THE EFFECTS OF THE APPARENT SIZE OF AFTERIMAGES IN STUDIES OF EMMERT'S LAW

Thesis for the Degree of Ph.D.

MICHIGAN STATE UNIVERSITY

FREDERICK N. DYER

1968

This is to certify that the

thesis entitled

The Effects of the Apparent Size
of Afterimages in Studies of
Emmert's Law

presented by

Frederick N. Dyer

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Psychology

Terrence M. Allen
Major professor

Date July 2, 1968

O-169

ABSTRACT

THE EFFECTS OF THE APPARENT SIZE OF AFTERIMAGES
IN STUDIES OF EMMERT'S LAW

by Frederick N. Dyer

Emmert's law states that the projected size of afterimages (AIs) is directly proportional to the projection distance. Many studies of the projected size of AIs have found near-projected AIs to be larger than the prediction of Emmert's law and far-projected AIs to be smaller. This suggests that the eye has greater magnification with distant fixation than near but this is contrary to the accepted belief that a small magnification at near occurs. However, greater magnification with distant fixation would also explain a number of perceptual anomalies such as "overconstancy" and greater visual acuity at a distance than up close. The problem of the study was to account for the deviations from Emmert's law that often occur. This was approached by carefully measuring the projected size of AIs and by investigating the "apparent size" of AIs at different projection distances.

Each of 12 Ss formed and measured AIs with four different methods:

1. The traditional outlining method where E adjusted calipers around the AI until S reported that the points touch its extremities.

2. An accurate coincidence method used on one previous study which did not indicate deviations from Emmert's law where a figure of the same shape as the AI was moved forward or backward until it just coincided with the AI. Distance of the figure was the dependent variable in this method.

3. A new coincidence method where an outline figure was adjusted in

size at a fixed distance until it coincided with the AI.

4. A method where the "apparent size" of AIs was assessed. S observed the AI, noted its size and then compared it to the space between caliper points. S was required to make a successive comparison of the size of the AI and the comparison stimulus instead of the simultaneous comparison requested in the three other methods. Previous studies of the apparent size of AIs which used large projection distances had shown that apparent size was less than the size predicted by Emmert's law. Two formation distances and three or five projection distances were used for each method.

Both coincidence methods gave results nearly coincident with Emmert's law. This indicated little magnification change in the eye for different fixation distances and leaves "overconstancy" and greater visual acuity at a distance unexplained. For the apparent size method, near-projected AIs were 35% greater than the prediction of Emmert's law and far-projected AIs were found to be slightly smaller than this prediction. The traditional outlining method gave results intermediate to the apparent size and coincidence methods with AIs about 15% larger at near projection distances than at far.

The study indicated that the outlining method is in part an apparent size measurement method where successive comparisons of AI size and comparison stimulus size occur. Deviations from Emmert's law in previous studies are thus artifacts of the measurement method.

An explanation of this interaction of apparent size of AIs with projection distance was presented which was based on the tendency of the eyes to deviate toward an intermediate rest position during the shift in attention from the comparison stimulus to the AI. This shift in fixation results in different metrics being used for the successive size judgments with the AI being magnified relative to the comparison stimulus for projection distances (and comparison stimuli) nearer than the intermediate rest position and minified relative to comparison stimuli beyond this intermediate position.

THE EFFECTS OF THE APPARENT SIZE OF AFTERIMAGES IN STUDIES OF EMMERT'S LAW

By

Frederick N. Dyer

A THESIS

Submitted to

Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Psychology

1968

ACKNOWLEDGMENTS

I wish to thank Dr. Terrence Allen, Dr. Paul Bakan, Dr. Richard Hart, and Dr. John Hunter for their many suggestions for setting up and running the experiment. I am particularly grateful to Dr. Allen for his willingness to supervise the project as well as for the critical insights that kept it solidly on course. I am also grateful to Dr. Matthew Alpern at the University of Michigan and Dr. Francis Young of Washington State University who generously supplied me with information regarding physiological optics, basic visual processes, and afterimage measurement. I would also like to thank my friends, particularly Jerry Gillmore, who provided me with hours of pilot afterimage data and, more importantly, with useful criticism of the measurement apparatus and procedure. Finally, I wish to thank my wife, Jean, who contributed to the success of the project at every level.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER I: THE PROBLEM

Emmert's (1881) law for afterimages deals with their size when they are projected at different distances and states that afterimage size increases in direct proportion to the distance. Some controversey has arisen regarding whether Emmert's law refers to the physical projection distance or to the apparent projection distance (Boring, 1940; Young, 1951; Edwards, 1950). It is now generally accepted that Emmert was referring to the physical distance since his own experiments involved the measured distance to the projection screen. This controversy was probably stimulated by different results in many afterimage measurement studies from the strict proportionality of afterimage size to projection distance that Emmert's law predicts. The more typical finding has been that afterimages are reliably measured to be somewhat larger than Emmert's prediction at near projection distances and equal to or smaller than Emmert's law would predict at far projection distances. Studies demonstrating this typical deviation from Emmert's law will be discussed in detail in the next chapter.

No one has satisfactorily explained these systematic deviations from Emmert's law. A likely explanation would be that the optical magnification of the eye changes with different viewing distances. Greater magnification of the eye at a distance than up close would be required to produce this typical finding of smaller afterimages with distant projection than with close projection.

Such a change in magnification with fixation change could provide an explanation for a number of other poorly explained phenomena of visual perception. These are "overconstancy", where distant objects are overestimated in size, greater visual acuity at a distance than at near, the unexpected appearance of figural aftereffects when inspection and test figures presented at different distances from the eye but of equal visual angle are used, and a finding of a higher critical-flicker-frequency for an 80-inch-distant one-inch diameter stimulus than for a 40-inch-distant, ½-inch diameter stimulus both of which, presumably, should be stimulating the same retinal area. However, the science of physiological optics predicts a slight magnification at near, not the magnification at far described above (Helmholtz, 1866; Pascal, 1952), and one recent afterimage measurement study (Onizawa, 1954, Series B) gave data that would support this traditional view. Unlike the typical afterimage measurement method which involves outlining of the afterimage with some device such as calipers or a beam compass, Onizawa's method in Series B of his experiment involved an outline target of fixed size and the same shape as the afterimage. This target was moved away from the observer until it was reported to exactly coincide with the afterimage. The distance of the coincidence target was the dependent variable in this method. Other support for the traditional physiological optics interpretation of the eye's magnification was provided by a study where photographs of the images on the retina were obtained (Heinemann, 1961). These studies will also be described in more detail in Chapter II.

The basic problem of the dissertation was to determine which, if either, of the afterimage measurement methods is a valid measurement of the optical magnification of the eye at different distances of fixation. In addition, an explanation of the difference in results obtained by the two afterimage measurement methods was sought. It was felt that such an explanation could have considerable relevance for the perceptual anomalies of overconstancy, etc., as well as the afterimage measurement findings. There is some possibility that this involves the magnification and minifications of apparent size that can occur which are known as macropsia and micropsia, respectively (McCready, 1965). These apparent size changes occur primarily with alterations of the oculomotor adjustments of the eyes during object perception. They also apply to afterimages (e.g., Urist, 1959).

In the next chapter the afterimage measurement studies which have produced the two discrepant results are reviewed, along with other perceptual phenomena which could share an optical explanation (or perhaps some other explanation) with the typical deviations from Emmert's law that have repeatedly been found. In addition, material relevant to the optical explanation and to an apparent size explanation of these deviations is presented.

CHAPTER II: REVIEW OF LITERATURE

Included in this chapter is a review of (1) the relevant studies of afterimage measurement, (2) possibly related perceptual anomalies, (3) studies of the optical magnification of the eye, and (4) apparent size findings relevant to afterimage size. In addition, a hypothesis is developed to explain how apparent size could enter into what, at first sight, appear to be physical measurements of afterimages and specific experimental hypotheses derived from this hypothesis are presented.

Afterimage Measurement Studies

Prolonged fixation of a visual stimulus and even very brief presentations of a bright stimulus can lead to a distinct afterimage of the stimulus which can be seen for as much as several minutes after actual viewing of the stimulus ends (Brindley, 1963). These afterimages take two different forms, positive afterimages, which maintain the brightness relations of the initial stimulus, generally occur initially and are then followed by negative afterimages where these brightness relations are reversed. Both types are accounted for in a recent theory which states that the receptors in the retina which are exposed to a bright stimulus maintain continued "noisy" activity after external stimulation ceases (Barlow and Sparrock, 1964). Once formed, these afterimages do not change in size or position on the retina and thus provide a unique means of determining the relative magnification of the eye at different fixation distances. Since Emmert's law specifies that the afterimage will project sizes directly proportional to distance, it implies that no change in magnification occurs with different fixation distances.

Even before Emmert's study (1881), research was conducted which actually tested a more sophisticated hypothesis than the direct relationship between afterimage projection distance and afterimage size that Emmert proposed. In 1857 Bahr tested and apparently confirmed the prediction of Helmholtz (1866) of a two or three percent magnification of the eye with accommodation of the eye for very close distances. The report of this dissertation by Helmholtz (1866) did not specify any of Bahr's procedures, but only the positive results of the study. This is unfortunate since his procedure must have been quite sophisticated to indicate such small deviations from strict proportionality of afterimage size to projection distance.

Emmert's own article (1881) was largely theoretical but his small amount of data did not lead him to conclude that any deviation from straight proportionality was occurring. Questionable support for Emmert's law has been derived from several studies typified by the study of Norris (1934) which reported no data but simply stated that no deviation from Emmert's law was found greater than that which could be accounted for by the measurement error.

When quantitative results are presented, however, the more typical finding is about a 10 percent larger afterimage at close projection than at far. This is shown in a summary of the results of three afterimage measurement studies which were reported by Carr (1935) and which are reproduced below. A study by Schmulling gave the following:

Distance in cm.	35	50	100	150
Size in cm.	3.87	5.25	10.33	15.3
Ratio	.110	.105	.103	.102 (p. 366).

The following is from a study by Kluver:

Distance in cm.	12.5	25	50	100	200
Size in cm.	1.40	2.55	5.18	9.94	20.2
Ratio	.112	.102	.103	.099	.101 (p. 366).

Carr himself extended the results of the above to greater distances and part of his data follows:

Distance in feet	4	6	8	10	20	25	30
Size in inches	3.08	4.38	5.88	7.33	14.17	16.26	19.03
Ratio	.77	.73	.74		.71	.65	.63 (p. 366).

No discussion of procedures was given by Carr (1935) but it is fairly safe to assume that the afterimage was formed from a near stimulus and then projected at the various distances where it was outlined with calipers. It can be seen in all these results that the nearer projection distance led to the largest afterimage in angular measurement.

Another similar study that supported these findings of Kluver, Schmulling, and Carr was Series A of the experiment of Onizawa (1954). Afterimages were formed of a circle five cm. in diameter located 60 cm. from the eye, then projected at 30, 120, and 180 cm. and measured with calipers. Measured size was found to be eight percent larger at the 30 cm. projection distance than at the 120 and 180 cm. distances which were nearly identical in angular size.

The same finding appeared in four out of five subjects in a study by Young (1948). Afterimages formed of a one-inch square at 30.5 cm. from the eye were projected and outlined with boresight lamps. For these four subjects afterimages were measured to be about seven percent larger at ½ meter than at three meters. Beyond three meters these subjects showed another increase in afterimage size, but for the shorter distances the results are closely parallel to the studies mentioned above.

Larger measured afterimages at near than far projection distances suggest that the near outlining instruments are being relatively minified, i.e., reduced in size and thus require greater separation to span the afterimage than would be required to span the afterimage if they were not minified or were instead magnified. This interpretation of the magnification of the eye is contrary to the interpretation of physiological optics, however (Helmholtz, 1924; Pascal, 1952; McCready, 1963). During visual accommodation the front surface of the crystalline lens of the eye moves forward a small amount and this increases the distance from the center of magnification to the retina. This results in the image on the retina being slightly expanded in the same way that an image formed by a lens on a sheet of paper is enlarged as the lens is moved a greater distance from the paper. The effect of this small magnification change on afterimage size would be in the opposite direction from the typical deviations from Emmert's law.

