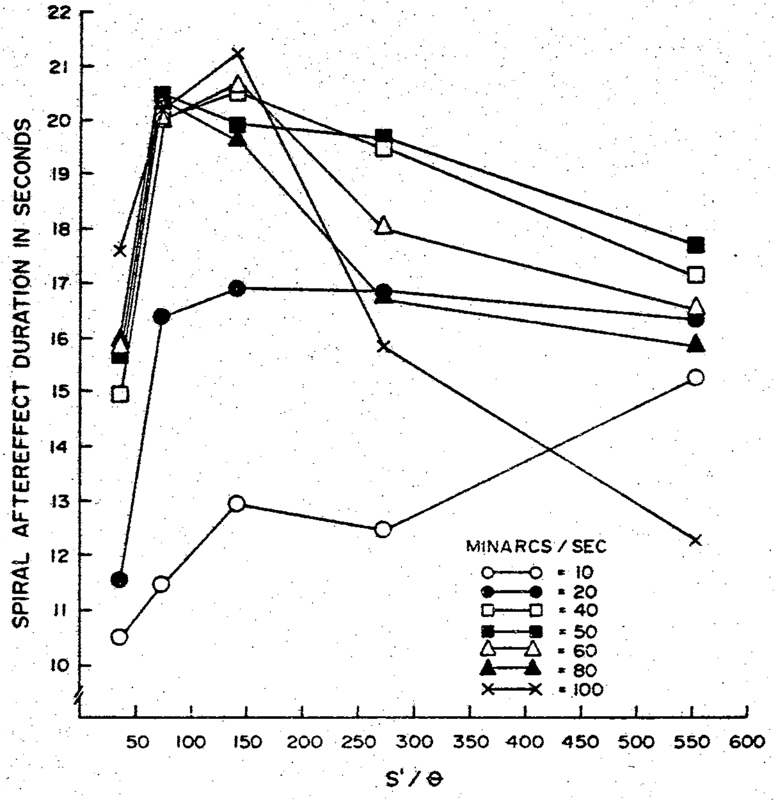

Figure 16. Duration of the Spiral Aftereffect (in Seconds) as a Function of the Ratio (S'/θ) of Perceived Size (in Inches) per Unit of Retinal Size (in Radians) for Seven Speeds of Eliciting Motion (in Minarcs/sec) in the Size Constant Condition

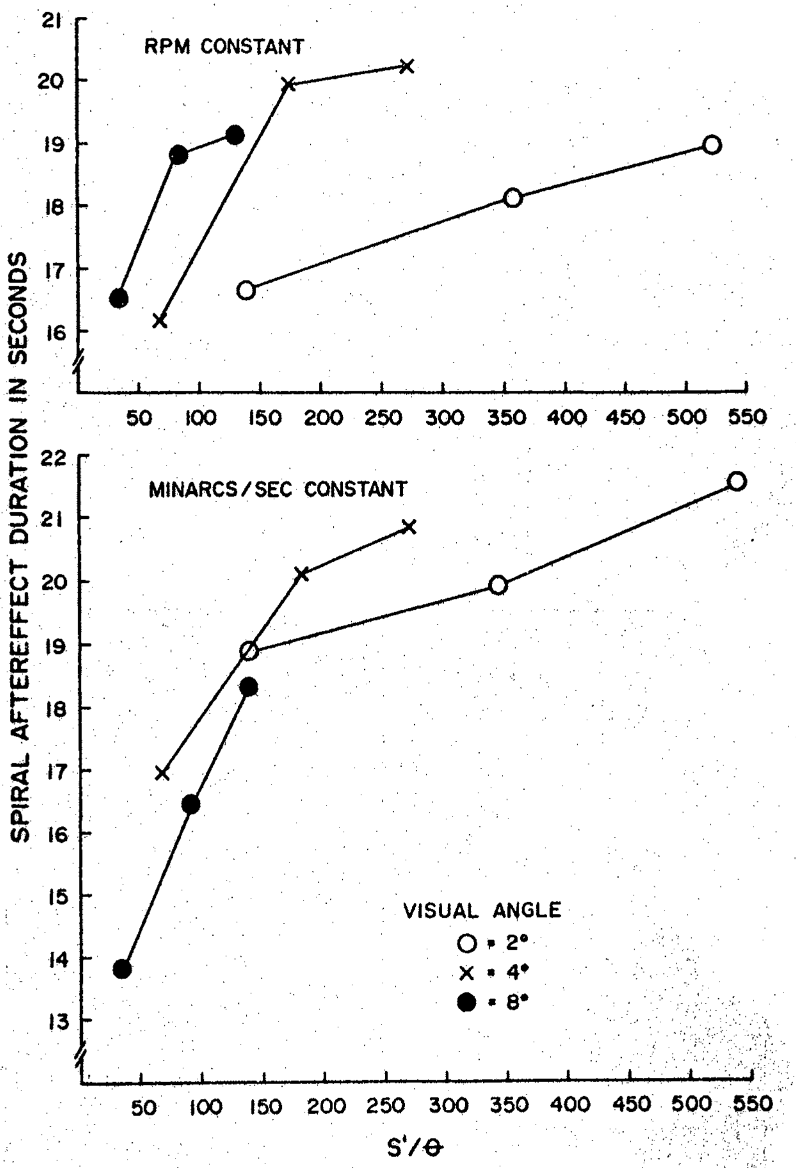

Figure 17. Duration of the Spiral Aftereffect (in Seconds) as a Function of the Ratio (S'/θ) of Perceived Size (in Inches) per Unit of Retinal Size (in Radians) for Three Spiral Sizes (4-, 10-, 16-Inch Diameters) for Each of Three Visual Angles (2^o, 4^o, and 8^o) for the RPM Constant and the Minarcs/sec Constant Sessions in the Angle Constant Condition

striking difference between the two sessions. An obvious effect of visual angle upon the SAE duration is seen in the rpm constant session. Here all three plots differ one from another and each appears to represent an individual function. This result is not found in the minarcs/sec constant session where the nine data points for the three visual angles more closely approximate a monotonic function.

The relationship between perceptual variables and the SAE duration in the size constant condition is seen in Figure 16. Here SAE duration increases as $\frac{S'}{\theta}$ increases, but only from the 8° up to the 2° angle. Beyond this point, there is a decline in duration scores. (In fact, the decline from 2° to ½° of visual angle is statistically significant in four of the cases; see Appendix Table LVII.) Hence, although factors associated with size constancy principles account for some of the changes in SAE scores, they do not totally explain those conditions which affect the duration of the spiral aftereffect.

CHAPTER IV

DISCUSSION

The discussion of the results will proceed with an initial consideration of the effects of the Pre and Post data. Then, the visual perception data will be discussed in order to utilize this information in discussing the relationship between SAE duration and perceptual phenomena. The effects of the speed of eliciting motion are dealth with separately in a subsequent section. The six hypotheses, of this study, will be discussed in the appropriate sections as the data is dealt with, and thus not in sequential order. Finally, a concluding section is presented in which the experimental results of the SAE are applied to the clinical situation.

Pre and Post Experimental Data

The question of whether or not the results of a study such as this might be affected by habituation and fatigue is a valid one when it is considered that each subject was asked to render between 52 and 64 judgments daily in an hour and a half's time and for a seven-day period. Wohlgemuth suggested changes in aftereffect as a result of continued stimulation, as early as 1911. Following this, the effects of habituation or adaptation upon the spiral aftereffect were noted in a number of studies (Eysenck, Holland, and Trouton, 1957; Holland, 1965; and Scott, *et al.*, 1966). The effects of adaptation were markedly significant in the Scott, et al. study due to the fact that they had subjects continually observe a rotating spiral for four hours a day on four successive days. Yet, Williams and Collins (1970) reported no fatigue or habituation effects for SAE duration scores over a period of five days. The present results also indicate that there is no progressive decline in the duration measures either within a day or over the course of seven days of experimentation.

Aside from the fact that the subjects, in this study, only spent an hour and a half per day making duration judgments, which themselves were separated by three-minute rest intervals, only one type of spiral (type A) was used in the present experiment. Roehrig and Rutschmann (1963) had stated that this is more beneficial in terms of obtaining duration scores than sequential use of both types (A and B) of spirals. Although Panagiotou and Roberts (1966) found that, when one spiral type is used, there is a general inhibitory effect of one trial on the succeeding one, this effect progressively diminishes when the intertrial interval is increased up to five minutes. It would appear that both the use of one type of spiral and a sufficient intertrial interval eliminates any marked habituation and fatigue factors. These facts were demonstrated by both the Williams and Collins (1970) results and those of the present study. Furthermore, a three-minute intertrial interval, which was used in both of the latter studies, seems fully sufficient to accomplish the elimination of habituation and fatigue effects.

The discussion of the results may now proceed with confidence that the results are unlikely to be contaminated by adaptation, fatigue, or habituation effects.

Visual Perception Data

It had been mentioned that perceived size and distance measures were not collect in previous SAE studies, but were used only in *post hoc* hypothesizing (Granit, 1927, 1928; Williams and Collins, 1970). The perceptual data collected in this study, then, may be used to evaluate directly the extent to which apparently independent perceptual variables affect the SAE duration. Since size and distance judgments usually follow certain well-established principles, within given limits, it would be necessary first to demonstrate that the data obtained in this study are in accord with these lawful relationships. In order to do this, perceived distance and size for both the size constant and angle constant conditions will be considered together.

The principle of size constancy was discussed in Chapter I. From the size constancy principle, one would predict that, in this study, perceived size (S') would bear a linear and proportional relationship to actual size (S), of the spiral diameter. That such is the case for the size constant condition has already been demonstrated in Table XVI and Figure 10. Despite the change in visual anlge (and, therefore, a necessary change in distance) from $\frac{1}{2}^{\circ}$ to 8°, for the four-inch spiral, the estimates of the spiral size remain very close to the actual diameter of four inches. The slight peaking effect at the 4° angle (Figure 10) is interesting with regard to Granit's (1927) original proposition that this visual angle is approximately optimal for perception of the spiral aftereffect. Table XXI and Figure 13 show that the same relationship obtains between S' and S, a positive linear and proportional one, for the angle constant condition.

