SOME THEORETICAL IMPLICATIONS REGARDING THE EFFECTS OF AGE AND PHYSICAL PARAMETERS ON THE DELBOEUF AND EBBINGHAUS ILLUSIONS

A Thesis

Presented to

The Faculty of Graduate Studies and Research

University of Manitoba

In Partial Fulfillment

of the Requirements for the Degree

of Master of Arts

by

Neil Butchard

March, 1976

"SOME THEORETICAL IMPLICATIONS REGARDING THE EFFECTS OF AGE AND PHYSICAL PARAMETERS ON THE DELBOEUF AND EBBINGHAUS ILLUSIONS"

by

NEIL BUTCHARD

A dissertation submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF ARTS

ABSTRACT

On the basis of developmental trends, illusions have often been categorized as Type I, which increase with age, and Type II, which decrease. The Delboeuf and Ebbinghaus illusions have traditionally been assigned to these two categories, respectively. However, studies of developmental trends for these two illusions have yielded contradictory results.

Examination of the available studies suggests that they can be ordered systematically by supposing the following: (1) Type I and Type II illusions correspond to the categories of assimilation and contrast illusions; (2) given specific physical parameters and age levels, both the Delboeuf and Ebbinghaus illusions can become assimilation <u>or</u> contrast illusions; and (3) age trends for each illusion reflect the development of one underlying process--a tendency to shift from assimilative to contrast-based perception.

In the present study an attempt was made to find if these suppositions were correct by testing the hypotheses that (1) both assimilation and contrast forms of both illusions should occur; and (2) similar age trends for each illusion should occur. Children of ages five and one-half, seven and one-half or nine and one-half years inspected a series of Delboeuf and Ebbinghaus illusions whose inducing circle sizes were varied. Subjects adjusted a comparison circle to match the perceived size of a test circle.

Children of all ages showed the normal or positive form of the two illusions. Younger children showed a significant contrast or negative form of the Ebbinghaus illusion, and older children, a

non-significant tendency toward the contrast form of the Delboeuf illusion. These results partially supported the first hypothesis. However, no age trends were found. The latter result, which did not support the second hypothesis, was attributed to differences in methodology used in the present study as compared to that used in other studies.

ACKNOWLEDGMENTS

The author wishes to thank Dr. R. Niemi for his expert guidance and untiring input, without which this thesis could not have been produced. I would also like to thank the members of my committee, Dr. L. Brockman, Dr. V. Di Lollo, and Dr. J. McIntyre.

Finally my love to Krista who did not get to see her daddy and Pam who did not get to see her husband.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

CHAPTER I

INTRODUCTION

A Brief Overview

One of the areas that has always intrigued those concerned with man's functioning is how he perceives the world around him. Special interest has been focused on those percepts where the subjective judgement does not coincide with the objective parameters. These percepts have been categorized as illusions and encompass a large range of phenomena. It has been felt that if one could understand these apparent anomalies in perception, a fuller and more comprehensive understanding of the general processes of perception could be produced.

Optical geometric illusions are one of the sub-groups of illusions which have been extensively investigated. These illusions consist of a number of line drawings which produce subjective distortions of size, length, or symmetry. Part of the reason they have commanded such a large share of the research on illusions is that the illusory figures are easy to produce and that illusion production is highly reliable. Another reason for their extensive use may be the fact that Piaget (1942, 1969) has made these figures an integral part of his theory of perceptual development.

Piaget (1942, 1969) has suggested that there are basically two types of illusions which can be separated on the basis of their developmental trends. The amount of Type I illusion or primary illusion increases with age, while the amount of Type II illusion or secondary illusion decreases with age. However, the results for the developmental trends in illusions are contradictory and confusing (Wohlwill 1968). It is with this confusion that the present study is concerned. For a discussion of the developmental trends for a large variety of illusions see Wohlwill (1968). Of particular interest here are two physically similar forms of the Type I and Type II illusions, the Delboeuf and Ebbinghaus illusions, respectively.

The Delboeuf illusion is shown in Figure 1. It consists of a test (T) circle surrounded by a larger inducing (I) circle. The T circle is usually judged against a comparison (C) circle. In this case the T circle is judged larger than its physical size. That is, it is judged to be closer in size to the I circle than it is physically. This phenomenon has been referred to as assimilation (Pressey, 1967, 1971). Changing the size of the I circle changes the judged size of the T circle. If we make the I circle large enough the T circle is judged to be smaller than its actual size. When this happens the figure is often referred to as the "negative Delboeuf". That is, the distortion of the T circle size seems to be in the opposite direction to normal.