If such relative magnification at a distance were the case, it could account for the data of a very different afterimage measurement study done by Ohwaki (1955). This also involved outlining measurements of afterimages but the afterimages were <u>formed</u> at different distances (50, 75, 150, and 200 cm.) and were all projected at the same distance (100 cm.). All forming stimuli were four degrees 34 minutes in height and Emmert's law would predict a measured afterimage of eight cm. at the 100 cm. projection distance for all. Instead, the average for five very similar subjects were 7.86, 8.01, 8.44, and 8.70 cm. for the 50, 75, 150, and 200 cm. formation distances, respectively. Minification at near and magnification at far could also produce this result.

Both types of afterimage measurement experiment led to deviations from Emmert's law of about 10 percent from far to near.

Related Perceptual Anomalies

Not only does this optical explanation work well for these two different types of afterimage measurement studies, but it also could account for several other important perceptual anomalies. These are overconstancy, greater visual acuity at far than near distances, figural aftereffects when inspection and test figures are of the same visual angle but are at different distances, and a greater critical flicker frequency for a distant stimulus than a near one of equal visual angle.

Overconstancy refers to a highly reliable finding that the size of objects at a distance is overestimated relative to the size of objects at near (Wohlwill, 1963; Epstein, Park and Casey, 1961). It is called overconstancy since it is as if the constancy process that permits us to recognize an object as the same object when it is moved away, is overworking.

One excellent study in which the phenomenon of overconstancy appeared was done by Heineman, Tulving, and Nachmias (1959). They required subjects to match a near target subtending a visual angle of one degree with a variable target presented at a greater distance, with the match to be made on the basis of visual angle. On the average, subjects chose a .8 degree target to match the near one degree standard indicating that the distant target appeared larger than it was. The order of magnitude is similar to that of the afterimage studies and relative magnification at far could also account for these findings.

Also congruent with this explanation are studies which have indicated greater visual acuity at far than at near distances. Freeman (1932) found acuity at 300 cm. to be 63 percent greater than at 30 cm. Luckiesh and Moss (1933) found a 17 percent increase in acuity at 280 cm. over 120 cm. Giese (1946) found acuity measured at the reciprocal visual angle to increase from .95 at 20 cm. to 1.63 at 100 cm., almost 100 percent. McCready (1963) performed more careful experiments using optical means to vary the accommodation distance of acuity targets and also found small but significant improvements in acuity with increased distance on the order of 6 to 10 percent for the two subjects in the study. McCready accepted the traditional physiological optics interpretation of the eye's magnification at different fixation distances. He considers these results to be related to the minifications and magnifications of apparent size that result from changes in the oculomotor adjustments of accommodation and convergence. He admitted that this is "empty" magnification similar to the enlargement of a photo with no increase in the detail of the photo occurring. It is not clear how such empty magnification could account for these results.

Ganz (1966) has recently shown the importance of an interaction between the afterimage of the inspection figure and the test figure in the figural aftereffect. One figural aftereffect involves concentric circles. If the circular inspection figure is smaller than the test figure (also a circle), the afterimage of the inspection circle repells the real contours of the test figure causing it to appear larger than an equal-sized comparison figure which did not have inspection figure contours inside it. If the circular inspection figure is larger than the circular test figure the test figure is made to appear smaller by a similar repulsion of the real image by the afterimage according to this explanation of Ganz. Using this figural aftereffect, Sutherland (1954) found with a circle of four inches in diameter at 57.6 inches from the eye as the inspection figure, and with a 10 inch diameter circle 144 inches away from the eye as the test figure, that the test figure was seen to be expanded. Conversely, when the inspection figure was the distant 10 inch diameter circle and the inspection figure was the nearer four inch diameter circle, the test figure appeared to be contracted. Thus in both instances the distant figure behaved as if it were larger on the retina than the close one although both subtend the same visual angle at the eye. Story (1962) replicated this finding but found that it did not occur with monocular vision, with small circles, or with disks instead of outlines of circles. This finding by Sutherland also suggests that minification of the eye takes place with near viewing and/or magnification of the eye takes place with far viewing.

Spigel (1964) compared the critical flicker frequency (CFF) for a luminous one-inch diameter circle located 80 inches from the eye with the CFF for a ½-inch diameter circle at 40 inches. He also determined the CFF for the one-inch diameter circle at 40 inches. CFFs for the three target-distance combinations were as follows:

1-inch diameter stimulus at 40 inches	31.3
1-inch diameter stimulus at 80 inches	30.5
½-inch diameter stimulus at 40 inches	27.6

All differences were reported to be significant. The latter two stimuli would subtend the same visual angle but the results suggest that the one-inch diameter stimulus at 80 inches is timulating more retinal area than the ½-inch diameter stimulus at 40 inches. This finding would also follow if minification took place at near relative to far.

If an optical magnification change with fixation distance does not account for the above anomalies then they may share some central mechanism that increases the "gain" of the visual system during distant fixation relative to near fixation. The same mechanism could perhaps account for the typical afterimage measurement deviations from Emmert's law. However, prior to accepting such a central explanation it is important to consider the evidence against the simpler peripheral explanation that magnification is relatively greater at a distance.

Evidence Contrary to an Optical Explanation of these Anomalies

Although greater magnification for far fixation relative to near fixation could account for all of the above anomalies of perception and afterimage data, systematic studies such as those of Helmholtz and Bahr have not found such magnification changes. Another check of this explanation (Heinemann, 1961) was made in an attempt to account for "overconstancy".

Heinemann used a technique where the retinal images of targets were actually photographed. The targets used were of a constant visual angle of four degrees and were presented at 25 and 100 cm. The actual size of the retinal images was determined by relating them to prominent blood vessels on the retina. Results for the single subject indicated that the retinal image was very slightly larger for the target presented at 25 cm. This supports the traditional interpretation of optical magnification of the eye and not a minification at near and magnification at far which would be required if overconstancy were an optical phenomenon.

In a recent afterimage measurement study, Onizawa (1954) compared the classical measurement technique where the extremities of an afterimage are outlined with beam compass points, calipers, boresight lights or some other device, with a new technique where a coincidence figure of the same shape as the afterimage and of a fixed size was moved toward or away from the subject until he reported that it just matched the afterimage in size. In this new method the distance of the target was the dependent variable.

With the calipers outlining method in Series A of Onizawa's experiment he found the typical afterimage data where near projected afterimages are larger than those projected at a distance. In Series B with the coincidence figure measurement method the distances of the coincidence target indicated a very slight magnification of the eye for near projection, i.e., the data supported the traditional magnification interpretation of physiological optics.

Onizawa found the variation in responses to be 3 to 5 times greater with the outlining technique than with the coincidence technique of Series B and concluded that the latter method was preferable for measuring afterimages. He does not recognize, or at least does not account for the statistically significant differences between the outlining measurements and Emmert's law that occurred for the outlining measurements. Perhaps the most striking difference between the outlining method and the coincidence method was the variable distance of the target in the latter. It might be argued that the increased saliency of distance with the coincidence technique produced these different results.

An Apparent Size Explanation of the Afterimage Data

The results of Series A and Series B of the Onizawa study suggest that either optical changes of two types can occur in the eye, or, as is more likely, the perceptual processes involved in outlining measurements and in coincidence measurements are different. It is probable that coincidence measurement involves a unitary viewing of the afterimage and the coincidence target. Outlining with calipers or some other device, on the other hand, may be a dual measurement process with the outlining device and the afterimage being viewed at least somewhat independently and successively. Outlining measurements would thus fit the criteria for apparent size measurements where an object's size is remembered and compared to the size of another object.

The apparent size of afterimages has been investigated for far projection distances (Price, 1961; Hastorf and Kennedy, 1957; Crookes, 1959). In these studies afterimages and real objects have been presented on projection screens, (not at the same time), with the objects constructed to be the same shape as the afterimages and to the size that Emmert's law would predict for the afterimage at the distance of the projection screen. Comparison objects at a different distance were then adjusted until they appeared to be the same size as these afterimages and objects. All studies found the apparent size of the afterimages to be less than the apparent size of the real objects.

If apparent size of the afterimages were entering into the outlining measurement method, this would account for the small afterimages at a distance that are typically found. No one has reported data for the apparent size of afterimages when they are projected closer than five feet. If they should be found to appear larger than what Emmert's law would predict at close distances then the typical results for the calipers outlining technique at close distances could also be accounted for by apparent size influencing these measurements.

At least three factors argue for an apparent size explanation of the typical results of the calipers outlining technique. One is that the making of outlining measurements of afterimages with calipers is difficult for the subject and could lead to what may be an easier successive assessment of first the afterimage size then the size of the space between caliper points.

A second factor is that large changes in apparent size of objects can take place when normal convergence and accommodation positions for these objects are altered. Leibowitz and Moore (1966) found the perceived size of distant objects to be reduced several-fold by viewing them with accommodation and convergence levels corresponding to near distances. Lie (1965) altered only convergence during perception of a repeating pattern and found changes in apparent size of similar magnitude. These apparent size changes are not confined to real objects. Three studies (Gregory, Wallace, and Campbell, 1959; Taylor, 1941; Urist, 1959) have shown that convergence in particular produces large changes in the apparent size of afterimages, even when they are observed in complete darkness.

The third factor that argues for apparent size influencing outlining afterimage measurements is that the oculomotor adjustments that are responsible for the apparent size changes can take place during afterimage perception without altering either the fusion or blurredness of an afterimage. If the afterimage-forming stimulus is fused and in focus when the afterimage is formed no adjustment of the eyes can separate or blur it (Zajac, 1960).

Greater convergence than normal for objects leads to the objects appearing smaller than normal. Underconvergence leads to large apparent size. To produce large appearing afterimages at near and small appearing afterimages at far in this successive measurement hypothesis, one would expect convergence to be at a position farther than the near projection screen when the afterimage size is assessed and to be at a closer position than the far projection screen when the size of the afterimage projected at that distance is assessed. It is known that in the absence of a visual stimulus, accommodation tends to adopt an intermediate distance and convergence is known to adopt a position conforming to that of accommodation (Alpern, 1962). This position is about one meter from the eye. If, when the afterimage size was assessed in this hypothesized "successive" process the eyes drifted away from the projection screen toward this intermediate position only to return to the distance of the "real" caliper points when their spacing is assessed both of the above convergence relationships would be met.

The well-done Ohwaki (1955) study would require a slightly different explanation than this assumption of an intermediate convergence rest position. In this study afterimages were all projected at the same distance (100 cm.) after being formed at 50, 75, 150, and 200 cm. The afterimages formed at the closer distances were smaller than those formed farther away. This could be explained if convergence were enroute from the formation distance to the projection distance when the afterimage size was assessed and at the 100 cm. projection distance when the space between the caliper points was assessed. This would lead to too great convergence when the afterimage was assessed with the distances closer than 100 cm. and too little convergence when the afterimage was assessed for the formation distances greater than 100 cm. Small afterimages would again accompany overconvergence and large afterimages would again accompany under-convergence, in this explanation.

The main purpose of this study was to test this apparent size explanation for the afterimage data. Unfortunately, this apparent size explanation does not account for the other perceptual anomalies which were so parsimoniously explained by the hypothesis of greater retinal image magnification at far than at near. In fact, the cogency of the optical explanation creates a need for additional evidence that this magnification change with fixation distance change does not occur, along with the need to test the alternative apparent size explanation for the afterimage data. To meet both needs the experiment described in the next chapter was designed. It tests the following specific hypotheses.

Hypotheses

1. The apparent size of afterimages is greater than Emmert's law would predict for projected size at near projection distances and is less than this figure at far projection distances.

2. The apparent size of afterimages influences measurements made with calipers or other outlining devices and these measurements have the same relationship to Emmert's law as described in Hypothesis 1 for the apparent size measurements.

3. When apparent size is eliminated from afterimage measurements these measurements deviate little or none from the predictions of Emmert's law.

4. The saliency of distance in Onizawa's moving coincidence target measurement method does not account for its accuracy and small deviation from Emmert's law, but the same result will be obtained using a coincidence target where distance is held constant.

5. When apparent size is eliminated from afterimage measurements, formation distance will have little or no effect on afterimage size with forming stimuli of equal angle for the different distances.

6. The apparent size of afterimages which are formed at close formation distances will be less than the apparent size of afterimages formed from stimuli of equal visual angle but at greater distances.

CHAPTER III: METHOD

The following experiment was conducted to test the hypotheses presented in Chapter II. It was basically a methodological experiment with each subject measuring afterimages with four different measurement methods.

Design

Method 1. This represented the "classical" outlining technique and involved calipers which were adjusted by the experimenter around an afterimage at the projection screen until the subject reported that they just touched the top and bottom of the afterimage.