Using the same principles, one would predict a positive linear and proportional relationship between D' (perceived distance) and D (actual distance). Table XV and Figure 9 indicate that this was true of the judgments made in the size constant condition, while Table XX and Figure 12 bear out the same prediction for data obtained in the angle constant condition.

On the basis of these data, "hypothesis five" of this study is confirmed. Perceived size measures, in the angle constant condition, do increase as the diameter of the spiral increases.

If S' increases with increases in S, as the present data indicate, the $\frac{S'}{\theta}$ will also increase. Since this ratio has been shown to be a more precise predictive measure for the perceived depth between familiar objects (Gogel and Mertens, 1967, 1968) and depth perception with whiteness contrasts (Gogel and Mershon, 1969), due to the fact that it takes into account the variables of size, distance, and visual angle (Size-Distance Invariance Hypothesis), it would be more desirable to use it in evaluating the effects of perceived size on the SAE duration. The plot of $\frac{S'}{\theta}$ to perceived distance indicates another linear and proportional relationship (Figures 14 and 15). Thus, if the relation between $\frac{S'}{\theta}$ and the SAE duration are likewise linear and proportional, it may be pointed out that the perceptual phenomena do indeed influence the duration of the spiral aftereffect.

Measures of perceived speed are not commonly collected in SAE studies. Hence, this study provides an opportunity to examine the effects of this variable in a somewhat novel situation. As was seen in the size constant condition, as retinal speed (minarcs/sec) of the spiral increases, for a given angle, the perceived speed also increases (see Figure 8); however, the effects of retinal speed on perceived speed are confounded here since a change in physical speed is necessary to obtain varying levels of retinal speed. When one looks at perceived speed across angles, in this condition, one finds that, with retinal speed constant, the perceived speed decreases as the visual angle increases. This inverse relationship between perceived speed and the visual angle, in the size constant condition, can be attributed to physical speed since the physical speed decreases as the angle increases. In other words, as the physical speed increases, under these conditions, so does the perceived speed.

In the angle constant condition, it can be seen that the perceived speeds for each of the three different size spirals subtending a given visual angle (both in the rpm constant and minarcs/sec constant sessions) are almost identical (Figure 11). Considering the fact that, within a given angle, the physical speed, the retinal speed, and the visual angle are all constant, this result is not at all unexpected. Whatever very slight increases may exist between spiral diameters, might be accounted for by size constancy principles, i.e., spirals perceived as larger may also be perceived as rotating slightly faster than smaller spirals subtending the same visual angle.

When the physical speed is held constant (rpm constant session), a slight but consistent difference in perceived speed is seen among angles at each spiral size. Since the 8° angle has the highest perceived speed and the 2° angle has the lowest, this difference may be attributed to the effects of different retinal speeds. That is, the retinal speed (minarcs/sec) used in the 2° angle, for the three spiral sizes, was one-fourth that of the retinal speed used for the three spiral sizes in the 8° angle. However, when the retinal speed is held constant, in the minarcs/sec constant session, substantial differences appear in perceived speed for a given size spiral at different distances from the observers. In this instance, the 8° angle consistently has the lowest perceived speed values for the three spiral sizes; these are significantly different from those of the 2° angle. But the physical speed of the spiral subtending a 2° angle is four times that of the spiral subtending an 8° angle (although retinal speed is the same). Hence, in this case, differences in physical speed contribute greatly to differences in perceived speed.

On the basis of these data, one might posit some general rules regarding judgments of perceived speed of rotating visual stimuli which have not been offered previously. With rotating stimuli of different size, but with physical speed and visual angle (and, therefore, retinal speed) held constant, judgments of perceived speed will be essentially the same. When physical speed is held constant for a given stimulus size, changes in distance (visual angle) produce only slight changes in perceived speed although retinal speed is changed markedly; in this case, perceived speed increases with larger visual angles. When retinal speed is held constant for a given stimulus size, changes in distance (visual angle) produce significant changes in perceived speed which accompany the large changes in physical speed required to maintain a constant retinal speed; in this case, perceived speed decreases with larger visual angles.

Relationship of SAE Duration to Perceptual Events

That the SAE duration is significantly influenced by factors other than visual angle and retinal speed is clearly evident in the angle constant condition. When variables such as the visual angle, physical speed, and retinal speed are held constant, a reasonable prediction would be that the duration of the spiral aftereffect would itself remain constant. That such is not the case is demonstrated in the work of Granit (1927, 1928), Williams and Collins (1970), and the present investigation. Granit (1928) mentioned the possibility of a phenomenal variable affecting the SAE duration; while Williams and Collins (1970) developed the hypothesis (*post hoc*). The present study proceeded from the viewpoint that such interaction was likely and actually investigated the relationship between certain perceptual variables and the SAE duration by obtaining data for all of the foreseeably associated phenomenological factors.

Granit (1927, 1928), in conducting a size constant condition, placed the waterfall drum at various distances from the subject. This provided SAE duration data for several visual angles and resulted in a peaking effect for the duration scores between 2° and 4°. He then repeated the procedure three times, but used a reduction screen varying in diameter from 6 to 9 to 12 cm. As a result of this procedure, he obtained consistently longer durations when using the 12-cm screen than either the 6-cm or 9-cm screen. Granit (1927) spoke of the relationship between increasing duration and increasing stimulus size as the "linear effect". While he did not conduct an angle constant condition *per se*, one can draw from his data the fact that, for any given angle, increases in SAE durations resulted from increases in size and distance of the stimulus.

For his size constant condition, Granit obtained an initial increase in SAE duration, up to a maximum between 2° and 4°, after which the duration scores declined; he explained this on the basis of the anatomical arrangement of the visual receptors. Due to the increased retinal size and retinal speed of the spiral, which accompanied the angle increases, Granit (1927) anticipated an increase in SAE duration. However, when this did not occur beyond the 2° to 4° range, he posited the hypothesis of rod inhibition of cone functioning. Pure cone functioning exists within visual angles up to 2°, with cone domination extending up to 4°; the same range in which the duration scores peak. However, beyond 4°, the influence of the rods becomes more marked and, hence, the inhibition hypothesis. Williams (1969) noted that there was supporting evidence for this view, particularly the electrophysiological work with ON and OFF responses in the eye. Matokawa and Ebe (1953) have reported that, with humans, ON responses are associated with rods and OFF responses with cones. Hence, the durational decline beyond 4° might be attributed, as Granit (1928) suggested, to an increasing inhibition of cone function as proportionately more and more rods are activated.

Thus, Granit (1927, 1928) was faced with two apparently contradictory situations. On the one hand, as the stimulus size and distance increased, the SAE duration increased; on the other hand, as the retinal size increased (above 4°), the duration decreased. Granit (1927) suggested that size constancy might be operating differently in these two situations.

Williams and Collins (1970) utilized angle constant, size constant, and distant constant conditions in their study. They found, in their (4°) angle constant condition, that the SAE durations increased with increases in stimulus size and distance, as Granit (1927, 1928), albeit somewhat obtusely, had reported earlier. Williams and Collins (1970) also obtained a peaking effect between 2° and 4° of visual angle in their size constant condition. Like Granit, they felt that factors associated with size constancy could be applied in order to explain these results. Thus, they hypothesized that increases in SAE duration as stimulus size and distance increased (in their angle constant condition), were probably determined by perceived size of the spiral per unit of its retinal size.

The present investigation also confirms the fact that size constancy factors affect the SAE duration. Results of the angle constant condition indicate that duration scores increase as the size of the spiral (and its distance from the observer) increases (see Figure 17). This confirms "hypothesis four". The perceptual consequence of these physical changes, however, is the significant point here, since visual angle, rpm, and SEM are all constant. The data show that perceived size (S') and perceived distance (D') increase as spiral size (S) and its distance (D) from the observer increase. Hence the increase in SAE duration may be attributed to factors associated with perceived size (specifically, $\frac{S'}{\theta}$), as was suggested by Williams and Collins (1970). This fact confirms "hypoothesis six" of the present investigation. However, in the angle constant condition, there are differences among visual angles in SAE duration depending on whether rpm or minarcs/sec is held constant. It appears that $\frac{S'}{\theta}$ may be more predictive of SAE duration across a number of visual angles when minarcs/sec are held constant, at least within the range of angles studied here. That is, with rpm constant, the plot of the effect of $\frac{S'}{\theta}$ on the SAE duration yields three distinctive sets of data (see Figure 17). However, when minarcs/sec are constant, the duration points for the different visual angles and different size spirals array themselves in such a fasion as to suggest a monotonic function. These data suggest a possibly important interaction of retinal speed with other perceptual factors ($\frac{S'}{\theta}$) in accounting for SAE duration measures. Present results do not permit any clearer delineation of the role of retinal speed in that interaction. Although $\frac{S'}{\theta}$ accounts for the primary SAE results obtained in the angle constant condition, it is only partially effective in explaining the changes in SAE duration recorded in the size constant condition. In the latter, a peaking effect was generally observed between 2° and 4° of visual angle, despite constant SEM rates. Beyond that interval, as retinal size increased, the duration decreased; prior to the interval, the duration decreased. This curvilinear relationship between duration and visual angle is well supported; in addition to specific mention by Granit (1927, 1928) and by Williams and Collins (1970), it can be found in the data of Pickersgill and Jeeves (1958), Costello (1960b), Fozard, et al. (1965), and Collins and Schroeder (1968). However, "hypothesis three", of the present study, is only partially confirmed, since a peaking was obtained for visual angles of 2°, 4°, and 8° only; angles of $\frac{1}{2}^{\circ}$ and 1° did not show it. Thus, even with minarcs/sec held constant, some effects related to visual angle appear in the data.

As Williams and Collins (1970) noted, the peaking effect cannot be explained on the basis of the $\frac{S'}{\theta}$ ratio, since SAE durations should continue to increase at the small visual angles in the size constant condition. The present results indicate that, from 8° to 2° of visual angle, SAE durations increase as $\frac{S'}{\theta}$ increases. From the Williams and Collins (1970) data, this range can be extended from 16° to 2°. However, the relationship between $\frac{S'}{\theta}$ and SAE durations does not hold for angles smaller than 2°. Thus, some other factor or factors must be operating.