The Ebbinghaus illusion or Titchner Circles is shown in Figure 2. It consists of a T circle surrounded by a number of larger I circles. The T circle is judged against a C circle. In the standard illusion the T circle is judged as being smaller than its physical size. That is, it is judged as being further in size from the I circle's size than it is physically. Note that although the Delboeuf and Ebbinghaus illusions have common physical features,

Fig. 1. The Delboeuf Illusion:

<u>A</u> the standard form,

<u>B</u> the negative form.

A

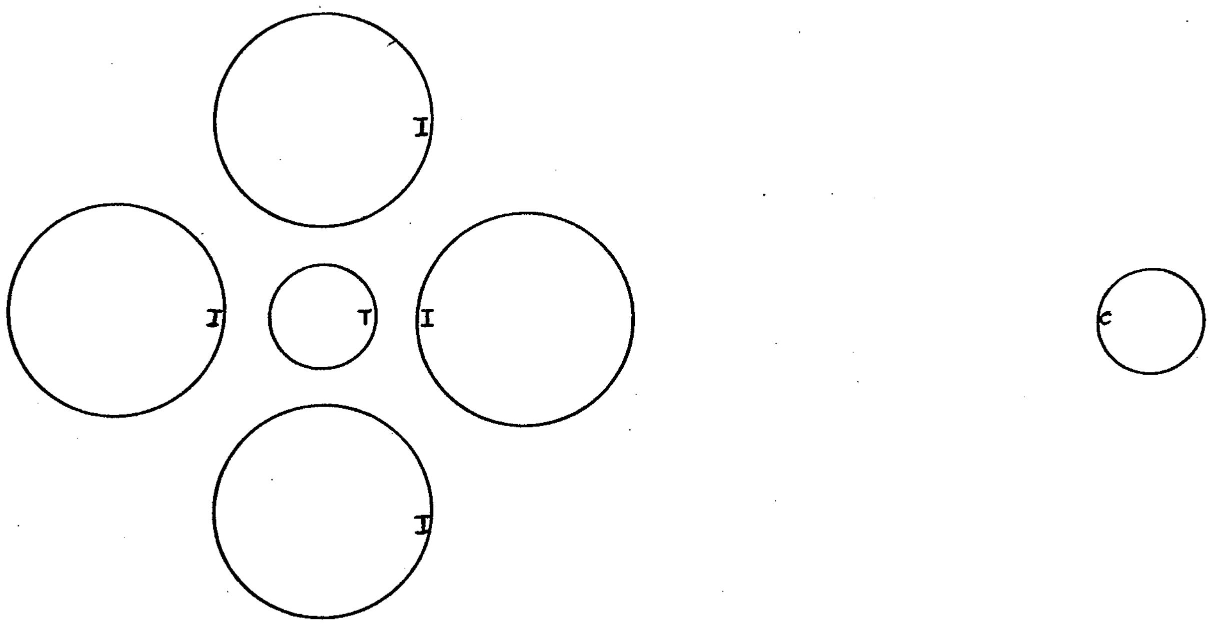
B

Fig. 2. The Ebbinghaus Illusion:

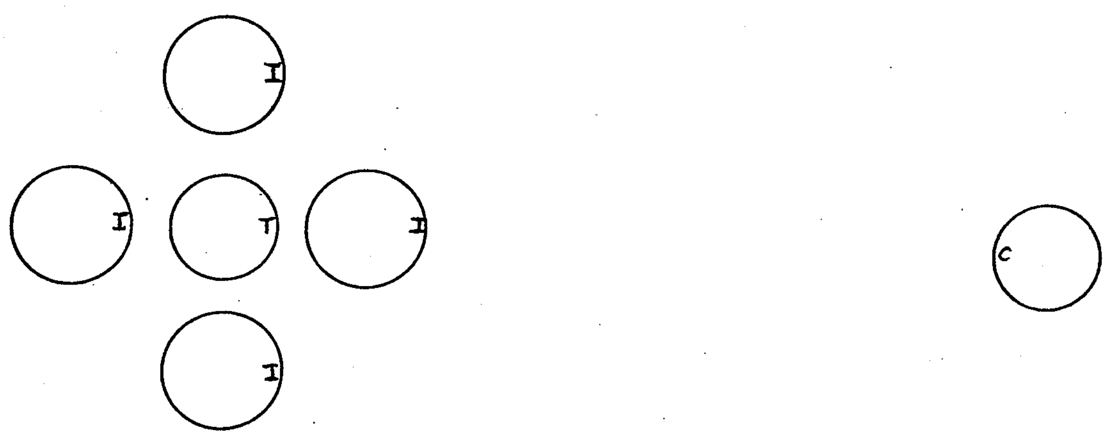
A the standard form

B the negative form.