Method 2. This method was based on the coincidence technique used by Onizawa (1954) in Series B of his experiment. A figure of similar shape as the afterimage was presented on a movable projection screen and the experimenter moved it closer to or farther away from the subject on an optical bench until the subject reported that it coincided in height with the afterimage.

Method 3. This was also similar to the Onizawa coincidence technique, except that the target was fixed in distance instead of size and its size was adjusted by the experimenter at this fixed distance until the subject reported that it coincided in height with the afterimage.

Method 4. This involved the apparent size of afterimages. Calipers were used in this method but they were not presented around the afterimage as in Method 1. Instead they were presented to the right of an area where the afterimage was observed and were kept in motion so that the subject could not directly compare afterimage and caliper points but instead first looked at the afterimage then remembering its size instructed the experimenter to adjust the calipers until they appeared to span the afterimage.

Perhaps for the first time in any afterimage measurement experiment, this experiment combined multiple formation distances (as in Ohwaki's study) with the more common multiple projection distances. All 24 combinations of the four measurement methods described above, two formation distances of 50 and 200 cm. and three projection distances of 25, 100, and 400 cm. were presented to each subject. In addition, eight other measurements were made using the two caliper measurement methods (1 and 4) at 50 and 200 cm. projection distances after formation at both 50 and 200 cm. Pilot work had indicated that only these two techniques showed sufficient deviation from the predictions of Emmert's law to provide sufficient information to warrant the additional measurements at these distances. Each subject thus formed and measured 32 afterimages. Each afterimage was measured a number of times during the approximately three minutes that it lasted.

Apparatus

The two stimuli which were used to form afterimages were both outlines of the right half of a square (See Fig. 1). A small dot was located at what would be the center of the square and was the point which the subjects fixated during formation of the afterimage. At the 50 cm. formation distance the figure was four centimeters high and the outline was three mm. wide. The stimulus used at the 200 cm. formation distance was 16 cm. high and the outline was 1.2 cm. wide. Both stimuli subtended the same

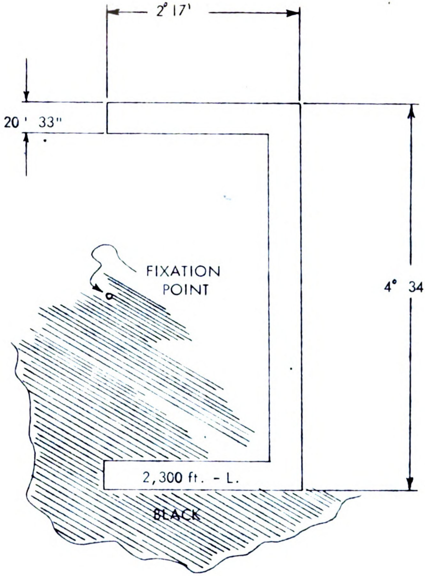

FIGURE I. PATTERN AND SIZE FOR BOTH AFTERIMAGE FORMING STIMULI visual angle of four degrees 34 minutes. The figures were outlined in black tape on translucent material and transilluminated. Brightness of both figures was 2,300 ft. L.

These forming-stimuli were presented at eye level and were located on a long platform which was grooved at the 50 and 200 cm. distances to accurately locate the stimuli and the light source. The distance from the stimulus was measured to the entrance-pupil of the eye which is located three mm. behind the front surface of the cornea. A wooden rod 47.7 cm. long was placed against the center of the 50 cm. forming-stimulus and a headrest and chinrest were adjusted until the rod just brushed lightly against the closed eyelid of the subject. Figure 2 shows the distances to the various targets which result from the establishment of this 50 cm. distance.

Since the close 25 cm. projection target was located 25 cm. from the 50 cm. target along the perpendicular bisector of the line joining the eyes, the actual distance of this projection target would be 25.122 cm. considering a large 7 cm. interpupillary distance. This .5 percent error is very small relative to the differences being investigated and for practical purposes is disregarded.

Three tracks in the form of optical benches were aligned and centered at 25, 100, and 400 cm. and the projection targets were placed on these tracks. Centimeter scales were glued to the tops of these tracks so that distances of the moving slide which carried the coincidence target for Method 2 could be easily determined. For the other measurement technique the slide with its appropriate projection target was clamped on these

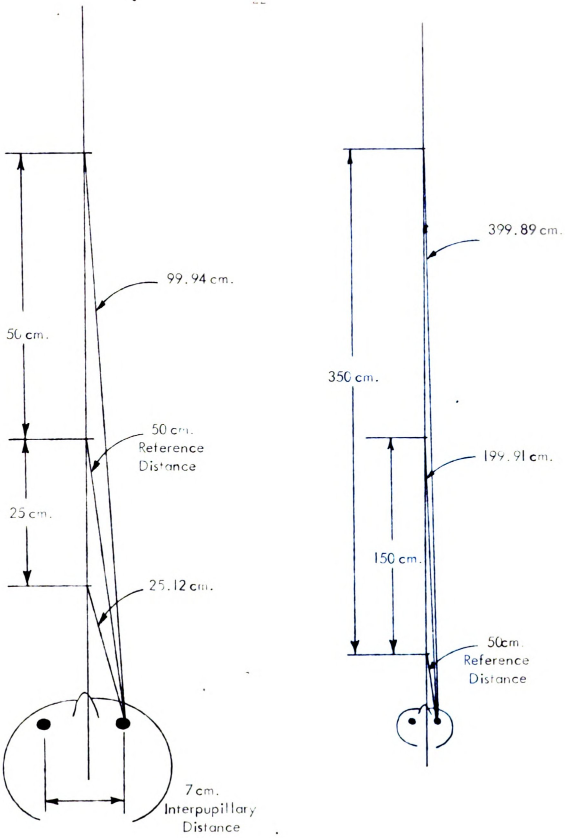

Figure 2. Distances to projection target centers.

tracks at the 25, 100, and 400 cm. distances.

The projection target for the outlining technique (Method 1) was a blank sheet of grey posterboard with a fixation point centered on it at eye level. The same projection target was used for the apparent size measurements (Method 4). For this method, however, fixation points were located somewhat to the left of center to allow more room on the projection screens to move the calipers up and down at a location to the right of the area where the afterimage was projected. At the 50 and 200 cm. projection distances, which were also the afterimage formation distances, the projection screens were not clamped to tracks but were inserted into the forming-stimulus holder. This was either already located at the proper distance during formation of the afterimage or was moved there after afterimage formation if projection was at the other distance.

Two sets of calipers were used for the two calipers measurement techniques. One which opened to 21 cm. was used for the 25, 50, 100, and 200 cm. projection distances. A large calipers was constructed of the same general shape as the smaller calipers to measure afterimages at the 400 cm. distance. This calipers could easily open to twice the 32 cm. height which Emmert's law would predict for afterimages at this distance.

The three coincidence targets for the second measurement technique were of the same proportions as the forming stimuli but were the left halves instead of the right halves of squares. At the 25 cm. projection distance this was a 2 cm. target with outlines 1.5 mm. wide. At the 100 cm. this was an eight cm. target with six mm. outlines and at 400 cm., it was 32 cm. high with 2.4 cm. outlines. A fixation point corresponding to the one on the forming-stimuli was located on each of these targets. This fixation point was viewed after an afterimage was formed and the target was then positioned by the experimenter at a distance from the subject where the afterimage and coincidence target were reported to be the same height. At this point, the combined figure of afterimage and coincidence target looked like a completed square. Since the coincidence target was located alongside the afterimage a vernier type of measurement was involved. This was found in pilot work to be more accurate than having a coincidence target which overlapped with the afterimage. This may have been because the contours of a real image interact to a great extent with afterimage contours, pushing each other around, so to speak.

A similar vernier principle was used in the third measurement technique. At the 25 cm. projection distance this consisted of two 1.5 mm. bands which formed a taper that varied from 1.5 cm. apart at one end to 2.6 cm. apart at the other end with the 1.1 cm. difference taking place over a length of 38 cm. This taper was exposed in a slot, 1 cm. wide which was bordered on the right by a blank grey projection field which the afterimage was viewed against (See Fig. 3). The afterimage thus butted up against the exposed pair of lines in a similar manner to the way the coincidence target and afterimage met in the second measurement method described above. The experimenter slid this taper along until the subject reported that the height of the afterimage just coincided with the height of the bands.

A similar target was used at the 100 cm. distance. The taper

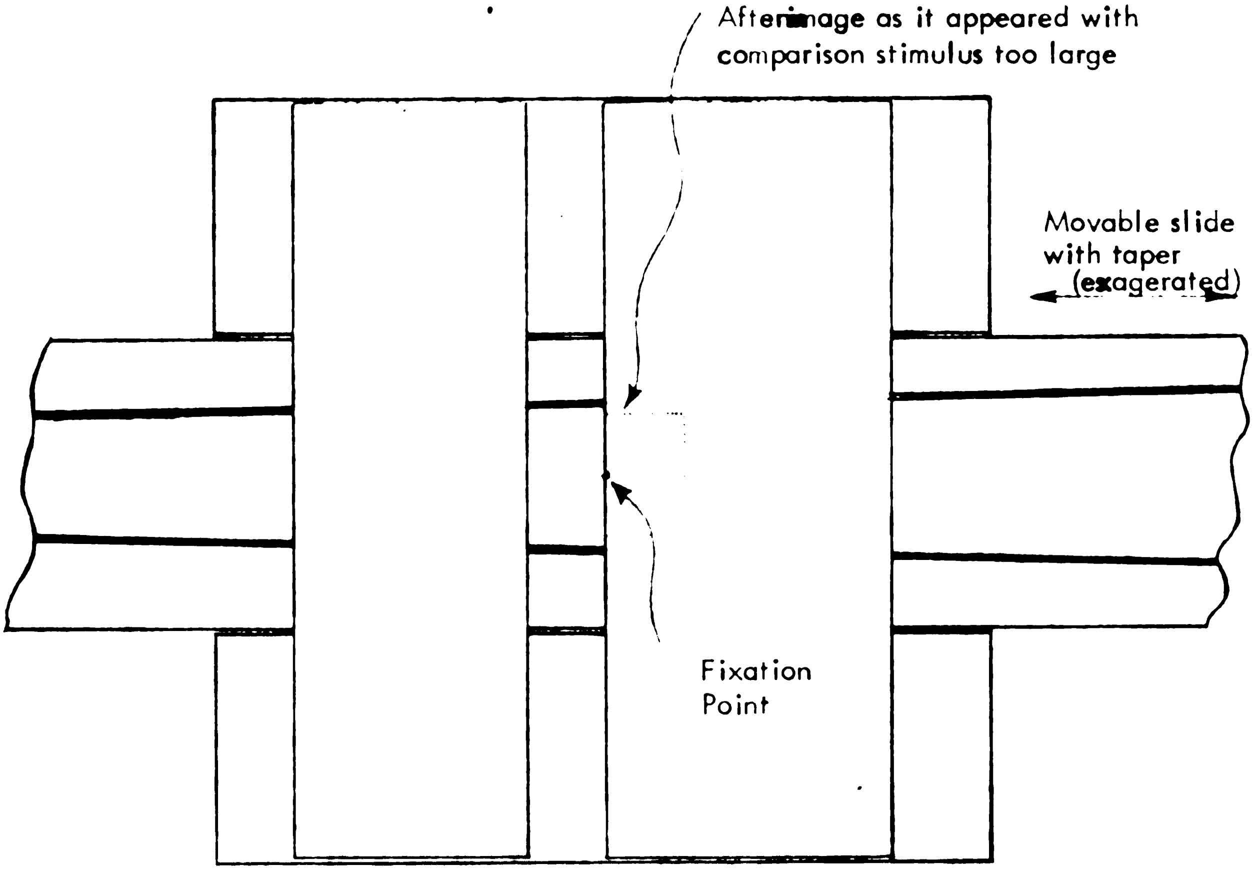

Figure 3. Taper coincidence target.

ranged from 7 cm. to 9 cm. and took place over 71 cm. The width of these bands was 6 millimeters corresponding to the width of the fixed size figure in Method 2. At the 400 cm. distance a different measurement method was used although similar in principle since the distance remained fixed while the target changed in size. An adjustable figure similar to that used in the second method was constructed from cardboard which could be varied in height from 25 cm. to 38 cm. This was held alongside of the afterimage projection area and adjusted by the experimenter until it coincided in height with the afterimage. A taper target was not used at this distance because the large size posed difficulties of construction and adjustment.