Williams and Collins (1970) suggested several possibilities to account for the decline in SAE durations below 2° of visual angle. Since they kept rpm constant in their size constant condition, they suggested that the decline in scores from the 2° to the 1° angle might be due to differences in the effects of SEM at low rates (40 to 20 minarcs/sec), or to perceived speed differences, or to rod-cone inhibition. Although they were correct about the different results obtained at low rates of SEM, the present study shows that peaking occurs even when minarcs/sec are held constant. The present study also shows that perceived speed does not account for the peaking effect, because perceived speed values increase (Figure 8), for the $\frac{1}{2}^{\circ}$ and 1° visual angles, while the SAE duration scores decrease for these angles. Further, the explanation cannot be in the breakdown of the $\frac{S'}{\theta}$ ratio at extreme limits because SAE duration, in the angle constant condition, increases throughout the $\frac{S'}{\theta}$ range (Figure 17) but, for the same range, in the size constant condition, the durations for $\frac{1}{2}^{\circ}$ and 1° decrease (Figure 16).

If the distance constant data obtained by Williams and Collins (1970) are correct, it is unlikely that the solution to the peaking of SAE scores at $2^{\circ} - 4^{\circ}$ lies in Granit's (1928) rod-cone interaction. With rod inhibition as a factor, one would expect a progressive decline in SAE duration as the visual angle (spiral size) increased in a distance constant condition; yet, Williams and Collins found no such change in SAE duration scores over a $4^{\circ} - 16^{\circ}$ range. Thus if their data are correct, a rod-cone interaction cannot account for the results, although size constancy factors (ideally $\frac{S'}{\theta}$ in a distance constant condition would have an identical value for each spiral size or visual angle) would predict no change in the duration scores (and none were obtained).

Perhaps the most reasonable hypothesis is that which takes into account physiological limits. The logical extension of the effects of size constancy factors on SAE duration in a size constant condition would demand that, as the stimulus became infinitely smaller (and infinitely more distant), the duration score would increase infinitely. This is untenable from a physiological, neurological, or psychological point of view. Instead, what seems likely is that as the retinal elements stimulated become very few, a decrease in the SAE duration occurs. In all likelihood, the range below which this decline occurs is 2° - 4° of visual angle. This hypothesis can be subjected to test by use of a distance constant condition with a range of visual angles from, say $\frac{1}{2}^\circ$ to 16°. If Granit's (1928) hypothesis is correct, the duration scores should increase steadily from $\frac{1}{2}^\circ$ through 16° of visual angle. If Williams and Collins (1970) data are correct, there should be no change in the duration scores from 4° through 16° (on the basis of equivalent $\frac{S'}{\theta}$), and perhaps, from 2° - 16°. However, at visual angles smaller than 2° (in spite of equivalent $\frac{S'}{\theta}$ ratios), there should occur a progressive decline in SAE durations, if the hypothesis offered here is correct. This decline would not be predicted by either rod-cone interaction or size constancy factors.

Speed of Eliciting Motion

In an effort to account for difference in SAE duration resulting from changes in physical speed, size and distance (visual angle), and retinal speed (a variable not often considered), Scott and Noland (1965) proposed use of the measure of the speed of eliciting motion. Based upon the fact that the movement of the stimulus pattern across the retina varies with the viewing distance, they suggested, with the support of several sets of data, that SAE duration scores would increase over a range of 30 to 132 minarcs/sec and would then decline. Stager and Burton (1964) had designated the effective (increasing duration) range as 148 to 172 minarcs/sec. However, Collins and Schroeder (1968) found duration scores to increase only between 30 and 60 minarcs/sec, under certain conditions, while Williams and Collins (1970) found SEM had no effect upon duration scores between 50 and 200 minarcs/sec under other conditions. Further data in the latter study, however, led to the suggestion that retinal speed might influence SAE durations below approximately 50 minarcs/sec.

The present results confirm the notion that SAE duration scores are differently affected (they increase) as SEM values increase up to 40 minarcs/sec. Thus, "hypothesis one" of the present investigation is confirmed. No significant effect was found upon SAE durations over a range of SEM values from 40 to 100 minarcs/sec for the 2°, 4°, and 8° visual angles. However, there was a significant decline in SAE duration between 40 and 100 minarcs/sec for the $\frac{1}{2}^{\circ}$ and 1° angles. Thus, "hypothesis two" is only partially confirmed. There seem to be at least two factors which help to explain the decline in duration for the 100 minarcs/sec point in the $\frac{1}{2}^{\circ}$ and 1° visual angle. The physical speeds necessary to maintain 100 minarcs/sec for these angles were very high; and regardless of retinal speed, characteristics of the stimulus appeared to be changed, i.e., blurring occurred at these speeds. Certainly this would affect the length of the duration. In addition, these angles are represented by a very small retinal area. Hence, there are much fewer retinal elements available effectively to respond to the stimulus - again a factor which would tend to decrease the SAE duration.

Scott and Noland (1965) felt that the SAE duration was highly predictable when one took into account the SEM values. However, recent results appear to restrict the influence of SEM on SAE duration to a much narrower range than proponents originally proposed. Had Scott and Noland's view been correct, then one would anticipate, in the minarcs/sec constant session (angle constant condition) of this study, that the perceived speed judgments would have been the same, without any effects of visual angle. Inspection of Figure 11 indicates that this is not the case. Hence, SEM is interacting with other variables. In the rpm constant session, however, where retinal speed did vary among angles, the slight variation in SAE duration scores between angles for a given spiral diameter may be attributed to differences in SEM (Figure 11). In the size constant condition, the SEM values at 10 and 20 minarcs/sec did have a different effect upon SAE duration than did higher retinal speeds. Hence, the predictive value of the speed of eliciting motion, as proposed by Scott and Noland (1965), has a more markedly limited utility than they had concluded.

Clinical Implications

A need to standardize the technique involved in acquiring duration data for the spiral aftereffect has been voiced by many authorities. Yet, the elusive quality of the parameters underlying the functioning of the SAE has made this more than a routine challenge. It is not necessary to enumerate the benefits of such a standardization procedure.

Most evident, of course, is the advantage of obtaining reliable and comparable data from a variety of studies. Whether the SAE is to remain a laboratory technique or become a clinical test, it is essential to have data which are reliable and comparable. Before reliable differentiating criteria can be devised for clinical purposes, a definite set of procedures should be set down to assure that the same effects are being measured. Once this is done, the value of the spiral aftereffect as a diagnostic tool (for separating organics and non-organics), or as a differential diagnostic tool (specifying types of organicity; differentiating organic from functional pathology, etc.) can be ascertained. It may also prove to be a useful tool in gauging perceptual maturation of children, as Snyder and Freud (1967) suggest.

Based on the results of this and related studies, the following recommendations are made in terms of the clinical use of the SAE:

(1) The spiral should subtend a visual angle between 2° and 4° in order to maximize the range of possible response variability. Since visual angle is a product of size and distance, the following characteristics represent sample procedures which may be used.

Visual Angle	Spiral Diameter	Distance from Observer
2°	4-inch	9.5 feet
2°	8-inch	19.1 feet
2°	16-inch	38.2 feet
4°	4-inch	4.77 feet
4°	8-inch	9.5 feet
4°	16-inch	19.1 feet.

(2) The disc speed should be sufficient to maintain a speed of eliciting motion at or above 50 minarcs/sec. For 50 minarcs/sec, this

would mean a disc speed of 160 rpm for a 2° visual angle, and 80 rpm for a 4° angle.

(3) It is preferable and advantageous to use only one type of spiral and the A type is recommended. This is a spiral of contracting stimulation which yields an expanding aftereffect.

(4) An intertrial interval of at least three minutes should be utilized in order to avoid the effects of habituation and fatigue.

(5) While various stimulus durations have been discussed in the literature, a 15-second exposure-time seems sufficient to elicit appropriate illusory responses for most subjects. Freud (1963) has also suggested a stimulus duration of 15 seconds.

(6) It is felt that preliminary trials in which the subject can experience the illusion, and, if necessary, have it described for him, are essential in assuring adequate responses (Mayer and Coons, 1960; London and Bryan, 1960).

CHAPTER V

SUMMARY

The purpose of the present investigation was to attempt to isolate the effects of visual angle, of the speed of eliciting motion (retinal speed), and of certain perceptual phenomena, especially perceived size, on the duration of the spiral aftereffect. Specifically, the hypotheses investigated in this study were:

Size Constant Condition

(1) Retinal speed will affect SAE duration, over a range of visual angles, below 50 minarcs/sec. Duration will increase as SEM increases. This hypothesis was confirmed.

(2) Retinal speed will have no effect on SAE duration at rates between 50 and 100 minarcs/sec. This hypothesis was only partially confirmed, because the comparison of these two rates for the $\frac{1}{2}^{\circ}$ and 1° angles indicated significant declines in duration scores. These declines were attributed partly to the very high physical speeds necessary to produce 100 minarcs/sec at these angles, as well as to the fact that the smaller and smaller number of retinal elements stimulated at these angles are probably unable to respond efficiently to high physical rates of stimulation.

(3) Peaking effects between 2° and 4° of visual angle will be evidenced in SAE duration scores in spite of maintaining a constant

retinal speed. This hypothesis was partially confirmed in that peaking effects occurred for visual angles of 2°, 4°, and 8°. However, the effect was not obtained for visual angles of $\frac{1}{2}^{\circ}$ and 1°. Several possible explanations for this occurrence were explored but they did not appear to satisfy the present data or those of other studies. It was suggested, instead, that physiological limits must be considered. Specifically, that as the number of retinal elements stimulated become very few (at less than 2° of visual angle), a decline in SAE duration occurs.

Angle Constant Condition

(4) The duration of SAE will increase with increases in the diameter of the spiral. This hypothesis was confirmed.

(5) Perceived size measures will increase, in the same condition, under the same circumstances. This hypothesis was confirmed.

(6) Increases in SAE duration can be attributed to increases in perceived size. This hypothesis was confirmed.

Size constancy principles explain most of the results. That is, in the angle constant condition, increases in duration scores were related to increases in $\frac{S'}{\theta}$ (perceived size per unit of retinal size). In the size constant condition, increases in duration scores were attributable to $\frac{S'}{\theta}$ from 8° to approximately 2° of visual angle. Increases in $\frac{S'}{\theta}$ at angles smaller than 2° failed to produce an increase in SAE durations. This was attributed to the severe reduction in the number of retinal elements stimulated at the smaller angles.