A



B



the standard forms produce opposite effects on the judged size of the T circle.

Increasing the size of the I circle in the Ebbinghaus causes the illusory effect to increase in magnitude. There is some evidence that when the I circles are fractionally larger than the T circle young children will judge the T circle as being larger than it is physically. This effect does not appear in the judgements of adult subjects (Weintraub and Cooper, 1972). When it does occur in the judgements of young subjects it will be referred to as a negative Ebbinghaus illusion.

As pointed out earlier, there is considerable confusion in the literature with regard to developmental trends for illusions. Table 1 illustrates this point with respect to the Delboeuf and Ebbinghaus illusions. For example, with the standard Ebbinghaus two authors have found that the amount of illusion increases with age (Wapner and Werner, 1957; Weintraub and Cooper, 1972), while two other authors have found the amount of illusion to decrease with age (Russell, 1934; Sigurdson, 1972). For the positive Delboeuf illusion, where all the results are in the same direction, the amount of decrease in the illusion with age varies greatly among the studies.

A method which might help unravel the contradictions in the developmental studies is to consider a second classification system for illusions. The "Assimilation Theory of Illusions" (Pressey, 1967, 1971; Pressey <u>et al</u>., 1971) suggests that illusions can be classified as to the presence or absence of assimilation, of the

TABLE 1

Reported Age Effects for the Ebbinghaus and Delboeuf Illusions

TYPE OF AGE EFFECT

ILLUSION TYPE		Increase with age	No change	Decrease with age
DELBOEUF	Positive (assimilation)		Santostefano (1963)	Piaget (1942) Weintraub and Cooper (1972) Sigurdson (1972)
DELBOEUF	Negative (contrast)	Santostefano (1963)		Piaget (1942)
EBBINGHAUS	Positive (contrast)	Wapner and Werner (1957) Weintraub and Cooper (1972)	Russell (1934)	Sigurdson (1972)
EBBINGHAUS	Negative (assimilation)			Weintraub and Cooper (1972)

element to be judged, towards the inducing portion of the figure. In the case of the Delboeuf, when the T circle is judged to be closer in size to the I circle it is an assimilation illusion. When the reverse happens, that is, where the T circle is judged further in size from the I circle (smaller) than it really is, the illusion is classified as a contrast illusion. The Ebbinghaus falls into this category of illusion. Although the standard form of the Ebbinghaus is a contrast illusion, the negative form of the illusion is an assimilation illusion.

The categories of Type I and Type II illusions closely match the categories of assimilation and contrast illusions, respectively. It may be that when the I circle is changed to produce a negative Delboeuf, a developmentally different type of illusion is present. This would in part explain some of the confusing results.

Now suppose that each of the Type I and Type II illusions contain some Type I characteristics and some Type II characteristics at all times, but that one of the characteristics predominates. As we change the I circle size we change the relative amounts of Type I and Type II characteristics. We can expect apparently different developmental trends for the amount of illusion with different parameters of I circle size and subject's age.

This is exactly what was hypothesized in the present study. It was thought that the divergent results in the area can be explained by looking at the developmental trends as a function of age, the basic type of illusion, and the parameters used to produce that illusion. It was hypothesized that systematically varying these parameters would produce a clear series of developmental trends for the Delboeuf and Ebbinghaus illusions.

To understand fully the rationale and implications of the present study, it is necessary to review the relevant literature in the area. A discussion of the theoretical basis for both the developmental theories of illusions and the assimilation theory of illusions are presented first in order to provide an understanding of the theoretical frameworks used in developmental studies of illusions.

Following this are separate sections on the Delboeuf and Ebbinghaus illusions. In each section the parameters which affect the illusions are considered first. This provides an understanding of the range of stimuli being used in the developmental studies. Finally, the evidence presently available on developmental trends for both positive and negative forms of the illusions is presented. This is followed by an integration of the data presented in the previous sections and the rationale for the present study.

Developmental Differentiation of Optical Geometric Illusions

Binet (1895) carried out a study on the developmental changes in the Muller-Lyer illusion (Figure 1.1, Appendix 1). Using the method of constant stimulus he measured the amount of illusion for 60 children of nine years, and 45 children of 12 years. He found that the illusion decreased with increasing age. In his discussion of the findings he cited previous data which suggested that the size-weight illusion increased with age (Dressler, 1894). This led him to the conclusion that illusions could be classified into two groups on the basis of whether they increased or decreased with age. He further suggested that those which decreased with age such as the Muller-Lyer "are innate" while those that increased with age "are acquired".