Procedure

Twelve subjects, six men and six women ranging in age from 17 to 24 were used in the study. Visual acuity, with correction if necessary, was excellent in both eyes and this was the only criterion used in their selection. Subjects were all undergraduate college students, few of which had any previous experience in psychology experiments. They were paid 4 dollars for approximately three hours of data collection time.

The 32 afterimages were measured by the subject in two one and one-half hour sessions on two separate days. All 16 at one session were formed at one of the two formation distances and the initial formation distance was alternated among subjects, three of each sex starting with the 50 cm. forming distance and the others with the 200 cm. distance. Presentation of the 16 was random for each session.

At the first session, subjects were introduced to the apparatus, the distance of the headrest was adjusted, and instructions and practice given with each of the afterimage measurement techniques. Then when a subject stated that he understood how to make the different measurements and his afterimage measurements indicated this to be so, the regular experiment was begun.

To form each afterimage, subjects placed their heads in the head and chin rest and fixated the fixation point on the forming-stimulus. This was then illuminated for 20 seconds after which the forming-stimulus was removed and the appropriate projection target was presented at the appropriate distance. Measurements of this afterimage then began immediately and continued for three minutes or more unless the afterimage faded prior to this time. The time of each measurement from the end of stimulation was recorded. This was done to control for the shrinkage in afterimage size over time that occurred with most subjects. Young (1948) also reported such a decline in afterimage size with time. His procedure controlled for this by taking a single measurement at a fixed time after the afterimage was formed. The present method of obtaining several measurements and keeping track of the elapsed time provided much more data, with instances of as many as a dozen measurements per afterimage for some subjects.

As soon as one afterimage was faded to the point where further measurements could not be made, a new afterimage was formed, projected, and measured. After ten such formations and measurements, the vision of the subject was tested on the Bausch & Lamb Orthorater. Acuity of the eyes together and singly was determined at both far and near. Lateral and vertical phorias were also determined at the two distances. In addition, color vision and depth perception were also tested. Half of these vision tests were made at one session and half at the next since they provided a welcome break for both subject and experimenter. Following the vision testing the final six afterimages of the session were formed and measured.

In all four measurement methods the measuring device was initially positioned larger on the first measurement of an afterimage followed by the device being positioned smaller, then large and small positionings were alternated until the afterimage was no longer measurable. The calipers measurement techniques, in particular, were highly influenced by the initial separation of the points.

Very early afterimage measurements were often considerably larger than succeeding ones. This, no doubt, resulted from the enlarged fuzzy appearance of afterimages after they were first formed which was noted by several subjects and probably observed by all. In addition, very late afterimage measurements in the sequence were often much smaller or much larger than the others in the sequence. For these two reasons measurements earlier than one minute after formation and later than three minutes after formation were not included in the main results.

Since the scalloping that resulted from alternating the initial position of the measuring device for a measurement was quite pronouned with some measurement techniques, it was essential that an even number of measurements be used in computing the mean for the series of measurements of a single afterimage. If there were an odd number of measurements between one and three minutes the following procedure was used. If there were seven or nine measurements the measurement closest in time to either 1 or 3 minutes was eliminated and the mean calculated with six or eight measurements respectively. If there were three or five measurements between one and three minutes, the closest measurement to one and three minutes which was not previously included was included to make four or six measurements.

This fixed procedure of averaging all measurements over a fixed time period should have eliminated any bias produced by diminution of the size of the afterimage over time. For most subjects this diminution was considerably smaller than the unsystematic variation and very little variance reduction would have been derived from covarying observation time, a procedure that had been initially considered.

CHAPTER IV: RESULTS

The order of presentation of the results is determined by their relevance to (1) the questions regarding the apparent size of afterimages at different projection distances and the influence of this apparent size on typical afterimage measurements made with calipers or compass points, and to (2) the question of whether magnification changes take place in the eye for different fixation distances which could account for the perceptual anomalies of overconstancy, changes in visual acuity at different distances, etc. The remaining findings of sex differences, practice effects, and individual differences follow. These latter results are only tangentially relevant to the above theoretical questions.

Changes in Afterimage Size with Projection Distance for Different Measurement Methods

The analysis of variance of afterimage measurements for the three common projection distances indicated that the main effects of measurement method and projection distance and the interaction of these two variables accounted for more than 70 percent of the total variation (see Table 1 for the analysis of variance). F-ratios for method, projection distance, and their interaction were 40.7, 84.5, and 69.5, respectively.

These are the main findings of the dissertation and are illustrated in Fig. 4. In this figure the mean visual angle of the comparison stimulus required to match the subjects' afterimages is plotted at the 25, 100, and 400 cm. projection distances for all four measurement methods and also at the 50 and 200 cm. projection distances for the calipers and apparent-size measurement methods.

TABLE I: Analysis of Variance

Source of Variance	Sum of Squares	df	Mean Square	F
Between Subjects				
A (Sex)	.031432	1	.031432	6.31*
B (Order of Formation Dist)	.003275	1	.003275	0.66
AB	.008613	1	.008613	1.73
Subjects Within Groups	.039900	8	.004988	
Within Subjects				
C(Formation Distance)	.007644	1	.007644	2.16
AC	.004464	1	.004464	1.26
BC	.000082	1	.000082	0.02
ABC	.000842	1	.000842	0.23
C x subj. w. groups	.028347	8	.004545	
D (Projection Distance)	.510245	2	.255122	84.52**
AD	.006193	2	.003097	1.02
BD	.012978	2	.006489	2.15
ABD	.009321	2	.004661	1.54
D x subj. w. groups	.048297	16	.003018	
CD	.009880	2	.004940	3.88*
ACD	.000358	2	.000179	0.14
BCD	.004894	2	.002447	1.92
ABCD	.000513	2	.000256	0.20
CD x subj. w. groups	.020365	16	.001273	
E (Measurement Method)	.655440	3	.218480	40.75**
AE	.018565	3	.006189	1.15
BE	.005180	3	.001727	0.32
ABE	.007752	3	.002584	0.48
E x subj. w. groups	.128686	24	.005362	
CE	.012343	3	.004114	1.63
ACE	.017080	3	.005693	2.25
BCE	.004205	3	.001402	0.55
ABCE	.003895	3	.001298	0.51
CE x subj. w. groups	.060669	24	.002528	
DE	.738578	6	.123096	69.48**
ADE	.011346	6	.001891	1.07
BDE	.017234	6	.002872	1.62
ABDE	.020120	6	.003353	1.89
DE x subj. w. groups	.085035	48	.001772	
CDE	.013194	6	.002199	2.34*
ACDE	.004666	6	.000778	0.83
BCDE	.030470	6	.005078	5.41**
ABCDE	.004686	6	.000781	0.83
CDE x subj. w. groups	.045041	48	.000938	
TOTAL	2.631350	287		

*Significant at .05 level
**Significant at .001 level

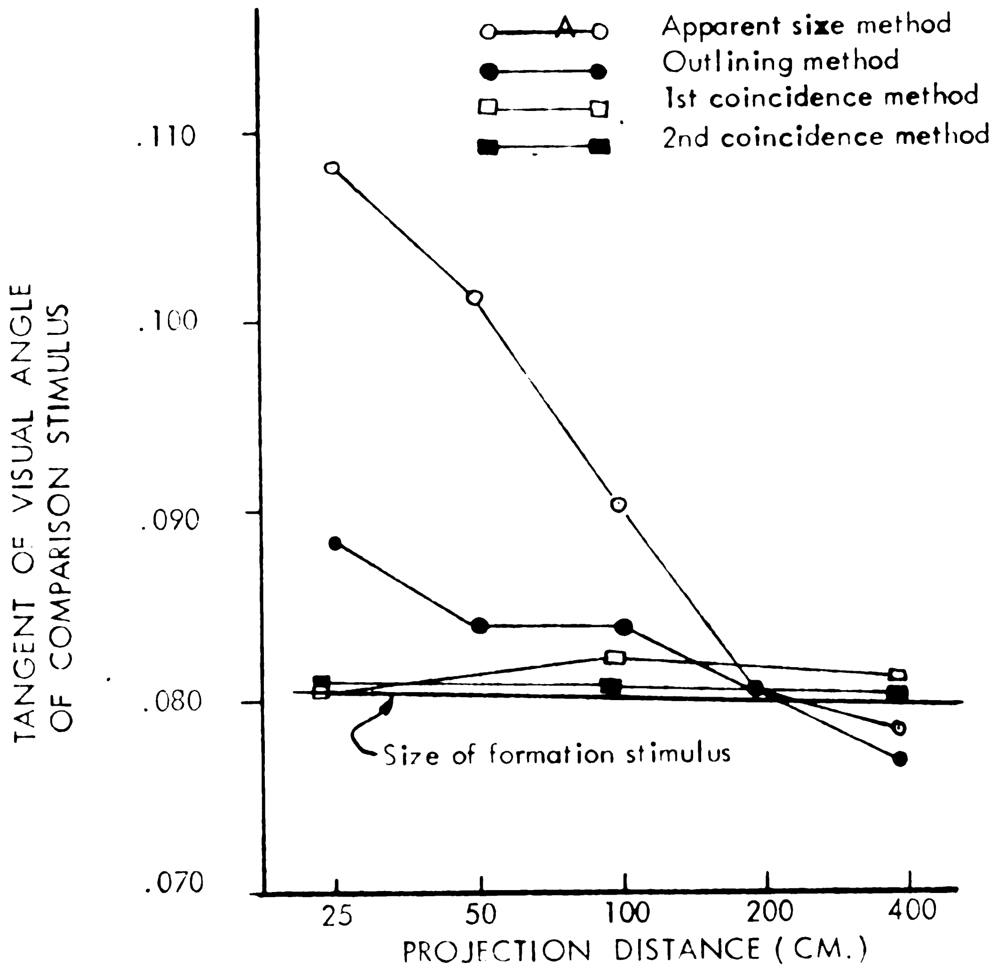

Figure 4. Afterimage measurements for the different methods and projection distances.

The ordinate in Fig. 4 and in all following plots of the data represents the tangent of the visual angle of the matching target. For the apparent size, calipers, and taper measurement methods this was obtained by dividing the size of the space between the caliper points or between the outer edges of the tapered lines by the fixed distance of the particular projection screen being used: 25, 50, 100, 200, or 400 cm. For the other measurement method with the movable slide, the tangent of the visual angle was obtained by dividing the 2, 8, or 32 cm. target height by the distance that it was positioned from the subject when it matched the afterimage in size.

The tangent of the visual angle of the formation stimulus was .0800 for both the 50 and 200 cm. stimuli. (The .0800 figure obtained by dividing the distance of the target into the size of the target underestimates the actual visual angle, which would be obtained exactly by determining the arctangent of .0400 and doubling it. The tangent of the actual visual angle is thus .08017, a negligible difference.) Emmert's law predicts that all of the data would fall on the horizontal line representing this .0800 tangent.

Findings with the Coincidence Measurement Method. The line representing the .0800 tangent of the visual angle of the forming-stimuli is also presented in Fig. 4. It can be seen that only slight deviations from it did, in fact, occur for the slide and taper coincidence measurement methods. This corresponds to a similar finding by Onizawa (1954) for the slide technique.

T-tests were calculated to determine whether the deviations from Emmert's law at each projection distance are significant, and also to test whether the measurements by the two coincidence methods differ from each other. These are presented in Table II.

The small (average 1%, maximum 3%), but significant positive differences between some projection distance measurements with these coincidence techniques and the .0800 figure that Emmert's law predicts can probably be accounted for by the enlargement of the afterimage as a result of diffraction, spherical abberation, and the small tremor movements of the eye. These factors would combine to produce slightly blurred afterimages which thus would be slightly larger and would require slightly larger targets to match them than the targets that formed them.

The absence of significant differences at the extreme projection distances for the two coincidence measurement techniques would support Hypothesis 4 that it was not the saliency of distance in the slide technique that accounted for the Onizawa (1954) findings but something related to the coincidence measurement process.