Several general rules regarding perceived speed were offered. In an angle constant condition, perceived speed judgments, for a given visual angle, will be essentially the same for a variety of spiral sizes. When physical speed is held constant, perceived speed judgments increase with larger visual angles. When retinal speed is held constant, perceived speed judments decrease with larger visual angles.

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TABLE XXIII

FORMULA FOR THE COMPUTATION OF A VISUAL ANGLE, AND A SAMPLE DERIVATION OF THE VISUAL ANGLE FOR A 10-INCH SPIRAL AT A DISTANCE OF 12 FEET FROM THE OBSERVER

Where:

r = spiral radius

d = distance of the spiral from the observer

$VA = 2 \log \tan \frac{r}{d}$.

Thus, for a 10" spiral at 12':

$VA = 2 \log \tan \frac{5}{144}$ where $\frac{5}{144} = .03472$

$$VA = \log \tan 2(.03472)$$

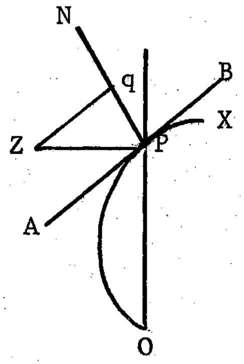
$$VA = \log \tan .06944$$

$$VA = 4^{o}$$

TABLE XXIV

FORMULA FOR THE SPEED OF ELICITING MOTION (SEM), AND A SAMPLE DERIVATION FOR A 3-THROW ARITHMETIC SPIRAL, 4 INCHES IN DIAMETER, ROTATING AT 66.7 RPM AT A DISTANCE OF 4.77 FEET FROM THE OBSERVER

Where:



AB = a tangent line to curve OX at P

PN = the normal line to curve OX at P (perpendicular to tangent line)

$\overline{PZ}$ = physical rotational velocity or rpm

$\overline{PQ}$ = projection of $\overline{PZ}$ on PN, so that Q is the foot of the perpendicular

$\rho = a\theta$ = equation for deriving an arithmetic spiral.

$$\overline{PQ} = \frac{2\ a\pi\omega\rho}{\sqrt{\rho^2 + a^2}}$$

where:

$a = \frac{2}{\theta} = .1061$

π = pie = 3.1417

ω = rpm = 66.7

ρ = spiral radius = 2

d = distance from observer.

TABLE XXIV (Continued)

$$SEM = (\frac{\overline{PQ}}{60})\varphi$$

where

$\varphi = \psi_1 - \psi_2$

$\psi_1 = \arctan \frac{\rho}{d}$

$\psi_2 = \arctan \frac{\rho - 1}{d}$.

$$P = a\theta$$

where

$\theta = 6\pi$

$a = \frac{2}{6\pi} = .1061$.

$$\overline{PQ} = \frac{2\ a\pi\omega\rho}{\sqrt{\rho^2 + a^2}} = \overline{PQ} = \frac{2(.1061)(3.1417)(66.7)(2)}{\sqrt{4 + .01125721}}$$

$$\overline{PQ} = 44.4668$$

$$\frac{\overline{PQ}}{60} = .74111$$

$$\psi_1 = \frac{2}{57.24} = .03494 \qquad \arctan = 120'$$

$$\psi_2 = \frac{1}{57.24} = .01747 \qquad \arctan = \frac{60'}{60}$$

$$\varphi = 60$$

$$SEM = (\frac{\overline{PQ}}{60})\varphi = (.74111)60 = 44.47 \text{ minarcs/sec} \quad .$$

TABLE XXV

SPIRAL AFTEREFFECT DURATION SCORES[1] (IN SECONDS) OBTAINED FROM EACH SUBJECT FOR THE STANDARD STIMULUS USED DURING THE PRE AND POST TRIALS WHICH PRECEDED AND FOLLOWED EACH EXPERIMENTAL SESSION

	Days													
	1		2		3		4		5		6		7	
S	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	23.53	17.50	19.63	25.73	17.92	14.75	15.23	14.03	15.71	14.95	16.38	35.64	22.16	17.89
2	9.66	8.43	6.59	5.80	9.66	10.02	8.45	7.22	9.14	9.44	7.95	10.21	9.79	13.98
3	20.67	5.81	11.36	10.08	9.30	8.82	8.82	9.08	6.14	4.68	8.03	8.85	8.39	8.69
4	22.95	23.90	27.67	19.28	22.20	30.78	26.19	33.56	40.38	32.45	31.53	26.16	35.20	17.71
5	19.96	19.68	23.96	33.12	18.47	16.94	15.75	23.89	20.08	16.76	17.08	26.64	17.50	24.81
6	13.08	12.29	11.41	12.22	11.87	11.12	12.23	13.08	16.52	12.53	13.93	17.91	16.88	14.83
7	22.63	31.48	23.92	28.44	24.95	26.87	19.58	19.23	17.92	14.20	11.07	13.44	10.36	22.24
8	11.67	20.52	17.41	20.46	15.19	19.69	19.32	25.24	26.03	28.52	25.91	23.04	33.17	32.87
9	22.56	20.13	23.99	33.82	18.65	14.72	21.09	26.34	22.25	24.07	15.16	27.35	18.46	26.18
10	14.61	14.59	13.31	14.89	14.25	16.67	14.74	20.16	18.21	19.08	17.03	20.12	18.08	18.33
11	23.86	14.02	21.28	19.37	12.76	15.90	21.67	17.75	19.89	26.51	19.49	23.64	21.75	28.01
12	10.57	10.22	11.49	14.36	9.63	10.85	10.87	10.37	8.81	10.15	11.45	9.49	11.11	11.39
13	15.95	10.68	14.34	9.24	9.21	12.29	12.01	11.09	13.46	7.28	4.30	8.07	5.53	8.40
14	22.53	13.60	20.89	10.95	16.91	11.65	13.66	19.44	8.58	10.96	7.29	8.59	12.60	12.96
Mean	18.16	15.92	17.66	18.41	15.07	15.79	15.69	17.89	17.37	16.54	14.76	18.51	17.21	18.45
SD	5.32	6.81	6.30	8.98	5.02	6.35	5.24	7.59	8.80	8.47	7.46	8.87	8.77	7.46

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[1] Each value is a mean of two readings.

TABLE XXVI

PERCEIVED SPEED SCORES (IN PERCENTAGES) OBTAINED FROM EACH SUBJECT FOR THE STANDARD STIMULUS (ROTATING AT 75 RPM) USED DURING THE PRE AND POST TRIALS WHICH PRECEDED EACH EXPERIMENTAL SESSION

	Days													
	1		2		3		4		5		6		7	
S	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	25	25	25	35	25	25	25	25	25	30	25	30	25	25
2	20	35	30	30	40	55	40	30	45	70	50	70	50	75
3	10	10	25	25	25	25	25	25	25	25	25	25	25	25
4	30	40	20	25	25	25	25	50	40	25	25	40	25	30
5	40	30	35	50	25	40	30	40	30	35	35	50	35	40
6	30	35	45	50	40	25	40	25	35	20	25	25	35	30
7	20	40	30	30	30	60	30	30	30	40	30	50	30	50
8	30	30	30	40	20	30	30	30	30	40	30	30	40	30
9	20	15	15	30	20	35	20	35	20	25	25	40	30	30
10	30	30	30	50	40	40	30	40	30	40	40	60	40	60
11	30	30	20	40	30	40	30	30	30	50	30	40	40	40
12	25	15	25	40	25	20	25	40	25	25	25	25	25	25
13	35	15	25	25	25	25	25	25	20	25	25	30	25	25
14	20	30	25	30	25	15	25	15	20	25	20	25	25	30
Mean	26.07	27.14	27.14	35.71	28.21	32.86	28.57	31.43	28.93	33.93	29.29	38.57	32.14	36.79
SD	7.64	9.75	7.26	9.38	6.96	12.97	5.69	8.86	7.39	13.47	7.81	14.34	8.02	15.14

TABLE XXVII

PERCEIVED DISTANCE SCORES (IN FEET) OBTAINED FROM EACH SUBJECT FOR THE STANDARD STIMULUS (4.77 FEET FROM THE OBSERVER) USED DURING THE PRE AND POST TRIALS WHICH PRECEDED EACH EXPERIMENTAL SESSION

	Days													
	1		2		3		4		5		6		7	
S	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
2	5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
3	4	4	4	4	4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	5	5	5	5	5	5	5	8	5	5
5	4	4	4	4	4	4	4	4	4	4	4	5	5	5
6	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
7	4	4	4	4	4.5	5	4.5	4	4	4	4	4	4	4
8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
9	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
10	4	4	4	4	4	3	4	4	4	4	4	4	4	4
11	3.5	3.5	3.5	3.5	3.5	3.5	4	4	3.5	3.5	3.5	4	4	4
12	4	5	5	5	5	5	5	5	5	5	5	5	5	5
13	4	5	5	5	5	5	5	5	5	5	5	5	5	5
14	3	4	4	4	4	4	4	4	4	4	4	4	4	4
Mean	3.86	3.96	3.96	3.96	4.07	4.04	4.11	4.07	4.04	4.04	4.04	4.36	4.14	4.14
SD	0.46	0.50	0.50	0.50	0.58	0.69	0.56	0.55	0.57	0.57	0.57	1.18	0.60	0.60

TABLE XXVIII

PERCEIVED SIZE SCORES (IN INCHES) OBTAINED FROM EACH SUBJECT FOR THE STANDARD STIMULUS (4-INCH SPIRAL) USED DURING THE PRE AND POST TRIALS WHICH PRECEDED AND FOLLOWED EACH EXPERIMENTAL SESSION