Binet's concept of two distinct groups of illusions which could be separated by their developmental trends generated little research until Piaget (1942, 1969) began to reconsider the developmental properties of illusions. A study of the developmental trends for several illusions by Piaget (1942) supported Binet's concept of two developmentally distinct groups of illusions. Piaget, however, rejected Binet's concept that these illusion groups are innate and acquired. He alternatively suggested that Binet's "innate" group should be classified as "primary" (Type I) illusions, while his "acquired" group should be classified as "secondary" (Type II) illusions.

Some of the common Type I geometric illusions showing a decrease with age include the Muller-Lyer, Delboeuf, and the Sander Parallelogram. These three illusions are represented in Appendix 1 (Figure 1.1, Figure 1.2, and Figure 1.3, respectively). The Type II illusions are not as well represented among the optical geometric illusions but a few do show the standard increase in magnitude with age. These include the Oppol-Kundt and the Ebbinghaus which are represented in Appendix 2 (Figure 2.1 and Figure 2.2, respectively).

Piaget's choice of "primary" and "secondary" to express the two developmental groups of illusions, was based on what he felt are the underlying processes involved in the developmental changes. He felt that the primary illusions (which decrease with age) are viewed as "a single field effect" (Piaget, 1969, p. 3). That is, the illusion occurs because the figure is judged as a single unit and not as discrete parts. Support for this assumption was supplied by Piaget's studies which showed that the magnitude of primary illusions remained unaffected when presented for short periods of time in a Tachistoscope (T-scope). The time of presentation was so short that no visual exploration could occur. Piaget (1949, p. 14) defined the phenomenon, of "T-scope presentation of the stimuli .... which prevent visual exploration" as centration. Piaget (1969) also found that secondary illusions dissipated when they were presented in a T-scope. This led him to conclude that secondary illusions increase with age due to age-related increases in visual exploration and "couplings" (Piaget 1969, p. 69).

Piaget (1969) supported his concept of changes in centration and decentration with age by studying developmental changes in size of field of view and in subject's ability to concentrate on discrete visual area. He found that six year old children have a larger field of view (18.5 mm x 50.7 mm) than do adults (10.1 x 31.6 mm) when viewing a number of figures, such as verticals, horizontals and obliques. He further found that children cannot fixate on a given point for more than a very small fraction of a second while an adult can fixate for several seconds (Piaget, 1969, p. 138). These behaviours were taken to indicate that the child, due to his inability to fixate, combined with a tendency to attend to a large field, perceives figures wholistically. The adult, or older child who no longer utilizes this wholistic ability, view figures as discrete elements. This, for Piaget, explained why primary illusions decrease with age. That is, the wholistic type of percept, which Piaget assumed to be the basis of primary illusions, decreases with age. He further suggested that "a quantitative diminution of primary illusions .... are, indirect causes for fresh (secondary) illusions" (Piaget, 1969, p. 137). Although Piaget suggested that two processes function as the basis for the two illusion groups, he did not explain how they are related. He also did not state if the two processes can occur in the same illusion simultaneously. Although he did not deal with this question directly it may be inferred from his writings (Piaget, 1969) that he perceived the processes to be mutually exclusive and dependent on the figure being viewed.

A second system for describing illusions, which is relevant to the Delboeuf and Ebbinghaus illusions, is to classify the illusion by whether the element judged (T circle) is seen as being closer to (assimilation) or further from (contrast) its context (I circle). Until recently, this method has been purely descriptive. This descriptive dichotomy between assimilation illusions and contrast illusions has formed the basis for a sophisticated predictive theory of illusions (Pressey, 1967, 1971; Pressey _et al._, 1971). The theory makes the basic assumtion that an element such as the T circle is judged with respect to the other elements around it. In the case of the Delboeuf the T circle is judged as if it were on a set of circles, with itself and the I circle defining the two extremes of the set. Since the T circle is at the one extreme, the judgement of it is affected by the "tendency to the mean".

The Ebbinghaus illusion can also be thought of as a series of circles with the I and T circles defining the extremes. In this case, however, assimilation does not occur. Instead of producing a tendency to the mean the T circle is judged to be further from the mean in size than it is physically. The interesting fact about this method of classification is that the assimilation category closely matches Piaget's primary illusion category, while the contrast category matches the secondary category. It would be helpful to study what happens to the developmental trends of an assimilation illusion if it were to become a contrast illusion since it may developmentally behave as a Type I illusion.