<u>Results of the Apparent Size Measurement Method</u>. Very large deviations from Emmert's law were found with the apparent size measurement method. It will be recalled that this method involved calipers presented somewhat away from the portion of the projection screen where the afterimage was viewed and kept in motion to prevent any attempt at coincidence measurement. The afterimage projected at 25 cm. was found to be 38 percent larger than the afterimage projected at 400 cm. In the first row of Table III

TABLE II: Significance Tests of Differences

for Coincidence Methods

	PROJECTION DISTANCE		
	25 cm.	100 cm.	400 cm.
Slide & .0800	t=.60	t=6.8 p<.001	t=2.2 p<.05
Taper & .0800	t=3.3 p<.05	t=2.5 p<.05	t=0.9
Slide & Taper	t=1.1	t=3.9 p<.001	t=1.3

TABLE III: Significance Tests of

Differences for Apparent Size and Calipers Methods

	PROJECTION DISTANCE				
	25 cm.	50 cm.	100 cm.	200 cm.	400 cm.
Apparent size & .0800	t=11.8 p<.001	t=11.4 p<.001	t=5.7 p<.001	t=0.2	t=1.2
Calipers & .0800	t=10.6 p<.001	t=3.7 p<.001	t=4.3 p<.001	t=0.2	t=4.3 p<.001
Apparent Size & Calipers	t=7.8 p<.001	t=8.2 p<.001	t=3.9 p<.001	t=0.01	t=1.4

are presented the results of t-tests for the differences between the apparent size measurements and the .0800 prediction of Emmert's law for the five projection distances. The measurement at 400 cm. is not significantly less than the prediction of Emmert's law but it does correspond to similar findings by Crookes (1959), Hastorf and Kennedy (1957), and Price (1961) of a smaller apparent size than the size predicted by Emmert's law for afterimages projected at a considerable distance.

Results for the Calipers Measurement Method. The "classical" measurement method, where calipers were held around the afterimage and adjusted until the points were reported by the subject to just touch the extremities of the afterimage, also provided large deviations from the .0800 prediction of Emmert's law although the deviations were not as great as for the apparent size measurement method except at the 400 cm. projection distance. Afterimages projected at 25 cm. were found to be about 15 percent larger than the 400 cm. projected afterimages. The difference is in the general range of the typical findings of other studies (Carr, 1935, etc.) where afterimages were found to be larger at near projection distances than at far projection distances, when measured with calipers or with a beam compass.

The second and third rows of Table III present the results of t-tests for the differences between these measurements and the .0800 prediction of Emmert's law and between these measurements and the apparent size measurements, respectively. For the 25, 50, and 100 cm. projection distances the "classical" calipers measurements are significantly less than the apparent size measurements and significantly greater than the value predicted by Emmert's law. Apparent size and calipers measurements were nearly identical at the 200 cm. projection distance and neither differed significantly from the value predicted by Emmert's law at that distance.

Relation Between Calipers and Apparent Size Measurements. The fact that the calipers measurements are in between the apparent size measurements and the predictions of Emmert's law at 25, 50, and 100 cm., are nearly identical with this prediction at 200 cm. and are not significantly different at 400 cm. suggests that the calipers measurements are compromises between apparent size measurements and coincidence measurements (relative to the apparent size and calipers measurements coincidence measurements were all nearly equal to the .0800 figure predicted by Emmert). The direct relation between the magnitudes of the measurements for apparent size and calipers methods at the different distances (except for the negligible difference between the 50 and 100 cm. projection distance for the calipers technique) also supports such an interpretation. This direct relation was also generally the case for the data of individual subjects.

In addition, subjects who gave large apparent size measurements also tended to give large calipers measurements. In Table IV are presented correlations for the four different measurement techniques with separate correlations computed for each projection distance. The highest average correlations across subjects were between the apparent size and calipers measurements. (The high correlation between the calipers

TABLE IV: Correlations Between Pairs

of Measurement Methods at Each Projection Distance (N=12)

Projection Distance	App. Size & Calipers	App. Size & Slide	App. Size & Taper	Calipers & Slide	Calipers & Taper	Slide & Taper
25	.55	-.30	.29	.32	.75	.56
100	.52	.14	-.05	.15	.00	.09
400	.56	-.32	-.04	-.07	.13	.32
Average	.54	-.16	.07	.13	.29	.32

measurement technique and the taper measurement method at 25 cm. did not occur at the other distances and may be spurious.)

Factors Related to the Magnification Change Hypothesis

The results obtained with the two coincidence techniques have already been reported. Relatively little deviation from Emmert's law for these techniques was found at any distance. The standard deviation of the slide coincidence technique was .0022. That of the taper coincidence measurement technique was .0014. These compare to .0151 for the apparent size measurement method and .0063 for the calipers techniques. These much smaller variances with the coincidence techniques argue strongly for their superiority in providing an indication of the eye's magnification with different fixation distances over the calipers technique. Further evidence for the validity of the coincidence methods is provided by the lack of correlation between apparent size measurements and the coincidence method measurements at all measurement distances. If the coincidence measurements are biased, it at least is not by the same factor related to the apparent size measurements that biases the calipers measurements.

With respect to this theoretical question of magnification change, it is also important to note that the main effect of formation distance was not significant. Figure 5 shows the barely significant interaction of this variable with the variables of method of measurement and projection distance. The slight differences that did occur are for the calipers and apparent size techniques and then primarily at only the 100 cm. projection distance. These measurements were found to be less with the 200 cm.

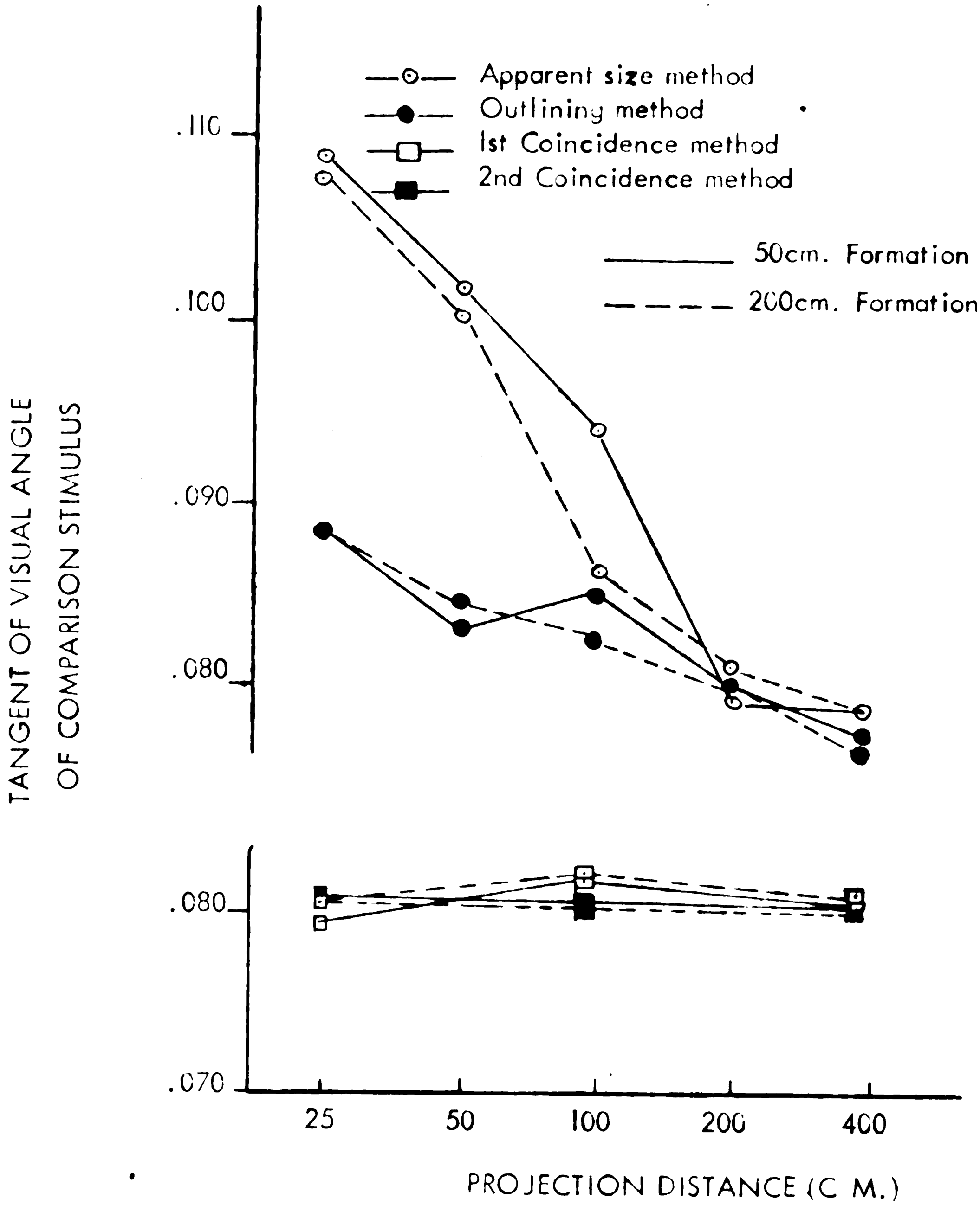

Figure 5. Afterimage measurements for different formation distances and methods.

formation distance than with the 50 cm. formation distance. This finding is not relevant to the magnification change hypothesis, but it is of considerable interest since it is opposite to the results of the Ohwaki study (1955) where afterimages formed at 200 cm. were larger than those formed at 50 cm. when both were projected at 100 cm.

For the low-variance coincidence measurement techniques the formation distances produce negligible differences in measured size. The mean for the 50 cm. formation distance for the two coincidence methods was .08088 for the 200 cm. formation distance the mean for the two coincidence methods was .08093.

<u>Sex Differences, Practice Effects, and Individual Differences</u>

<u>Sex Differences</u>. One other main effect was significant. Males were found to give larger afterimage measurements than females. Figure 6 shows the interaction of measurement method and projection distance with a further breakdown based on sex. It can be seen that very little difference between the sexes occurred with the slide and taper coincidence techniques and that this difference was greatest for the apparent size measurements.

<u>Practice Effects</u>. No significant difference appeared for a main effect that consisted of two levels of a variable based on whether the 50 cm. formation stimulus was presented at the first session or whether the 200 cm. formation stimulus was presented first. (This was variable "B" in the Analysis of Variance table.) A highly significant interaction with this variable was found, however. This interaction is illustrated in Figure 7. It is the "formation distance at the first session" by formation distance by measurement method by projection distance interaction.

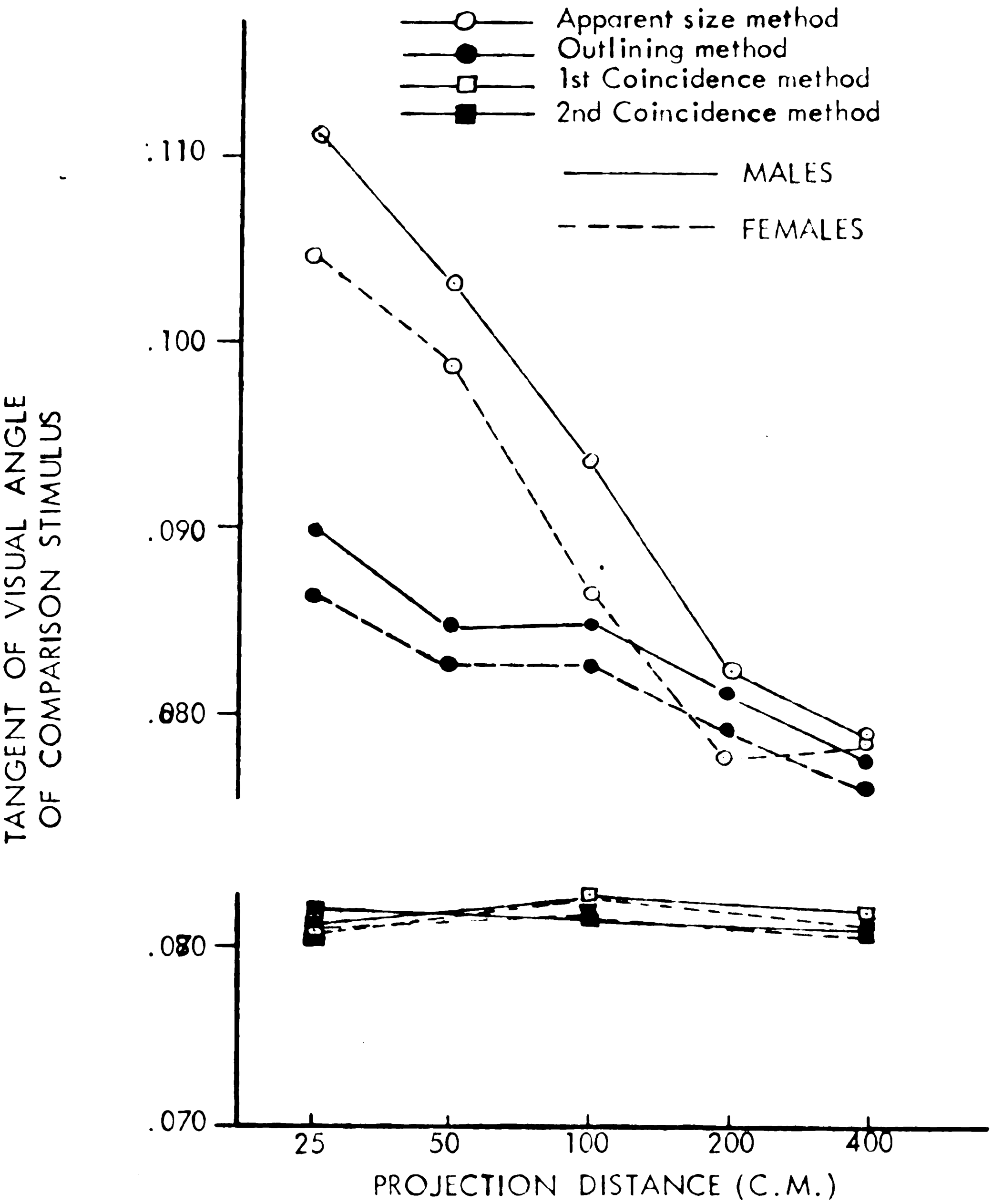

Figure 6. Afterimage measurements for different methods by males and females.