	Days													
	1		2		3		4		5		6		7	
S	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	5	5	5	4	4	5	5	5	5	5	5	5	5	5
2	5	6.5	7	7.5	8	8	8.5	7	8	7	7	7	7	7
3	5	4	4	4	4	4	4	4	4	4	4	4	4	4
4	6	6	6	6	6	6	6	7	6	7	6	6	6	6
5	4	5	5	5	5	5	5	5	5	5	5	4	5	5
6	4	4	4	4	4	4	5	4	4	4	4	3.5	4	4
7	6	6	6	6	6	6	5	5	6	6	6	5	5	5
8	3	4	3.5	3.5	4	4	4	4	4	4	4	4	4	4
9	5	4.5	4	4	4	4	4	4	4	4	4	4	4	4
10	5	4	4	4	4	4	4	4	4	4	4	4	4	4
11	4	4	4	4	4	3.5	4	4	4	4	4	3.5	4	4
12	4	4	4	6	6	6	6	6	6	6	6	6	6	6
13	4	6	4	4	6	6	6	6	6	5	6	4	4	4
14	6	4	4	4	6	6	6	6	6	6	6	4	5	4
Mean	4.71	4.79	4.61	4.71	5.07	5.11	5.18	5.07	5.14	5.07	5.07	4.57	4.79	4.71
SD	0.91	0.96	1.04	1.19	1.27	1.27	1.27	1.14	1.23	1.14	1.07	1.07	0.98	0.99

TABLE XXIX

SPIRAL AFTEREFFECT DURATION SCORES[1] (IN SECONDS) OBTAINED FROM EACH SUBJECT FOR EACH SPEED OF ELICITING MOTION (MINARCS/SEC) AT THE $\frac{1}{2}^{\circ}$ VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	14.08	20.15	16.07	15.70	14.84	16.21	10.05
2	11.75	17.51	17.04	20.06	20.32	15.19	14.56
3	8.51	8.68	9.09	6.88	10.92	9.90	8.25
4	17.86	19.95	22.41	21.20	21.97	19.49	7.80
5	20.00	17.53	16.58	12.87	16.59	18.90	14.92
6	9.23	10.01	9.82	9.21	7.13	5.58	2.51
7	32.49	24.18	28.62	34.13	28.32	30.65	20.44
8	20.30	19.83	22.80	26.60	22.52	16.22	16.41
9	18.82	20.06	20.82	18.56	19.58	20.23	18.49
10	8.77	10.95	10.91	11.68	9.11	9.64	11.10
11	20.84	24.35	23.42	29.23	18.82	18.37	18.41
12	13.58	13.48	18.88	17.90	18.26	13.38	15.16
13	10.52	11.56	11.49	11.94	11.35	13.95	5.49
14	6.80	10.59	11.70	11.57	11.50	13.86	7.90
Mean	15.25	16.35	17.12	17.68	16.52	15.83	12.25
SD	6.96	5.36	6.00	7.96	5.99	5.95	5.43

[1] Each value is a mean of three readings.

TABLE XXX

SPIRAL AFTEREFFECT DURATION SCORES[1] (IN SECONDS) OBTAINED FROM EACH SUBJECT FOR EACH SPEED OF ELICITING MOTION (MINARCS/SEC) AT THE 1° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	12.86	13.07	18.85	16.00	18.83	13.82	11.19
2	5.04	11.69	14.09	17.02	14.53	14.10	11.93
3	8.66	11.10	11.02	12.13	13.24	13.92	9.02
4	22.76	25.21	35.15	29.14	31.67	28.21	33.10
5	18.86	25.15	22.41	25.27	20.56	11.29	6.65
6	6.64	14.75	16.85	16.31	14.51	8.84	9.83
7	9.12	23.35	25.26	23.98	16.15	23.03	20.92
8	15.53	23.68	19.35	22.61	17.50	21.50	18.78
9	19.84	18.81	25.59	24.45	23.61	23.78	21.26
10	12.72	13.44	16.17	16.39	15.45	14.76	15.85
11	13.81	15.55	16.53	17.53	17.14	17.15	17.74
12	7.50	8.83	15.37	13.33	13.19	11.36	15.43
13	9.05	13.21	16.72	20.03	19.89	20.41	16.02
14	12.42	17.60	19.07	20.57	15.52	13.13	13.80
Mean	12.49	16.82	19.46	19.63	17.99	16.81	15.82
SD	5.29	5.56	6.06	4.93	4.93	5.67	6.64

[1] Each value is a mean of three readings.

TABLE XXXI

SPIRAL AFTEREFFECT DURATION SCORES[1] (IN SECONDS) OBTAINED FROM EACH SUBJECT FOR EACH SPEED OF ELICITING MOTION (MINARCS/SEC) AT THE 2° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	19.04	19.05	26.83	20.43	21.97	21.15	23.07
2	7.55	11.83	12.87	13.25	16.46	17.25	14.34
3	6.37	7.81	11.01	10.48	13.05	9.49	11.26
4	19.62	22.93	28.16	26.48	23.94	23.21	27.74
5	23.08	29.49	24.90	22.81	29.63	26.31	25.74
6	8.25	12.15	17.97	16.14	18.98	18.43	17.86
7	14.97	19.40	25.08	23.55	22.26	19.17	21.76
8	11.51	11.88	23.20	23.58	20.97	20.03	22.37
9	18.18	23.37	29.66	26.75	24.44	28.87	28.35
10	10.40	16.43	19.40	20.99	19.20	20.24	22.34
11	16.35	20.56	22.29	21.56	21.60	20.30	29.50
12	7.82	14.23	16.18	15.19	19.86	13.76	15.92
13	7.50	13.32	16.73	16.79	17.89	20.55	22.56
14	10.19	13.82	12.88	20.15	17.09	15.90	14.50
Mean	12.92	16.88	20.51	19.87	20.52	19.62	21.24
SD	5.50	5.86	6.08	4.87	4.04	4.85	5.69

[1] Each value is a mean of three readings.

TABLE XXXII

SPIRAL AFTEREFFECT DURATION SCORES[1] (IN SECONDS) OBTAINED FROM EACH SUBJECT FOR EACH SPEED OF ELICITING MOTION (MINARCS/SEC) AT THE 4° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	17.29	23.31	29.94	28.55	26.56	24.72	23.80
2	4.37	9.70	10.30	13.94	13.84	13.71	14.84
3	5.74	7.40	6.55	9.68	10.59	10.36	10.12
4	18.91	25.60	30.08	27.73	29.28	28.81	30.85
5	17.95	23.56	27.22	28.61	31.98	29.15	24.62
6	6.94	13.11	14.38	13.46	12.17	11.87	10.49
7	15.87	25.84	27.46	24.40	27.93	29.45	22.86
8	11.10	16.11	32.42	31.80	25.91	27.91	29.65
9	17.49	23.77	26.37	29.94	26.93	27.14	31.42
10	9.52	13.21	18.88	16.79	17.39	20.19	20.99
11	13.43	14.18	20.13	21.94	18.89	18.64	21.09
12	5.12	6.16	10.33	9.74	10.87	10.80	14.03
13	7.47	10.19	12.34	14.54	13.98	16.33	12.70
14	9.63	17.17	14.59	13.90	13.76	15.10	15.24
Mean	11.49	16.38	20.07	20.36	20.01	20.30	20.19
SD	5.25	6.92	8.74	8.01	7.71	7.38	7.41

[1] Each value is a mean of three readings.

TABLE XXXIII

SPIRAL AFTEREFFECT DURATION SCORES[1] (IN SECONDS) OBTAINED FROM EACH SUBJECT FOR EACH SPEED OF ELICITING MOTION (MINARCS/SEC) AT THE 8° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	9.62	6.28	12.52	13.27	12.37	15.02	14.60
2	4.33	5.59	7.38	7.28	5.98	7.71	7.43
3	6.08	4.92	9.23	9.07	8.51	9.57	11.86
4	16.82	15.77	26.67	29.61	31.02	30.28	32.78
5	20.75	22.65	22.88	17.05	23.61	19.52	23.76
6	6.06	9.01	8.62	9.45	12.01	13.27	14.37
7	19.52	19.35	33.83	26.30	19.90	22.33	28.25
8	12.04	15.97	18.12	18.77	20.55	24.18	25.43
9	8.77	11.89	9.31	20.03	22.13	22.77	23.00
10	5.15	7.14	8.46	9.67	11.40	11.95	14.25
11	15.48	18.05	17.09	23.04	21.08	21.26	23.64
12	2.80	4.42	9.50	9.27	8.59	7.54	9.29
13	7.31	9.15	7.44	8.49	9.39	5.13	4.49
14	12.44	11.23	17.76	17.52	15.16	11.77	12.74
Mean	10.51	11.53	14.92	15.63	15.84	15.88	17.56
SD	5.79	5.91	8.21	7.25	7.28	7.54	8.50

[1] Each value is a mean of three readings.

TABLE XXXIV

SPIRAL AFTEREFFECT DURATION SCORES[1] (IN SECONDS) OBTAINED FROM EACH SUBJECT FOR EACH SPIRAL DIAMETER (IN INCHES) AT THE THREE VISUAL ANGLES USED IN THE ANGLE CONSTANT CONDITION WITH RPM CONSTANT

	Spiral Diameter (inches)								
	2°			4°			8°		
Subject	4	10	16	4	10	16	4	10	16
1	19.19	17.15	15.56	17.85	23.05	14.75	31.11	24.50	18.96
2	14.52	15.88	17.00	9.72	8.33	9.45	9.22	10.52	10.57
3	7.65	10.13	8.50	10.79	9.97	10.66	8.30	8.16	9.03
4	22.42	21.44	14.90	29.06	32.27	28.95	29.53	28.81	31.74
5	21.40	25.32	25.83	23.24	26.02	26.54	15.45	24.28	20.29
6	14.96	12.97	16.73	14.15	17.88	14.93	11.78	17.75	12.31
7	18.74	16.76	19.41	13.78	19.89	23.75	20.34	23.43	23.98
8	18.42	20.09	25.71	30.96	31.58	33.59	24.49	27.98	28.82
9	23.59	26.82	30.01	28.47	26.70	28.37	28.74	23.62	24.74
10	22.37	20.65	18.16	18.27	20.38	15.57	15.38	16.64	17.88
11	24.52	28.12	29.93	23.13	29.34	35.14	17.12	26.25	34.51
12	10.34	12.23	17.72	9.29	11.78	15.70	9.35	14.06	14.54
13	4.87	14.57	13.69	5.31	9.53	15.44	5.79	10.55	7.38
14	9.11	12.33	12.83	6.20	12.20	10.81	5.10	6.63	13.67
Mean	16.65	18.18	19.00	17.16	19.92	20.26	16.55	18.80	19.17
SD	6.29	5.74	6.50	8.65	8.51	8.84	9.00	7.71	8.58

[1] Each value is a mean of three readings.