<u>The Delboeuf Illusion</u>

<u>Physical parameters affecting the Delboeuf Illusion.</u> In order to understand the results from developmental studies of the Delboeuf, it is necessary to understand the effects of different parameters on the illusion, since different developmental studies have used varying illusion parameters.

The standard Delboeuf illusion (Figure I) consists of a T circle with an I circle which either surrounds the T circle or is inside the T circle. The T circle is judged against a C circle. The T circle is judged to be larger than its physical size when surrounded by a larger I circle.

Piaget et al., (1942) studied the effect of changing I circle size on the perceived size of the T circle. They used five T circle radii (9, 12, 15, 18 or 36 mm) while the I circle ranged from the same size as the T circle to 75 mm in one mm steps. Subjects judged the T circle against a single paired C circle. The authors used "about 100 children" in four age groups (5-6 years, 7-8 years, and 10-12 years) and a group of 30 adults. The results showed that an increase in the I circle size led to an initial increase in the perceived size of the T circle. A further increase of the I circle produced a decrease in the illusion until the illusion became negative. That is, as the I circle expanded beyond a certain point the assimilation effect on the T circle decreased and a contrast illusion was finally produced. Piaget et al., (1942) also found that the magnitude of changes in the illusion, produced by changes in the I circle size, decreased with age; however, the shape of the curve for amount of illusion as a function of the I circle size reamined the same between ages. From these results Piaget produced a predictive formula for the amount of illusion as a function of an I/T circle size ratio.

Keats (1964) used the method of paired comparisons to validate Piaget's formula for the Delboeuf illusion. He used a T circle of 1 1/32 ins. in diameter and had I circles of 9/8, 5/4, 3/2, 2, 3, and 4 times greater than the T circle. His stimuli can be thought of as a series of I circle size to T circle size ratios (I/T ratio). This allowed comparison of illusions using different T circle sizes.

Each of his I/T combinations was presented with a comparison circle circle ranging from 7/8 to 1¼ ins. in diameter by 1/12 in. steps. Presentation of the 42 stimuli, one card for each possible combination, was done in random order. The subject simply had to state whether the T or C circle was larger. A group of 64 adults was used. The case in which the I circle was two and four times larger than the T circle a reversal of the illusion was obtained (contrast). The maximum illusion was found at an I/T ratio of 3/2 as predicted by the formula. The fit with the predicted curve was fair. Keats suggested that this poor fit was partially due to the large steps in size of the C circle and suggested that use of smaller C circle steps would refine the fit.

These findings were supported in a study by Ikeda and Ohonai (1955). Using the paired comparison technique they presented stimuli in a T-scope for ½ sec. duration. Using five college students they obtained six estimates per subject for each stimulus configuration (T = 30 mm, I = 10, 15, 20, 40, 60 or 80 mm, C = 22 to 36 mm in 1 mm steps). In the case where I was twice as large as T, an assimilation illusion was found but when an I/T ratio of 8/3 was used, a contrast effect similar to that found by Keats (1964) was obtained. A contrast effect was also found for an I/T ratio of 3/1. They further found that a more or less symmetrical function developed on either side of the point where I = T. Thus it appears that a contrast illusion can be obtained using the Delboeuf figure if a large enough I circle is used. The finding of a maximal illusory effect occurring at an I/T ratio of

3/2 has been replicated by Weintraub *et al*., (1969), Ikeda and Obonai (1955) and Weintraub and Cooper (1972).

This maximal value of 3/2 also occurred in a study of the Delboeuf illusion performed by Morinaga (1935, cited in Oyama, 1960), who further found that an I/T circle ratio of 5 or 6 to 1 produces a contrast effect. Morinaga moved the I circle's centre in steps away from the T circle until the circumferences of the two circles just touched. He found a general decrease in the assimilation effect and the eventual production of a contrast illusion. The figure which produced a contrast illusion (the I circle beside the T circle) was in effect an Ebbinghaus illusion with only one I circle.

It is worth noting parenthetically that Weintraub *et al*., (1969) have performed several studies on the effects of figure contrast and of broken vs. solid lines for the I and T circles on illusory magnitude. Using the staircase method, described on page 18 of the present report, they found that reducing the luminous contrast, or breaking the lines of the I circle, caused a general decrease in the illusion over all I/T ratios. When the contrast of the T circle was decreased or its line was broken, a general decrease in the magnitude of the illusion occurred. This produced a contrast illusion with a smaller I/T ratio than normal (5/3 or 6/3). It appears that the judged size of the T circle is drawn closer to the physical size of the I or to the T circle depending upon which has the greater contrast or greater completion of lines. This effect decreases slightly with age (Weintraub and Cooper, 1972).