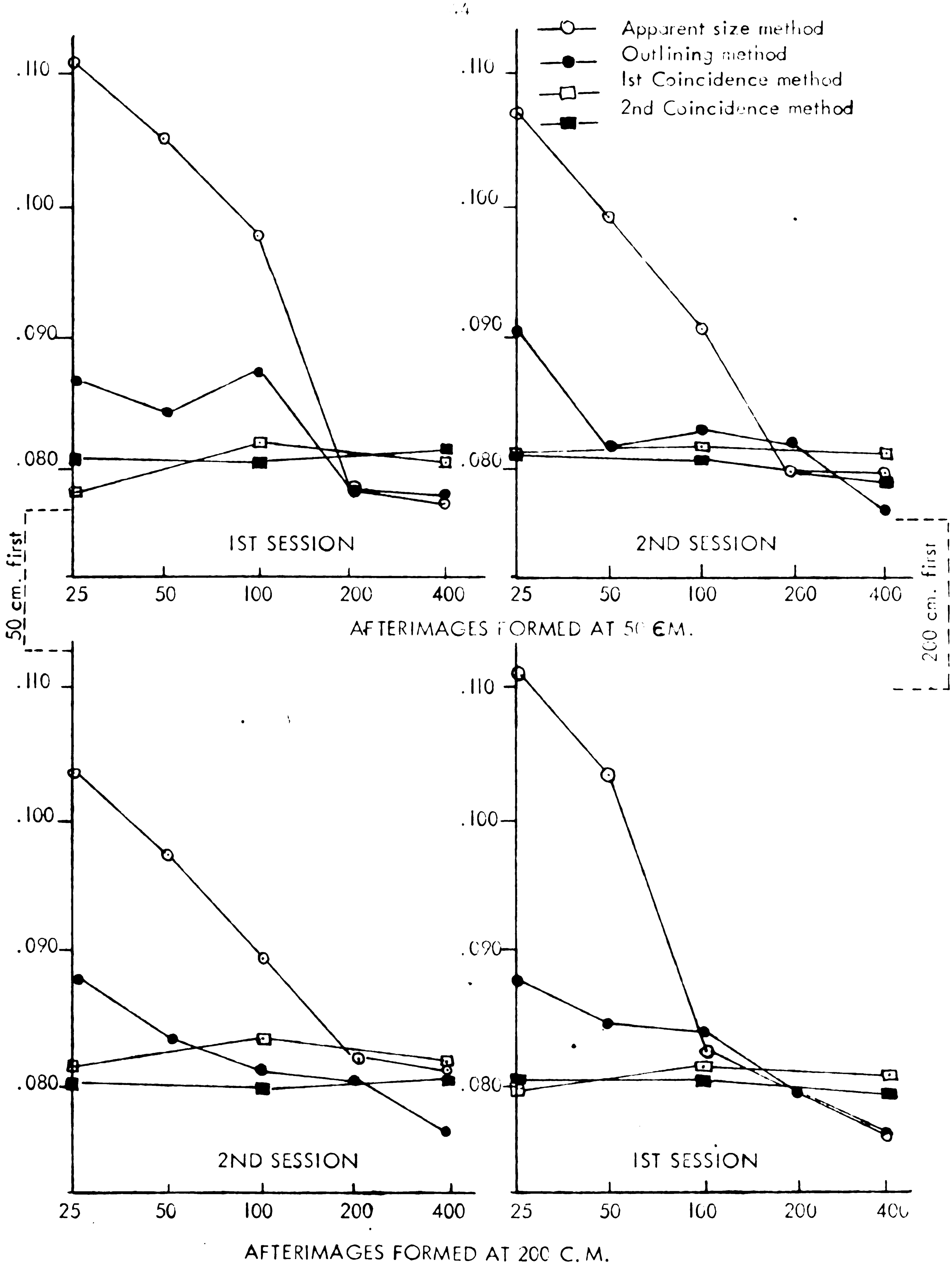

Figure 7. Afterimage msmts. at 1st and 2nd session for 50cm. formation first and 200 cm. formation first groups.

In the upper left hand corner of Figure 7 is presented the graph for the group receiving the 50 cm. formation stimulus at their first session and the graph depicts the data for this first session. Directly below this is the graph of data for the same group but for the 200 cm. formation stimulus which this group received at the second session. The right hand curves are for the group that received the 200 cm. formation stimulus distance first and top and bottom are again the 50 and 200 cm. formation distances, respectively. The diagonals of the figure thus represent the first experimental session from upper left to lower right, and the second experimental session from lower left to upper right.

Despite representing different formation distances the data of the two figures of the second session diagonal were quite similar, and except for less overestimation and underestimation of the apparent size measurements for the extreme projection distances did not differ basically from the overall means of the method by projection distance interaction (Figure 4). The first session diagonal, on the other hand, shows the greater overestimation and underestimation of these extreme projection distances that occurred. The effect of practice in the first session is to bring the apparent size measurements of the second session closer to Emmert's law. The first session diagonal also showed a large difference between measurements for the two formation distances. The apparent size measurement at the 100 cm. projection distance was found to be greatly overestimated when the afterimage was formed at 50 cm., but was estimated to be very much smaller when the formation stimulus was at 200 cm. Overestimation also appeared for the calipers data at the 100 cm. projection distance for the

50 cm. formation stimulus. Practice in session one again may have accounted for these 100 cm. projection distance differences not occurring in session two.

Individual Differences. Although the general pattern of the group means was followed by most subjects in the experiment, there was still wide variation in their results, particularly for the apparent size measurements. Individual data appear in Figures 8 through 11 of Appendix A. Figure 8 represents males in the group that received the 50 cm. formation stimulus first. Figure 10 and Figure 11 present data for males and females of the groups that received the 200 cm. formation stimulus at the first session. The curves plotted for an individual are the method by projection distance interactions and each point represents the mean of the observations for the two formation distances.

One difference from the overall means that appeared for K.L. and S.M. (Figure 9) and for J.S. (Figure 10) was a smaller apparent size method measurement for the 25 cm. projection distance than for the 50 cm. projection distance. For K.L. a similar relation appeared for the calipers measurements. For this subject, at least, this initial lower measurement value does not appear to be a chance occurrence.

Other differences appeared in the slope of the curve representing apparent size measurements when plotted against projection distance. These ranged from very steep (M.B., Fig. 11) to fairly flat (J.S., Fig. 10). Individual differences also appeared in the lateral displacement of these apparent size curves. D.S. (Fig. 10) and S.M. (Fig. 9) have these curves displaced to the right with only the 400 cm. projection distance measurement approaching the .0800 value predicted by Emmert's law. Others (C.T., Fig. 11; M.M., Fig. 11) cross the .0800 line at the 100 cm. projection distance or earlier.

The calipers measurements also reflected individual differences. This variation generally occurred along a dimension ranging from nearly exact correspondence to Emmert's law (J.R., Fig. 10; M.B., Fig. 11), to nearly identical measurements for calipers as those for the apparent size method (K.L., Fig. 9).

Individual differences in measurements with the slide and taper measurement methods are negligible and may reflect errors in location of the headrest for the subject or changes in the way in which his head was positioned in the headrest, as much as they reflect basic differences in some factor such as visual function of these individuals. This may be an indictment of the experimental apparatus and procedure but it is only meant as a restatement of the fact that the differences over distance with these measurement methods were very small. It will be argued in the next chapter that these small differences imply that for almost all size and distance perception research purposes, Emmert's law may be accepted as valid along with its corollary that the magnification changes of the eye for different fixation distances are negligible.

<u>Correlations of Measurements with Observer Characertistics</u>

Other data on the subjects was obtained beside the afterimage measurements. Correlations were computed between visual acuity, visual phoria, spherical correction of glasses (0 if none were worn), depth perception and age of subjects and their afterimage measurements for the various measurement methods at the different projection distances. With five borderline exceptions, none of the 96 resulting correlations were greater than the .50 required for statistical significance at the .05 level with an n of 12. Some patterns of correlations were suggestive, however. Exophoria, the tendency for the eyes to diverge, was somewhat associated with large afterimages at the 25 cm. projection distance, and conversely, exophoria's opposite, esophoria, was slightly associated with small afterimages at this projection distance. At the 400 cm. projection distance these relationships appeared to be somewhat opposite to those at the 25 cm. projection distance. Exophoria tended to go with small afterimages and esophoria with large afterimages.

Age despite its restricted range of 17 to 24, seemed to show a pattern with the 400 cm. projection distance measurements, also. For the slide and taper coincidence measurements methods it produced barely significant positive correlations, for the apparent size and calipers measurement methods, nearly significant negative correlations were found. This latter finding supported an observation from pilot work that the older the subject, the more he underestimated the distant afterimage with the apparent size measurement technique. These age differences are confounded with the number of years of close work attendant to college work and probably with many other factors. Specific investigations of variables such as phoria and age with larger ranges of variation and larger numbers of subjects are required before any conclusion can be drawn regarding their effects. Experimental manipulation of the phorias with prisms and lenses might be a better investigative procedure than correlational studies of this variable.

CHAPTER V: DISCUSSION

The main results and conclusions of this study can be summarized in three statements. (1) The apparent size of afterimages is greater than the value predicted by Emmert's law with close projection distances and equal to or less than this value for distant projected afterimages. (2) This apparent size enters into the classical calipers measurement method causing the large deviations from Emmert's law that have been found in previous studies. (3) The traditional interpretation of little or no change in the magnification of the eye at different fixation distances is supported, since measurement techniques utilizing coincidence targets do not show deviations from Emmert's law nor do afterimages formed at different distances with constant visual angle stimuli show any differences in size. Each of these statements is discussed in this chapter plus other findings related to the effect of formation distance on the apparent size of afterimages, sex differences, and practice effects. Finally important implications of the study are presented and further research needs in the area are outlined.

The Interaction of Apparent Size with Distance

Group means and also data from individual subjects clearly indicated that the apparent size of afterimages decreased with the distance of projection as was specified in Hypothesis 1. This interaction was predicted prior to the experiment, with the prediction based on the facts of the large changes of apparent size that occur with oculomotor change, and the absence of a fixation stimulus during the viewing of afterimages. The explanation derived for the interaction was that the subject first observed either the caliper point-spacing or the afterimage size, then at a slightly later time, observed the other. It was assumed that this period of time between the successive judgments allowed the eyes to assume slightly different fixation positions for each judgment. Close fixation has long been known to make things appear smaller and, conversely, far fixation makes things appear larger. To predict an interaction of apparent size with projection distance where afterimages are judged larger at near than at far, required that for close projection distances the afterimage portion of the successive size judgments be made with fixation at a greater distance than fixation during the judgment of the size of the caliper point spacing. Conversely, with far projection distances the afterimage size had to be assessed with closer fixation than occurred during the assessment of the spacing of the caliper points. A more detailed account of this explanation is presented in Chapter II.