TABLE XXXV

SPIRAL AFTEREFFECT DURATION SCORES[1] (IN SECONDS) OBTAINED FROM EACH SUBJECT FOR EACH SPIRAL DIAMETER (IN INCHES) AT THE THREE VISUAL ANGLES USED IN THE ANGLE CONSTANT CONDITION WITH SEM CONSTANT

	Spiral Diameter (inches)								
	2°			4°			8°		
Subject	4	10	16	4	10	16	4	10	16
1	19.17	20.42	23.64	20.27	19.21	22.60	15.66	17.19	18.85
2	10.88	12.99	14.43	9.91	13.51	14.24	8.12	7.34	10.95
3	10.29	12.15	13.44	9.38	8.99	9.58	7.09	8.19	9.45
4	24.23	28.09	28.03	28.32	32.68	28.53	24.70	25.40	30.11
5	19.98	21.06	22.15	21.83	25.12	23.98	16.54	21.65	22.89
6	14.14	14.70	15.49	14.98	11.93	14.22	8.10	11.51	16.94
7	24.45	21.52	25.34	19.55	20.24	21.03	9.64	10.91	16.42
8	24.00	23.22	29.32	23.10	31.02	32.72	29.51	30.31	29.43
9	31.75	29.56	32.65	25.67	26.48	27.23	22.24	26.67	24.99
10	17.21	18.47	19.70	15.08	17.11	17.23	11.41	15.21	13.95
11	27.87	33.36	33.30	23.29	31.50	28.43	25.37	27.96	25.58
12	14.25	14.77	12.82	12.27	17.36	20.82	3.20	11.16	14.54
13	10.70	15.60	19.33	5.61	14.54	11.45	5.42	5.61	10.36
14	15.68	13.41	13.08	7.92	12.06	20.10	6.70	11.53	12.60
Mean	18.90	19.95	21.62	16.94	20.13	20.87	13.84	16.47	18.36
SD	6.77	6.68	7.30	7.19	7.94	6.95	8.54	8.39	7.06

[1] Each value is a mean of three readings.

TABLE XXXVI

PERCEIVED SPEED SCORES (IN PERCENTAGES) OBTAINED FROM EACH SUBJECT FOR EACH SPEED OF ELICITING MOTION (IN MINARCS/SEC) AT THE $\frac{1}{2}^{\circ}$ VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	35	50	100	100	100	80	100
2	50	70	90	95	100	95	95
3	25	50	100	100	75	80	100
4	45	40	40	90	85	100	110
5	35	70	90	90	90	100	100
6	25	60	75	85	90	90	100
7	40	75	100	110	110	130	150
8	40	30	40	90	80	90	100
9	20	25	40	60	55	80	90
10	30	60	100	80	70	70	100
11	30	50	60	60	70	80	90
12	25	25	65	75	75	100	100
13	25	40	60	75	60	50	100
14	12	15	60	60	40	80	80
Mean	31.21	47.14	72.86	83.57	78.57	87.50	100.07
SD	10.30	18.78	23.76	15.98	19.16	18.27	15.71

TABLE XXXVII

PERCEIVED SPEED SCORES (IN PERCENTAGES) OBTAINED FROM EACH SUBJECT FOR EACH SPEED OF ELICITING MOTION (IN MINARCS/SEC) AT THE 1° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	15	30	40	90	80	100	100
2	30	45	40	65	80	88	90
3	10	50	75	75	75	100	100
4	25	40	60	60	60	80	90
5	30	50	80	100	100	100	100
6	15	60	60	70	75	80	90
7	25	35	50	90	80	90	110
8	20	30	20	70	70	90	90
9	20	35	20	40	40	60	85
10	30	40	50	60	70	80	80
11	10	20	30	30	50	60	80
12	15	40	50	75	75	40	100
13	30	50	60	50	30	80	70
14	15	25	30	50	50	80	75
Mean	20.71	39.29	47.50	66.07	66.79	8.57	90.00
SD	7.56	11.07	18.68	19.73	18.67	17.23	11.27

TABLE XXXVIII

PERCEIVED SPEED SCORES (IN PERCENTAGES) OBTAINED FROM EACH SUBJECT FOR EACH SPEED OF ELICITING MOTION (IN MINARCS/SEC) AT THE 2° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	15	20	30	50	30	50	75
2	30	40	60	75	65	80	85
3	10	25	50	50	25	25	75
4	17	15	25	35	35	40	35
5	15	35	65	80	50	75	80
6	15	25	50	65	60	55	55
7	30	30	30	70	80	80	90
8	30	40	60	60	60	70	70
9	15	25	30	30	30	35	35
10	20	30	50	60	50	70	60
11	20	30	50	50	50	60	80
12	15	20	30	40	40	65	75
13	20	25	40	45	40	60	50
14	15	15	25	40	60	50	40
Mean	19.07	26.79	42.50	53.57	48.21	58.21	64.64
SD	6.49	7.99	14.11	15.25	15.76	16.83	18.76

TABLE XXXIX

PERCEIVED SPEED SCORES (IN PERCENTAGES) OBTAINED FROM EACH SUBJECT FOR EACH SPEED OF ELICITING MOTION (IN MINARCS/SEC) AT THE 4° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	15	25	40	50	65	80	80
2	12	20	30	45	60	70	80
3	10	20	25	25	25	50	50
4	15	25	25	30	25	40	55
5	15	20	25	50	50	70	75
6	5	10	40	30	40	45	60
7	15	25	30	70	75	75	70
8	10	30	30	30	40	40	40
9	10	15	20	25	25	20	55
10	15	20	30	40	40	50	60
11	10	10	20	20	50	60	70
12	15	25	25	40	40	50	50
13	10	20	25	30	35	35	40
14	10	15	20	25	30	50	75
Mean	11.93	20.00	27.50	36.43	42.86	52.50	61.43
SD	3.12	5.88	6.43	13.65	15.53	16.84	13.79

TABLE XL

PERCEIVED SPEED SCORES (IN PERCENTAGES) OBTAINED FROM EACH SUBJECT FOR EACH SPEED OF ELICITING MOTION (IN MINARCS/SEC) AT THE 8° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	70	100
1	10	15	30	35	45	25	30
2	10	20	45	50	60	65	55
3	10	10	25	25	25	40	50
4	10	15	25	40	45	50	60
5	10	15	20	15	25	40	45
6	5	15	15	40	30	45	50
7	10	15	40	40	20	20	40
8	10	10	30	30	20	40	50
9	10	15	20	25	30	40	35
10	10	20	30	20	30	40	40
11	10	10	30	30	30	40	60
12	10	15	20	20	25	25	25
13	5	8	10	10	15	20	20
14	5	7	10	30	20	15	50
Mean	8.93	13.57	25.00	29.29	30.00	36.07	43.57
SD	2.13	4.01	10.19	11.07	12.25	13.61	12.47

TABLE XLI

PERCEIVED DISTANCE SCORES (IN FEET) OBTAINED FROM EACH SUBJECT DURING THE PRESENTATION OF EACH OF THE SPEEDS OF ELICITING MOTION (MINARCS/SEC) FOR THE ½° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	29	29	29	29	29	29	29
2	33	35	35	35	35	27	30
3	40	40	40	40	30	40	40
4	25	25	25	25	20	25	30
5	60	60	60	50	60	60	60
6	30	30	30	30	30	30	30
7	35	40	45	45	50	50	40
8	35	35	35	35	35	35	35
9	21	20	20	20	18	20	20
10	30	30	30	30	30	30	30
11	30	30	30	30	30	30	30
12	40	40	40	40	40	40	40
13	40	40	40	40	40	40	40
14	30	30	30	30	30	30	30
Mean	34.14	34.57	34.93	34.21	34.07	34.71	34.57
SD	9.31	9.54	9.85	8.10	10.96	10.56	9.34

TABLE XLII

PERCEIVED DISTANCE SCORES (IN FEET) OBTAINED FROM EACH SUBJECT DURING THE PRESENTATION OF EACH OF THE SPEEDS OF ELICITING MOTION (MINARCS/SEC) FOR THE 1° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	14	14	14	14	14	14	14
2	17	17	17	17	20	17	17
3	15	18	18	15	15	15	15
4	25	25	25	25	25	25	25
5	35	35	35	35	30	30	25
6	20	20	20	20	20	20	20
7	19	18	18	19	20	25	20
8	18	18	18	18	18	18	18
9	14	14	14	14	14	14	14
10	14	14	14	14	14	14	14
11	12	12	12	15	13	15	15
12	20	20	20	20	20	20	20
13	25	25	25	25	20	25	25
14	20	20	15	15	20	20	20
Mean	19.14	19.29	18.93	19.00	18.79	19.43	18.71
SD	6.05	5.95	6.06	5.94	4.73	5.13	4.14

TABLE XLIII

PERCEIVED DISTANCE SCORES (IN FEET) OBTAINED FROM EACH SUBJECT DURING THE PRESENTATION OF EACH OF THE SPEEDS OF ELICITING MOTION (MINARCS/SEC) FOR THE 2° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	7	7	7	7	7	7	7
2	9	9	9	10	9	9	9
3	8	8	8	8	8	8	8
4	12	12	10	12	12	10	10
5	8	9	9	8	7	7	8
6	9	9	9	9	9	9	9
7	9	7	9	9	9	9	9
8	8	8	8	8	8	8	8
9	7	7	7	7	7	7	7
10	8	8	8	8	8	8	8
11	8	8	8	8	8	8	8
12	10	10	10	10	10	10	10
13	15	12	12	10	15	15	15
14	7	7	7	7	7	7	7
Mean	8.93	8.64	8.64	8.64	8.86	8.71	8.79
SD	2.20	1.69	1.39	1.45	2.25	2.09	2.05