Developmental trends for the positive (assimilation) Delboeuf. The previously cited study by Piaget *et al.*, (1942) is one of the first studies in which age changes in the Delboeuf illusion were examined. Piaget suggested that although the magnitude of the positive Delboeuf decreased with age, the function of the I circle size to amount of illusion produced remained constant between ages. This conclusion was based on simple inspection of the data.

Santostefano (1963) conducted an investigation of the developmental trend for the positive and negative Delboeuf illusions. He used two positive illusions having T circles of 9 and 18 mm and I circles of 12 and 25 mm respectively. He also used two negative forms of the Delboeuf having T circles of 9 and 18 mm radius but this time having I circles of radius 45 and 55 mm respectively. He used ten boys and ten girls in each of three age groups (6, 9 and 12 years). Each subject judged whether or not the T circle was larger than the C circle. C circles ranged from 7 to 12 mm in $\frac{1}{2}$ mm steps for the nine mm T; and from 16 to 21 mm, in $\frac{1}{2}$ mm steps, for the 12 mm T. He then scored the responses as follows: If the judgement was in the expected direction it was given a value of plus one for each $\frac{1}{2}$ mm beyond the actual T circle size, and was given a value of minus one for each $\frac{1}{2}$ mm step judged in the opposite from expected direction. For example, with a nine mm T circle and the 12 mm I circle a response of larger for the T circle with respect to a 10 mm C circle was given a value of minus two. He then collapsed the scores for both positive illusions (T = 9 and

18 mm radii) and for the two negative illusions (T = 9 and 18 mm). This step was not justified as a $\frac{1}{2}$ mm change in the I circle for a T = nine mm is not proportionately equal to a $\frac{1}{2}$ mm change in the I circle for a T = 18 mm. It should be noted that this step may have increased the error variance and thus decreased the chance of a significant developmental trend being found.

For the positive illusion no significant age effect was found but a non-significant decreasing function for the amount of illusion by age was present. The lack of significance may have been due to the small sample size and the collapsing of the data.

Results for the negative illusion will be presented in a subsequent section.

Weintraub and Cooper (1972) conducted a further study of developmental trends for the Delboeuf. They also studied a figure they referred to as the "arc Delboeuf", (Figure 1.5, Appendix 1) and the Ebbinghaus illusion. They used 240 children equally divided among four age groups, 5, 7, 9 and 12 years, as well as an additional twenty college students. The T circle was 45 mm in diameter and the I circle 30 mm in diameter. The I and T circles presented were solid, broken or dotted lines of varying reflectance. Each I - T combination appeared on a card with a C circle which varied in size from 26 to 48 in $\frac{1}{2}$ mm steps. A group-modified (Hanley and Zerbolio, 1965) up and down "staircase method" (Cornsweet, 1962) was used. This method consisted of giving each subject only one judgement for each illusion. The next subject was given the card containing the same illusion with a larger or smaller C circle depending on the previous subject's response. That is, when a subject responded "smaller" to the C circle, the next subject received a C circle one size larger. This continued until a subject gave a response "larger". At this point the process was reversed. This created a situation in which the subjects' responses fluctuated aroung the group point of subjective equality. The use of this method removed two common errors, starting point error and error of the standard, (Hanley and Zerbolio, 1965). Its use, however, did not yield data that matched with more conventional methods and produced large variance (Wohlwill, 1968).

Weintraub and Cooper's (1972) results showed a significant decrease for the Delboeuf with age similar to that found previously by Piaget et al., (1942) and Santostefano (1963). Their results are, however, questionable since the I circle was inside the T circle, thereby creating a filled space illusion (Figure 1.4, Appendix 1). When a judgement was made of the T circle the distance across it was filled with the I circle causing it to appear larger than its actual size. This means that the observed developmental trends contained components from both the Delboeuf and filled space illusions.

Their data on the arc Delboeuf and the Ebbinghaus illusion will be presented later in the section on developmental evidence on the Ebbinghaus.

Sigurdson (1972) studied the effects of age on the standard Delboeuf. She used two age groups, (six-seven and eight-nine years), with 75 six-seven year olds and 74 eight-nine year olds. The T circle was 20 mm with I circles of 8 mm, 18 mm, 22 mm or 32 mm. There was a clear decrease in the illusion with age when the I circle was larger than the T circle, but a non-significant decrease in the illusion with age when the I circle was smaller than the T circle. This non-significant result may have occurred since a filled space illusion is produced when the I circle is smaller than the T circle.