The resting position of accommodation and convergence is at a somewhat intermediate position (Alpern, 1962) and the assumption was made in this explanation that the lack of a fixation stimulus during afterimage viewing allowed the eyes to move toward this fixation rest position. This assumption of fixation drift plus the assumption of successive measurements provided the necessary mechanism for the interaction. Admittedly, it was the need for this interaction to provide an explanation of the calipers data that led to the above derivation. However, at least some support is derived for this explanation of the interaction, by the fact that the interaction of apparent size with projection distance did occur. In addition, one subject spontaneously reported that his eyes drifted during apparent size measurements.

This study did not conclusively indicate that the apparent size of afterimages projected at a large distance (400 cm.) are smaller than Emmert's law would predict which was part of Hypothesis 1. However, this had already been shown by several other studies (Price, 1961; Hastorf and Kennedy, 1957; Crookes, 1959) where distant projection of the afterimages occurred.

The Influence of Afterimage Apparent Size on Calipers Measurements

Although the cause of the interaction of apparent size with distance of afterimage projection cannot be completely specified in this study. The high correlation of apparent size measurements and calipers measurements for the 5 projection distances strongly supports Hypothesis 2 that the typical deviations from Emmert's law in the studies of Carr (1935), Onizawa (1954), etc., result from the calipers measurements being in some part apparent size measurements. Individual data, as well as group means, supported this position. Even when the afterimages did not show the pattern of largest size at near and smallest at far, there were two instances (K.L., Fig. 9; H.H., Fig. 10) where the five measurements for calipers and apparent size correlated perfectly. Further support for this is derived from the significant moderate correlation across subjects for these two techniques.

Exactly how apparent size enters into the calipers measurements cannot be specified until the mechanism for the apparent size changes with projection distance is known. The fixation resting point hypothesis states that it results when the subject, knowingly or unknowingly, does not make a simultaneous comparison of afterimage and caliper points, but instead allows a little time and oculomotor change to intervene through successive judgments of their sizes. The reported difficulty of observing the small calipers points in these measurements might account for subjects giving such successive judgments rather than judgments of the simultaneous coincidence of points and afterimages.

The Magnification of the Eye at Different Fixation Distances

An explanation of the typical afterimage size finding (large afterimages at near projection distances and smaller afterimages at far projection distances) based on changes of the eye's magnification with the different fixation distances was very attractive. Such an explanation would not only account for the different sized afterimages, but also accounted for several other important perceptual anomalies, such as increased visual acuity at a distance over near, "overconstancy", figural aftereffects with stimuli of constant visual angle at different distances, etc. In providing an apparent size explanation of the typical afterimage finding, the study also cast doubt on this optical explanation for the other anomalies. Further, stronger evidence against a magnification change explanation of these anomalies was provided by the near coincidence to Emmert's law with the Onizawa-type slide coincidence technique and with another coincidence technique that differed from the Onizawa technique in that it used a projection screen at a fixed distance with a target that varied in size. Thus the data support Hypothesis 3 which stated that when apparent size is eliminated Emmert's law will hold, and the absence of differences between coincidence methods supported Hypothesis 4. Finally the absence of differences in afterimage size when afterimages were formed at different distances supported Hypothesis 5 and indicated that the magnification of the eye does not differ for the fixation distances of 50 and 200 cm.

Since there was relatively little difference between the overall means for the slide and taper techniques at the three projection distances, it is probably safest to conclude only that both methods indicate little if any change in the magnification of the eye at different distances of fixation. The Onizawa-type slide technique did result in slightly smaller afterimage measurements at the close projection distances than at the more distant ones which is what the traditional physiological optics explanation would predict would happen. On the other hand, the group means for the taper technique were nearly identical at the three distances and this suggests that Emmert's law is true as originally formulated. The group means for the two techniques did not differ among themselves by much more than two percent and data for individual subjects generally did not show much greater differences. An investigation with trained subjects might eliminate the differences between these two coincidence techniques and more closely illustrate actual magnification changes of the eye. The present study shows that such deviations are very small, much smaller than would be required to explain "overconstancy", for example.

<u>The Failure of Afterimage Size to Vary with Formation Distance</u>

Although the typical finding of large afterimages at near projection distances and small afterimages at far projection distances seems to be well accounted for by the assumption that successive apparent size judgments enter the caliper measurements, the Ohwaki (1955) finding of smaller afterimages with closer formation distances was not replicated in this study and Hypothesis 6 derived from Ohwaki's results was not supported. As mentioned in the last section, the differences with the coincidence measurement techniques for the 50 and 200 cm. formation stimuli were negligible. The slight differences that did appear actually cancelled each other instead of favoring larger or smaller afterimages at one formation distance or the other. Differences with the calipers and apparent size measurement methods were somewhat larger, but only at 100 cm. for the apparent size method were they significant. However, they were in the opposite relation to formation distance from the findings of the Ohwaki study when she used this same projection distance with the 50 and 200 cm. formation distances.

It is not clear why the Ohwaki finding was not obtained, although many differences existed between the present study and Ohwaki's. In her study the forming stimuli were red cardboard squares viewed under normal room illumination. The brightness of these squares was not given but it may have been as much as two orders of magnitude less than the 2,300 ft.-L. stimulus brightness of the present study. Because of this the afterimages must have been of much shorter duration than afterimages in the present study. This may account for the fact that she made only one measurement per afterimage. A check of first afterimage measurement data in the present study was made to see if a different pattern was present than for the means of all observations between one and three minutes. Little difference was found between the two with the 50 cm. formation distance again providing the largest afterimages (.0908 vs. .0899).

One important difference between the studies that may have existed is an absence of a fixation point on the projection screen in the Ohwaki study. She simply stated that the afterimage was "projected on the centre of a gray screen." An absence of a fixation point might have allowed the subjects to continue fixating at the distance of the formation stimulus when they were projecting the afterimage and assessing it for size. If this afterimage size assessment were then followed by a compass point spacing assessment at the actual projection distance, the relation of oculomotor adjustments would be such as to predict small afterimages with near formation and large afterimages with far formation. In the present study the presence of fixation points on the projection targets may have resulted in the eyes being at nearly the same distance for both ends of the successive judgment measurement process for this 100 cm. projection distance. If elimination of the fixation point on projection screens with the present apparatus and procedure were to produce the relationship between formation stimulus distance and afterimage size that Ohwaki obtained, it would give additional support to the successive judgment hypothesis.

Possible Explanations of Sex and Other Differences

The differences between apparent size and calipers measurements for males and females were quite large, particularly at the closer projection distances. To account for this the fixation-resting-point hypothesis would predict that the fixation-resting-point is more distant for males than females. Male eyes would thus be fixated at a greater distance when the afterimage size was assessed and thus the apparent size metric would be greater and the afterimage would look larger. One might account for such a difference in fixation rest position on the basis of greater participation by males than females in athletics and other activities that involve viewing at a distance.

However, individual differences, including the sex differences, might not reflect different fixation-resting-points, even if the fixation resting position explanation does apply. Instead, they could reflect differences in the amount that the eyes are allowed to drift away from the projection screen toward this rest position. Another possibility is that equal changes of fixation distance produce different changes in apparent size for different observers. Several investigators have shown that large changes in apparent size result from oculomotor changes (Hermans, 1954; Leibowitz and Moore, 1966; Lie, 1965), but little is known about individual variations in these apparent size changes.

In the first session there was found to be a greater overestimation of the apparent size measurements at 25 cm. and a greater underestimation of these measurements at 400 cm. than occurred in the second session. In terms of the successive judgment explanation, this would probably mean that subjects allowed their eyes to move closer to the fixation-resting-point during assessment of the size of the afterimage in the first session than in the second. The increase in familiarity with the distances of projection in the second session might account for this since they could allow more accurate fixation at these distances. Another possible explanation is that the time between the successive judgments decreased from the first session to the second and the reduced time prevented as much drift from the projection screen toward the fixation-resting-point in the second session as occurred in the first.

In the first session it was also found that the apparent size measurement at the 100 cm. projection distance was greatly overestimated for the 50 cm. formation distance but was estimated to be nearly 20 percent smaller for the 200 cm. formation distance. To account for this in terms of different oculomotor adjustments in successive size judgments would require the eyes to be adopting a rest position beyond the 100 cm. projection screen when the afterimage was formed at 50 cm. and to be adopting a rest position closer than the 100 cm. projection screen when the afterimage was formed at 200 cm. It could be argued that the 20 second fixation at one distance during afterimage formation might cause the eyes to seek a different fixation position to rest the eye muscles. If formation were close this new position might be expected to be far. If formation were far, then this new position might be closer than formation. This seem plausible, but it did not happen in the Ohwaki study where the assumption required to explain small afterimages with mean formation was that no oculomotor change took place after formation of the afterimage. No satisfactory explanation of the contradictory results of this study and the Ohwaki study seems possible at this time.

Important Implications and Future Research Needs

This final section reviews and discusses some implications of the present study. Perhaps the most important is the explanation the results provide of contradictory findings in past studies of Emmert's law. This explanation is that the apparent size of afterimages has often entered into outlining afterimage measurements, and the more that the data of some study deviated from Emmert's law in the typical direction, the greater this influence of apparent size was. When data were in accord with Emmert's law in a study or indicated somewhat smaller afterimages at near projection than at far projection, then the measurements were probably bona fide coincidences between the measurement device and the afterimage and actually reflected magnification of the eye at the different projection distances.

The study suggests that coincidence methods are sufficiently accurate to assess individual differences in magnification of the eye with different formation distances. A well-trained subject could probably demonstrate magnification changes of less than one percent. Because such changes are very small their measurement would probably be of little psychological importance but might be invaluable to physiologists and ophthalmologists for studying the structure of the eye, or changes in its structure during the development of refractive errors. The study indicates that the traditional outlining methods of afterimage measurement would not be appropriate for such research.

The study indicated sex differences and other interesting individual differences in the measurement of the apparent size of afterimages, and further investigation of these differences would surely prove enlightening. These differences were also reflected in the outlining measurements but apparent size measurements are more apt to get at these individual differences and the outlining measurement method should probably be avoided for these quite different purposes, also.

In agreeing with other research (Heinemann, 1961) indicating that the perceptual anomalies such as overconstancy are not the result of optical magnification, the study supported the view that some central magnification process occurs, instead. The process appears to be very general, applying to the apparent size of objects, visual acuity, flicker perception, figural aftereffects, and probably other perceptual phenomena, and thus must be classed as one of the most important perceptual processes. One approach to the study of this process would be to look at these anomalies and at the apparent size of afterimages in the same subjects and determine if a relation exists between the phenomena.

There is an immediate need to test the present fixation-rest-position explanation of the apparent size changes with distance that were found to occur. Photographic or other objective means for observing the position of the eyes during apparent size measurements should indicate if the size changes are related to changes in convergence of the eyes. If the drift in fixation were confined to visual accommodation this might be reflected in changes in the size of the pupil which would be expected to increase as the accommodation distance increased. Another approach to this question could involve manipulation of convergence and accommodation with prisms and lenses and observe the effect of this on the apparent size of afterimages.

One assumption in the fixation-rest-position explanation was that the afterimage of a fused stimulus did not constitute a fixation stimulus. A parallel assumption to this is that an afterimage formed while the stimulus is not fused would lead to disparate afterimages in the two eyes that would serve as a stimulus for fixation change. No adjustment of the eyes could fuse these afterimages and one could imagine the eyes becoming maximally converged or diverged (depending on the initial disparity) in an attempt to fuse them. Apparently no one has tested this possibility. An objective means of monitoring eye movements would be useful in this research, also.

These would appear to be the major implications of the present study and the more obvious avenues for research that could follow it in this relatively neglected area of study that falls somewhere between sensory psychology and the more cognitive or conscious aspects of perception.

REFERENCES

Alpern, M. Movements of the eyes. Part 1 in Davson, H. (Ed.) The Eye. Vol. 3, New York, Academic Press, 1962.

Barlow, H.B. and Sparrock, J.M.B. The role of afterimages in dark adaptation. Science, 1964, 144, 1309-1314.

Boring, E.G. Size constancy and Emmert's law. Amer. J. Psychol., 1940, 53, 293-295.

Brindley, G.S. Afterimages. Scientific American, 1963, 209, 84-93.

Carr, H.A. An Introduction to Space Perception, 1935.