TABLE XLIV

PERCEIVED DISTANCE SCORES (IN FEET) OBTAINED FROM EACH SUBJECT DURING THE PRESENTATION OF EACH OF THE SPEEDS OF ELICITING MOTION (MINARCS/SEC) FOR THE 4° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	3.5	3.5	3.5	3.5	3.5	3.5	3.5
2	3.5	4	3.5	3.5	3.5	3.5	3.5
3	4	4	4	4	4	4	4
4	5	5	5	5	5	5	5
5	4	4	4	4	4	4	4
6	3.5	3.5	3.5	3.5	3.5	3.5	3.5
7	4	5	5	5	4	4	4
8	4	4	4	4	4	4	4
9	3.5	3.5	3.5	3.5	3.5	3.5	3.5
10	4	4	4	4	4	4	4
11	3.5	3.5	3.5	3.5	3.5	3.5	3.5
12	5	5	5	5	5	5	5
13	5	5	5	5	5	5	5
14	4	4	4	4	4	4	4
Mean	4.04	4.14	4.11	4.11	4.04	4.04	4.04
SD	0.57	0.60	0.63	0.63	0.57	0.57	0.57

TABLE XLV

PERCEIVED DISTANCE SCORES (IN FEET) OBTAINED FROM EACH SUBJECT DURING THE PRESENTATION OF EACH OF THE SPEEDS OF ELICITING MOTION (MINARCS/SEC) FOR THE 8° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	2	2	2	2	2	2	2
2	2	2	2	1.75	1.75	1.75	2
3	2	2	2	2	2	2	2
4	2.5	2.5	2.5	2.5	2.5	2.5	2.5
5	2	2	2	2	2	2	2
6	1.5	1.5	2	1.5	1.5	1.5	1.5
7	2	2	2.5	2	1.5	1.5	2
8	2	2	2	2	2	2	2
9	2	2	2	2	2	2.5	2
10	2	2	2	2	2	2	2
11	2	2	2	2	2	2	2
12	2.5	2.5	2.5	2.5	2.5	2.5	2.5
13	2	2	2	2	2	2	2
14	2	2	2	2	1.5	1.5	2
Mean	2.04	2.04	2.11	2.02	1.95	1.98	2.04
SD	0.24	0.24	0.21	0.25	0.31	0.35	0.24

TABLE XLVI

PERCEIVED SIZE SCORES (IN INCHES) OBTAINED FROM EACH SUBJECT DURING THE PRESENTATION OF EACH OF THE SPEEDS OF ELICITING MOTION (MINARCS/SEC) FOR THE ½° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	5	5	5	5	5	5	5
2	8	8	7	8	6	7	6
3	3	3	3	3	4	3	3
4	6	6	8	4	6	7	8
5	5	5	5	6	5	5	5
6	5	4	4	4	4	4	4
7	3	6	4	4	4	4	4
8	2	2.5	2.5	2.5	2.5	2.5	2.5
9	5	5	5	6	6	5	5
10	5	5	5	5	5	5	5
11	3	3	3.5	3	3	3.5	3.5
12	6	6	6	6	6	6	6
13	4	4	3	3	3	3	4
14	6	8	6	6	8	8	6
Mean	4.71	5.04	4.79	4.68	4.82	4.86	4.79
SD	1.59	1.69	1.59	1.59	1.51	1.67	1.44

TABLE XLVII

PERCEIVED SIZE SCORES (IN INCHES) OBTAINED FROM EACH SUBJECT DURING THE PRESENTATION OF EACH OF THE SPEEDS OF ELICITING MOTION (MINARCS/SEC) FOR THE 1° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	5	5	5	4	5	4	5
2	8	8	6	7	7.5	7.5	7.5
3	4	4	4	4	4	4	4
4	6	6	7	7	7	6	7
5	4	4	4	4	4	4	4
6	4	4	4	4	5	5	5
7	6	5	4	5	5	6	6
8	3	3	3	3	3	3	3
9	4	4	4	4	4	4	4
10	4	4	4	4	4	4	4
11	3.5	3.5	3.5	3.5	3.5	3.5	3
12	6	6	6	6	6	6	6
13	4	4	4	4	4	4	4
14	6	6	8	6	6	6	4
Mean	4.82	4.75	4.75	4.68	4.86	4.79	4.75
SD	1.38	1.34	1.45	1.30	1.34	1.30	1.40

TABLE XLVIII

PERCEIVED SIZE SCORES (IN INCHES) OBTAINED FROM EACH SUBJECT DURING THE PRESENTATION OF EACH OF THE SPEEDS OF ELICITING MOTION (MINARCS/SEC) FOR THE 2° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	5	5	5	5	5	5	5
2	8	8	8	8.5	7.5	7.5	8
3	4	4	4	4	4	4	4
4	6	7	6	7	6	6	6
5	4	5	5	4	4	4	5
6	5	5	5	5	5	5	5
7	6	6	6	6	5	6	6
8	3	2.5	3	3	3	3	3
9	4	4	4	4	4	4	4
10	4	4	4	4	4	4	4
11	4	4	3.5	4	4	3.5	3.5
12	4	4	4	4	4	4	4
13	6	6	4	6	6	6	6
14	6	6	6	6	5	5	6
Mean	4.93	5.04	4.82	5.04	4.75	4.79	4.96
SD	1.33	1.45	1.32	1.50	1.16	1.24	1.34

TABLE XLIX

PERCEIVED SIZE SCORES (IN INCHES) OBTAINED FROM EACH SUBJECT DURING THE PRESENTATION OF EACH OF THE SPEEDS OF ELICITING MOTION (MINARCS/SEC) FOR THE 4° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	5	4	4	4	4	4	4
2	7	5.5	6	6.5	6.5	6	7
3	4	4	4	4	4	4	4
4	8	7	6	7	7	7	6
5	5	5	6	5	5	6	5
6	4	4	4	4	4	4	4
7	6	6	6	5	6	6	6
8	4	4	4	4	4	4	4
9	4	4	4	4	4.5	4	4
10	4	4	4	4	4	4	4
11	4	4	4	4	4	4	4
12	6	6	6	6	6	6	6
13	6	6	6	6	6	6	6
14	6	6	4	6	6	6	6
Mean	5.21	4.96	4.86	4.96	5.07	5.07	5.00
SD	1.31	1.08	1.03	1.12	1.12	1.14	1.11

TABLE L

PERCEIVED SIZE SCORES (IN INCHES) OBTAINED FROM EACH SUBJECT DURING THE PRESENTATION OF EACH OF THE SPEEDS OF ELICITING MOTION (MINARCS/SEC) FOR THE 8° VISUAL ANGLE IN THE SIZE CONSTANT CONDITION

	Speed of Eliciting Motion (minarcs/sec)						
Subject	10	20	40	50	60	80	100
1	5	5	5	5	5	4.5	4.5
2	8	8	7.5	7	7	7	8.5
3	4	4	4	4	4	4	4
4	7	6	6	6	7	7	7
5	5	5	5	5	5	6	5
6	4	4.5	4	4.5	4.5	4	4
7	6	6	7	6	5	5	6
8	4	4	4	4	4	4	4
9	4	4	4	4	4	4	4
10	4	4	4	4	4	4	4
11	4	4	4	4	4	4	4
12	4	6	6	6	6	4	4
13	5	5	4.5	4	4	4	4
14	4	4	5	4	4	4	6
Mean	4.86	4.96	5.00	4.82	4.82	4.68	4.93
SD	1.29	1.18	1.19	1.03	1.10	1.14	1.43

TABLE LI

PERCEIVED SPEED SCORES (IN PERCENTAGES) OBTAINED FROM EACH SUBJECT FOR EACH STIMULUS SIZE (IN INCHES) AT THE THREE VISUAL ANGLES USED IN THE ANGLE CONSTANT CONDITION WITH RPM CONSTANT

	Spiral Diameter (inches)								
	2°			4°			8°		
Subject	4	10	16	4	10	16	4	10	16
1	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
2	70.00	50.00	65.00	60.00	50.00	55.00	60.00	60.00	70.00
3	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
4	30.00	30.00	30.00	25.00	30.00	30.00	35.00	25.00	30.00
5	30.00	50.00	50.00	30.00	30.00	50.00	45.00	60.00	60.00
6	20.00	25.00	40.00	30.00	25.00	25.00	35.00	35.00	35.00
7	30.00	30.00	30.00	40.00	35.00	50.00	40.00	40.00	50.00
8	30.00	30.00	30.00	30.00	20.00	20.00	30.00	30.00	30.00
9	25.00	25.00	25.00	25.00	25.00	25.00	30.00	30.00	25.00
10	40.00	40.00	40.00	50.00	50.00	40.00	50.00	40.00	50.00
11	30.00	30.00	30.00	30.00	30.00	30.00	40.00	50.00	40.00
12	25.00	25.00	25.00	25.00	25.00	25.00	25.00	35.00	35.00
13	20.00	20.00	20.00	25.00	25.00	30.00	20.00	30.00	35.00
14	20.00	20.00	15.00	25.00	30.00	30.00	25.00	30.00	40.00
Mean	30.36	30.71	32.50	32.14	30.71	33.21	35.00	37.14	39.64
SD	12.63	9.58	12.82	10.69	8.96	11.03	11.09	11.72	13.37

TABLE LII

PERCEIVED SPEED SCORES (IN PERCENTAGES) OBTAINED FROM EACH SUBJECT FOR EACH STIMULUS SIZE (IN INCHES) AT THE THREE VISUAL ANGLES USED IN THE ANGLE CONSTANT CONDITION WITH SEM CONSTANT

	Spiral Diameter (inches)								
	2°			4°			8°		
Subject	4	10	16	4	10	16	4	10	16
1	50.00	50.00	50.00	25.00	35.00	35.00	25.00	25.00	25.00
2	60.00	65.00	50.00	60.00	70.00	70.00	50.00	45.00	50.00
3	50.00	75.00	50.00	25.00	25.00	25.00	25.00	25.00	25.00
4	50.00	50.00	50.00	30.00	30.00	40.00	25.00	20.00	30.00
5	55.00	60.00	70.00	45.00	40.00	50.00	30.00	30.00	30.00
6	60.00	50.00	60.00	30.00	35.00	25.00	20.00	20.00	20.00
7	70.00	50.00	75.00	40.00	50.00	50.00	30.00	30.00	30.00
8	40.00	40.00	40.00	30.00	40.00	30.00	30.00	40.00	40.00
9	40.00	35.00	30.00	25.00	25.00	25.00	25.00	20.00	15.00
10	40.00	60.00	50.00	30.00	40.00	40.00	30.00	40.00	30.00
11	60.00	50.00	60.00	40.00	30.00	40.00	30.00	30.00	30.00
12	40.00	40.00	35.00	25.00	25.00	25.00	20.00	20.00	20.00
13	40.00	40.00	45.00	30.00	45.00	40.00	20.00	20.00	25.00
14	25.00	20.00	25.00	20.00	15.00	25.00	20.00	20.00	20.00
Mean	48.57	48.93	49.29	32.50	36.07	37.14	27.14	27.50	27.86
SD	11.84	13.75	14.12	10.52	13.47	13.11	7.77	8.72	8.93