In summary, the majority of evidence suggests that the positive Delboeuf illusion seems to decrease with increasing age but one study showed a non-significant trend.

Developmental trends for the negative (contrast) Delboeuf illusion. In some of the experiments on developmental trends for the positive Delboeuf, authors have also looked at the trends for the negative form of this illusion (Piaget, 1942; Santostefano, 1963).

Piaget (1942) found that with an I/T ratio of 3/1 he could produce a negative (contrast) Delboeuf. Using the subject group previously mentioned he found that the negative illusion decreased with age in the same way as the positive illusion. The data were not, however, subjected to any type of statistical analysis and presentation of the results was rather vague, making reliable inferences difficult.

Santostefano (1963) approached the problem by studying both a positive Delboeuf, using an I/T ratio of 4/3 and a negative Delboeuf, using an I/T ratio of 5/1. The results for the positive illusion have been cited earlier. For the negative illusion, an increase in strength was found with increasing age. This is in direct contradiction to Piaget's (1942) results. He further found a significant interaction between age and sex for the negative illusion but not one for the positive illusion.

Contradictory results suggest that this area could stand further investigation to determine whether the negative Delboeuf increases or decreases with increasing age.

The Ebbinghaus Illusion

Physical parameters affecting the Ebbinghaus illusion. The standard Ebbinghaus illusion, or Titchener circles, consists of a single T circle surrounded by a number of I circles (Figure 2). As for the Delboeuf, T circle size is compared to the size of the C circle. In the standard form of this illusion the T circle is judged to be smaller than its physical size if the surrounding I circles are larger than the T circle.

Only a small amount of work has been done on the effects of varying physical parameters for the illusion. Morinaga (1956, cited in Oyana, 1960) in his study of the Ebbinghaus found that the amount of illusion increased as the number of I circles increased. Also as the I circles were moved further away from the T circle the illusion decreased. He further found that removal of the same portions of the I circle which had been used by Weintraub and Cooper (1972) in their "arc" Delboeuf figure, caused no change in the illusory effect.

Massaro and Anderson (1971) have recently replicated the

Morinaga (1956) study. The method of comparison was used with randomized I/T pairs and a C circle ranging from 8.5 to 21.5 mm in $\frac{1}{2}$ mm steps. The standard T circles were 13 or 17 mm in diameter with I circles having values of plus eight, plus four, zero, minus four, or minus eight mm, in diameter difference from the T circle. There were two, four or six I circles surrounding the T circle. In the second experiment the authors varied the distance from the centre of the T circle to the perimeter of the I circle from 3 to 6, 12 and 24 mm. They presented each of the 32 stimulus figures to each subject, one for each combination of all possible combinations of the variables. All stimulus pairs, one I/T combination and a single value of C, were presented randomly to ten subjects four times in a session. A second session was held the following day. The authors found a linear increase in the illusion with an increase in the number of I circles and a general linear increase in illusion with an increase or decrease in the size of the I circles. A gradual decrease in the illusion was found as the I circles moved further away from the T circle. It should be noted that in no case was an assimilative illusion found. This result may have occurred since older subjects, such as the university students used in the study, show very weak assimilation effects. It may be possible to produce an assimilation illusion when younger subjects are used. In fact an assimilation Ebbinghaus illusion has been found by Weintraub and Cooper (1972). This effect will be discussed in a later section.

Developmental trends for the positive (contrast) Ebbinghaus illusion. Developmental work on the Ebbinghaus illusion has not been as extensive as the work on the Delboeuf. Russell (1934, cited in Wohlwill, 1960) used children from 4½ to 6 years of age as well as a group of adults. He found a small decrease in the illusion from 4½ to 6 years of age.

Wapner and Werner (1957) used children from 6 to 19 years in a developmental study of the Ebbinghaus illusion. A T circle of 16.5 mm in diameter was surrounded by five I circles of 25 mm in diameter. The I/T configuration was compared to a variable T circle (9 to 21 mm in .75 mm steps) surrounded by seven I circles of 9 mm in diameter. Using ascending and descending trials with the method of comparison they found a significant increase in the illusion with age. The increase, however, was fairly erratic. This may have been due to the fact that the standard illusion was measured against a second form of the illusion, whose T circle changed in size.