Crookes, T.C. The apparent size of afterimages. Amer. J. Psychol., 1959, 72, 547-553.

Edwards, W. Emmert's law and Euclid's optics. Amer. J. Psychol., 1950, 63, 607-612.

Emmert, E. Grossenverhaltnisse der nachbilder. Klin. Monatsbl. f. Augenheilkunde, 1881, 19, 443-450.

Epstein, W., Park, J. and Casey, A. The current status of the size-distance hypothesis. Psychol. Bull., 1961, 58, 491-514.

Freeman, E. Anomalies of visual acuity in relation to stimulus distance. J. Opt. Soc. Amer., 1932, 22, 285-292.

Ganz, L. Is the figural aftereffect an aftereffect? A review of its intensity, onset, decay, and transfer characteristics. Psychol. Bull., 1966, 66, 151-165.

Giese, W.J. The interrelationship of visual acuity at different distances. J. Applied Psychol., 1946, 30, 91-106.

Gregory, R.L., Wallace, J.G., and Campbell, F.W. Changes in the size and shape of visual afterimages observed in complete darkness during changes of position in space. Quart. J. Exp. Psychol., 1959, 11, 54-55.

Hastorf, A.H. and Kennedy, J.L. Emmert's law and size constancy. Amer. J. Psychol., 1957, 70, 114-116.

Heinemann, E.G., Tulving, E. and Nachmias, J. The effect of oculomotor adjustments on apparent size. Amer. J. Psychol., 1959, 72, 32-45.

Heinemann, E.G. Photographic Measurement of the retinal image. Amer. J. Psychol., 1961, 74, 440-445.

Helmholtz, H. Handbuch der Physiologischen Optik. Vol. 1. Verlag von Leopold Voss, 1866.

Hermans, T.G. The relationship of convergence and elevation changes to judgments of size. J. Exp. Psychol., 1954, 48, 204-208.

Leibowitz, H. and Moore, D. Role of changes in accommodation and convergence in the perception of size. J. Opt. Soc. Amer., 1966, 56, 1120-1123.

Lie, I. Convergence as a cue to perceived size and distance. Scand. J. Psychol., 1956, 6, 109-116.

Lukiesh, M. and Moss, F.K. The dependence of visual acuity upon stimulus distance. J. Opt. Soc. Amer., 1933, 23, 25-29.

McCready, D.W. "Visual Acuity under Conditions that Induce Size Illusions" Ph. D. Dissertation, Univ. of Mich., 1963.

McCready, D.W. Size-distance perception and accommodation-convergence micropsia---a critique. Vision Research, 1965, 5, 189-206.

Norris, O.O. The nature of distance vision. J. Exp. Psychol., 1934, 17, 462-476.

Ohwaki, S. On the factors determining accommodation: research on size constancy phenomenon. Tohoku Psychologica Folia, 1955, 14, 147-158.

Onizawa, T. Research on the size of the projected afterimage. Part I. On the method of measurement. Tohoku Psychologica Folia, 1954, 14, 75-78.

Pascal, J.I. Effect of accommodation on the retinal image. Brit. J. Ophthal., 1952, 36, 676-687.

Price, G.R. On Emmert's law of apparent sizes. Psychol. Record., 1961, 11, 145-151.

Spigel, I.M. Size constancy and critical flicker frequency. Amer. J. Psychol., 1964, 77, 496-471.

Story, A.W. Has apparent size been tested as a factor in figural aftereffects? Quart. J. Exp. Psychol., 1961, 13, 204-208.

Sutherland, N.S. Figural after-effects, retinal size, and apparent size. Quart. J. Exp. Psychol., 1954, 6, 35-44.

Taylor, F.V. Changes in size of the afterimage induced in total darkness. J. Exp. Psychol., 1941, 29, 75-80.

Urist, M.J. Afterimages and ocular muscle proprioception. AMA Arch. Ophth., 1959, 61, 230-232.

Woholwill, J.F. "Overconstancy" in space perception. In Lipsitt, L.P. and Spiker, C.C. (Eds.) Advances in Child Development and Behavior. Vol. I. Academic Press, New York, 1963.

Young, F.A. The projection of afterimages and Emmert's law. J. Gen. Psychol., 1948, 39, 161-166.

Young, F.A. Concerning, Emmert's law. Amer. J. Psychol., 1951, 64, 124-128.

Zajac, J.L. Spatial localization of afterimages. Amer. J. Psychol., 1960, 73, 505-522.

APPENDIX A

Data for Individual Subjects

FIGURE 8. INDIVIDUAL DATA FOR MALES WHO FORMED AFTERIMAGES AT 50 CM. DURING 1 ST. SESSION

(Each point is the mean for both formation distances).

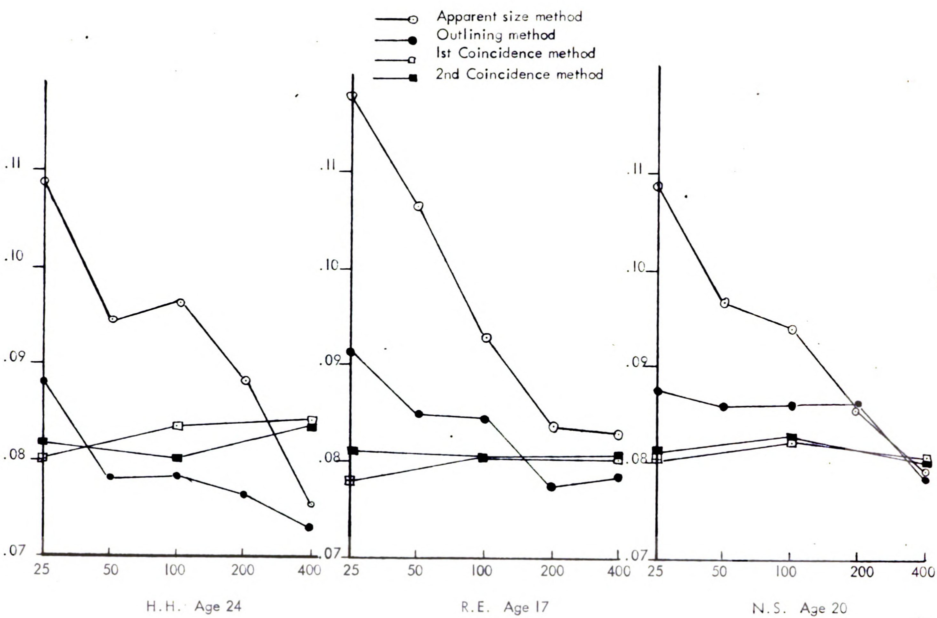

FIGURE 9. INDIVIDUAL DATA FOR FEMALES WHO FORMED AFTERIMAGES AT 50 CM. DURING 1ST SESSION

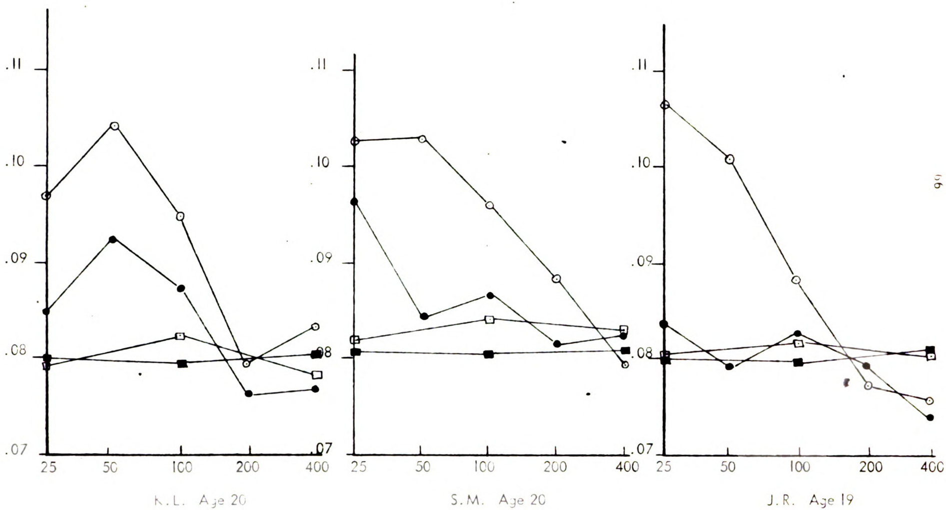

FIGURE 10. INDIVIDUAL DATA FOR MALES WHO FORMED AFTERIMAGES AT 200 CM. DURING 1ST SESSION.

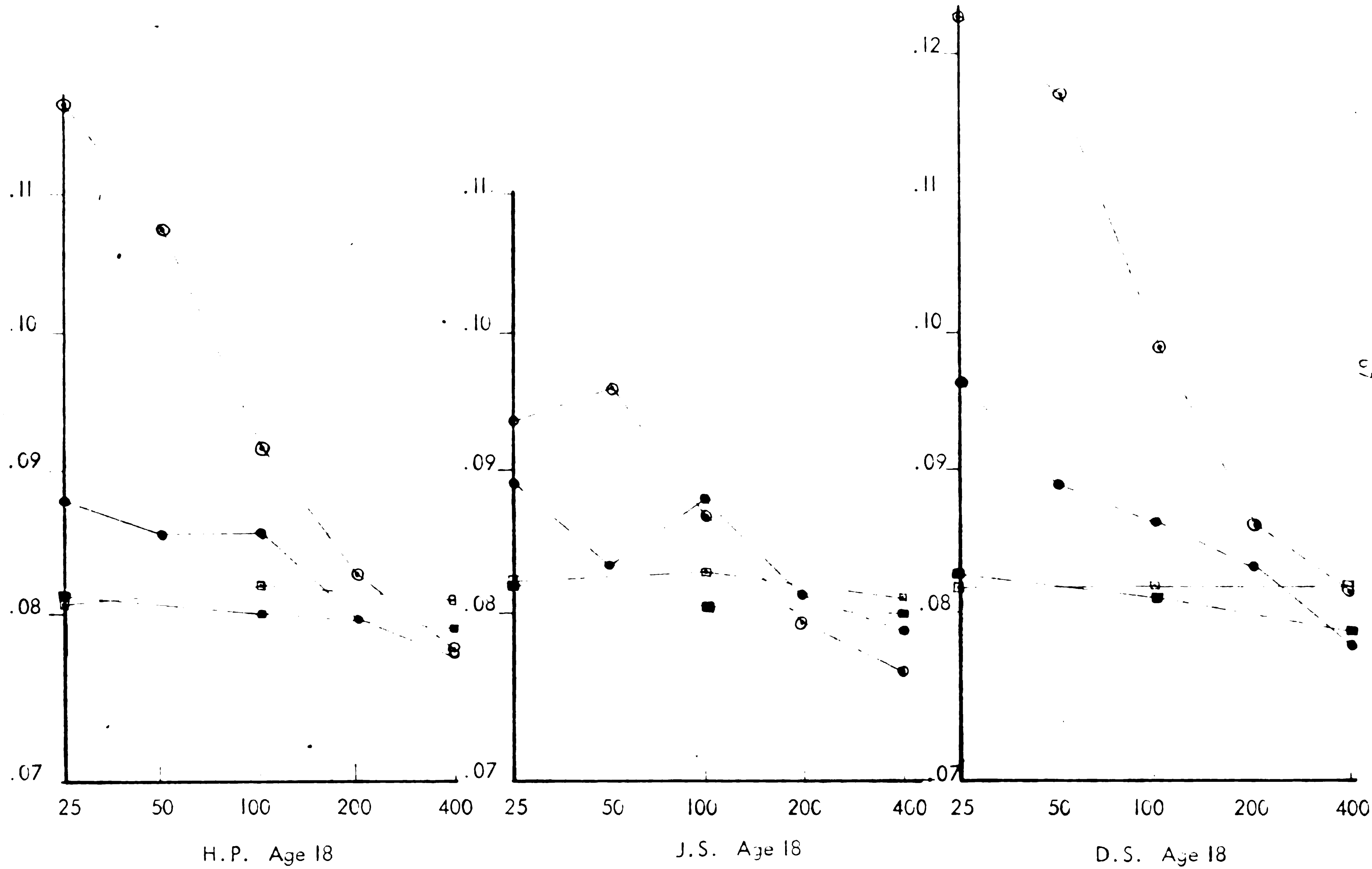

FIGURE II. INDIVIDUAL DATA FOR FEMALES WHO FORMED AFTERIMAGES AT 200 C.M. DURING 1ST SESSION