TABLE LIII

PERCEIVED DISTANCE SCORES (IN FEET) OBTAINED FROM EACH SUBJECT FOR EACH SPIRAL DIAMETER (IN INCHES) AT THE THREE VISUAL ANGLES USED IN THE ANGLE CONSTANT CONDITION WITH RPM CONSTANT

	Spiral Diameter (inches)								
	2°			4°			8°		
Subject	4	10	16	4	10	16	4	10	16
1	7.00	18.00	25.00	3.50	10.00	14.00	2.00	5.00	7.00
2	9.00	22.00	35.00	3.50	11.00	18.00	2.00	5.50	9.00
3	8.00	25.00	40.00	4.00	10.00	20.00	2.00	5.00	8.00
4	10.00	20.40	40.00	5.00	15.00	20.00	2.00	6.00	15.00
5	12.00	35.00	60.00	4.00	15.00	20.00	2.00	7.00	12.00
6	9.00	20.00	30.00	3.50	9.00	16.00	2.00	4.50	8.00
7	9.00	20.00	30.00	4.00	11.00	15.00	2.00	5.00	9.00
8	8.00	20.00	30.00	4.00	12.00	16.00	2.00	5.00	8.00
9	7.00	18.00	28.00	3.50	9.00	14.00	1.50	4.50	7.00
10	10.00	20.00	30.00	4.00	15.00	20.00	2.00	6.00	10.00
11	7.50	18.00	30.00	3.50	10.00	18.00	2.00	5.00	8.00
12	10.00	25.00	40.00	5.00	15.00	20.00	2.50	6.00	10.00
13	10.00	25.00	35.00	5.00	10.00	20.00	2.00	5.00	15.00
14	7.00	20.00	30.00	4.00	7.00	12.00	2.00	5.00	7.00
Mean	8.82	21.86	34.50	4.04	11.36	17.36	2.00	5.32	9.50
SD	1.49	4.54	8.74	0.57	2.65	2.82	0.20	0.70	2.71

TABLE LIV

PERCEIVED DISTANCE SCORES (IN FEET) OBTAINED FROM EACH SUBJECT FOR EACH SPIRAL DIAMETER (IN INCHES) AT THE THREE VISUAL ANGLES USED IN THE ANGLE CONSTANT CONDITION WITH SEM CONSTANT

	Spiral Diameter (inches)								
	2°			4°			8°		
Subject	4	10	16	4	10	16	4	10	16
1	7.00	18.00	30.00	3.50	9.00	14.00	1.50	4.50	7.00
2	9.00	20.00	32.00	3.50	11.00	18.00	1.75	3.50	9.00
3	8.00	25.00	40.00	4.00	10.00	20.00	2.00	5.00	8.00
4	10.00	25.00	35.00	5.00	10.00	20.00	2.00	8.00	10.00
5	12.00	25.00	50.00	5.00	15.00	25.00	2.00	6.00	12.00
6	9.00	18.00	30.00	3.50	10.00	18.00	1.50	4.50	9.50
7	9.00	20.00	30.00	4.00	11.00	20.00	2.00	5.00	9.00
8	8.00	20.00	30.00	4.00	12.00	16.00	2.00	5.00	8.00
9	7.00	18.00	28.00	3.50	9.00	14.00	1.50	4.50	7.00
10	8.00	20.00	30.00	3.00	12.00	20.00	2.00	6.00	10.00
11	8.00	20.00	30.00	4.00	10.00	15.00	2.00	5.00	8.00
12	12.00	25.00	40.00	5.00	12.00	20.00	2.50	8.00	12.00
13	12.00	25.00	35.00	5.00	15.00	20.00	2.00	7.00	12.00
14	7.00	15.00	30.00	4.00	10.00	14.00	2.00	5.00	7.00
Mean	9.00	21.00	33.57	4.07	11.14	18.14	1.91	5.50	9.18
SD	1.84	3.37	6.07	0.68	1.92	3.21	0.27	1.35	1.84

TABLE LV

PERCEIVED SIZE SCORES (IN INCHES) OBTAINED FROM EACH SUBJECT FOR EACH SPIRAL DIAMETER (IN INCHES) AT THE THREE VISUAL ANGLES USED IN THE ANGLE CONSTANT CONDITION WITH RPM CONSTANT

	Spiral Diameter (inches)								
	2°			4°			8°		
Subject	4	10	16	4	10	16	4	10	16
1	5.00	11.00	18.00	5.00	11.00	15.00	5.00	11.00	15.00
2	7.00	15.00	20.00	7.00	20.00	27.00	7.00	15.00	20.00
3	4.00	10.00	15.00	4.00	10.00	15.00	4.00	10.00	15.00
4	6.00	12.00	24.00	6.00	12.00	24.00	6.00	12.00	24.00
5	4.00	10.00	16.00	4.00	10.00	18.00	5.00	10.00	18.00
6	4.00	12.00	24.00	4.00	10.00	24.00	3.50	12.00	18.00
7	6.00	20.00	20.00	5.00	12.00	20.00	5.00	12.00	20.00
8	4.00	12.00	18.00	4.00	12.00	20.00	4.00	9.00	20.00
9	4.00	10.00	14.00	4.00	10.00	14.00	4.00	10.00	14.00
10	4.00	10.00	15.00	4.00	10.00	15.00	4.00	10.00	15.00
11	3.50	12.00	15.00	4.00	12.00	18.00	4.00	12.00	16.00
12	6.00	18.00	24.00	6.00	18.00	24.00	6.00	18.00	24.00
13	4.00	10.00	14.00	4.00	12.00	16.00	4.00	10.00	16.00
14	6.00	12.00	18.00	4.00	12.00	18.00	5.00	12.00	18.00
Mean	4.82	12.43	18.21	4.64	12.21	19.14	4.75	11.64	18.07
SD	1.14	3.13	3.70	1.01	3.04	4.17	1.01	2.37	3.22

TABLE LVI

PERCEIVED SIZE SCORES (IN INCHES) OBTAINED FROM EACH SUBJECT FOR EACH SPIRAL DIAMETER (IN INCHES) AT THE THREE VISUAL ANGLES USED IN THE ANGLE CONSTANT CONDITION WITH SEM CONSTANT

	Spiral Diameter (inches)								
	2°			4°			8°		
Subject	4	10	16	4	10	16	4	10	16
1	5.00	11.00	15.00	5.00	11.00	15.00	4.00	11.00	15.00
2	7.00	15.00	19.00	7.00	22.00	25.00	7.00	18.00	24.00
3	4.00	10.00	18.00	4.00	10.00	18.00	4.00	10.00	18.00
4	6.00	14.00	24.00	6.00	14.00	24.00	6.00	15.00	24.00
5	5.00	10.00	18.00	5.00	10.00	16.00	4.00	10.00	18.00
6	4.00	12.00	24.00	4.00	10.00	24.00	3.50	12.00	24.00
7	6.00	12.00	20.00	5.00	12.00	20.00	5.00	10.00	20.00
8	4.00	12.00	20.00	4.00	12.00	20.00	4.00	12.00	20.00
9	4.00	10.00	14.00	4.00	10.00	14.00	4.00	10.00	14.00
10	4.00	12.00	15.00	4.00	12.00	15.00	4.00	10.00	15.00
11	4.00	10.00	15.00	4.00	12.00	16.00	3.50	12.00	18.00
12	6.00	18.00	24.00	6.00	18.00	24.00	6.00	18.00	24.00
13	4.00	10.00	18.00	4.00	12.00	16.00	4.00	12.00	16.00
14	5.00	12.00	20.00	4.00	14.00	20.00	4.00	14.00	20.00
Mean	4.86	12.00	18.86	4.71	12.79	19.07	4.50	12.43	19.29
SD	1.03	2.32	3.44	0.99	3.42	3.91	1.07	2.82	3.63

TABLE LVII

RESULTS OF t TESTS FOR CORRELATED DATA COMPARING SPIRAL AFTEREFFECT DURATION SCORES OBTAINED AT 2° OF VISUAL ANGLE WITH THOSE OBTAINED AT ½° OF VISUAL ANGLE FOR EACH OF THE SEVEN SPEEDS OF ELICITING MOTION (MINARCS/SEC) IN THE SIZE CONSTANT CONDITION

Minarcs/sec	t
10	1.49
20	0.39
40	2.46[1]
50	1.18
60	2.67[2]
80	2.42[1]
100	5.33[4]

[1] $p < .05$.

[2] $p < .02$.

[3] $p < .01$.

[4] $p < .001$.

VITA

2

Kevin D. Mehling

Candidate for the Degree of

Doctor of Philosophy

Thesis: THE INFLUENCE OF RETINAL SPEED AND RETINAL SIZE ON THE DURATION OF THE SPIRAL AFTEREFFECT

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Education: Graduated from Saint Francis Xavier High School, New York City, in June, 1951. Entered Saint Peter's College, Jersey City, New Jersey, where he majored in Philosophy and received the degree of Bachelor of Arts in June, 1955. He received a Master of Arts degree from Fordham University, New York, New York, in February, 1959, in the field of Psychology. In September, 1967, he entered Oklahoma State University as a doctoral candidate in Psychology. While there, he was a Graduate Teaching Assistant for two years and was awarded the Oklahoma Jaycee War Memorial Scholarship. The degree of Doctor of Philosophy in Psychology was conferred on July 31, 1970. An internship in Clinical Psychology was served, from September, 1969 to August, 1970, at the University of Oklahoma Medical Center.

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