Weintraub and Cooper (1972) performed a study of developmental trends for the Ebbinghaus illusion in which, unlike the majority of studies so far discussed, rigorously controlled measures of the illusions were used. They used two forms of the Ebbinghaus, the first being the standard form with a T circle of 20 mm in diameter surrounded by four I circles of 40 mm in diameter, and an arc form which consisted of a T circle of 20 mm in diameter surrounded by four arcs. The arcs were produced by taking the standard Ebbinghaus figure and removing the outer 3/4 of them

(Figure 1.4, Appendix 1). These two figures were both compared against a C circle ranging from 15 to 25 mm by .5 mm steps. Comparisons were made using the group staircase method. Developmental trends were investigated by using 240 subjects who were divided equally between the four age groups of 5, 7, 9 and 12 years. A group of 20 university students was also included. The developmental curves obtained for the two forms of the illusion had the same logarithmic shape and differed only in their absolute values. The standard Ebbinghaus illusion was perceived as an assimilation illusion when viewed by five year old subjects, but was perceived as a contrast illusion when viewed by nine year old subjects. The arc form was strongly assimilative at five years and decreased in magnitude with increasing age, but never became a contrast illusion but levelled off well within the assimilation range.

Sigurdson (1974) studied the magnitude of the Ebbinghaus illusion as a function of age. She used a 20 mm T circle surrounded by five I circles with radii of 8 mm, 18 mm, 22 mm or 32 mm. Her results showed a decrease in the illusion with increasing age. This result is questionable since she collapsed her age groups for race, (Indian - white), environment, (rural - urban) and sex without considering interactions of these variables with age.

Although contradictory results are present with respect to the developmental trend for the positive Ebbinghaus illusion, inappropriate methodology and different stimulus parameters may account for some of this ambiguity. Further well-controlled studies would help to clarify the area. This could be accomplished by using an adequate range of both age and size of I circles. It would also be necessary to compare the T circle in the test target to a single C circle to avoid having the illusion judged against another form of the same illusion. If these precautions were exercised, a large enough subject sample was used, a clearer understanding of the developmental trends for the Ebbinghaus illusion would be obtained.

Developmental trends for the negative (assimilation) Ebbinghaus illusion. In only one study were the developmental trends of a negative Ebbinghaus illusion reported (Weintraub and Cooper, 1972). The method used has been presented in an earlier section. The negative Ebbinghaus showed a very rapid decrease with age and became a positive (contrast) illusion. This implies that the negative (assimilation) Ebbinghaus yields results which appear as if they were from a primary (Type I) illusion. A replication of this experiment would be of value and interest to see if the results are substantive.

Statement of the Problem

The data on developmental trends for the positive Delboeuf illusion are contradictory. Some tend to suggest that a decrease in the illusion occurs from childhood to adulthood (Piaget, 1942; Weintraub and Cooper, 1972; and Sigurdson, 1972). Santostefano's (1963) results do not support this contention but suggest that no age change occurred for some I/T ratios, while an increase with age occurred for other I/T ratios.

Age-related results for the Ebbinghaus illusion are also contradictory. Russell (1934) found that no significant age-related change occurred in the Ebbinghaus illusion, while Sigurdson (1974) found a decrease in the Ebbinghaus illusion with age. Sigurdson's (1974) results were supported by Weintraub and Cooper's (1972) data which showed a decrease, for an Ebbinghaus figure having a particular I/T ratio, as age increased. All of the remaining Ebbinghaus figures in the Weintraub and Cooper (1972) study increased with increasing age. Wapner and Werner (1957) have also found an increase in the Ebbinghaus illusion with increasing age.

Thus, there appears to be a great deal of confusion about the developmental trends for both the Delboeuf and Ebbinghaus illusions. Some of this confusion seems to result from the use of different I/T ratios. As Table I illustrates, this confusion regarding the direction of developmental trends for the Ebbinghaus and Delboeuf illusions may be clarified by grouping them into their standard and negative forms. If we hypothesize that assimilation illusions are equivalent to Type I illusions and that contrast illusions are equivalent to Type II illusions, we would predict that both the standard Delboeuf and the negative Ebbinghaus illusions (assimilation illusions) would show a decrease in magnitude with age. The standard Ebbinghaus illusion and the negative Delboeuf illusion (contrast illusions) will increase in magnitude with age. Table I shows that all but four studies (Russell, 1934; Piaget, 1942; Sigurdson, 1974; and Santostefano, 1963) fit into cells based on these predictions. Of these four studies, Sigurdson's (1972) study contains methodological problems which may have adversely affected her results. Piaget's (1942) results are also questionable since no statistical evaluation of the developmental trend was performed. The other two divergent results suggest that no change in illusory magnitude occurs with increasing age. Therefore, it appears that the classification of the Delboeuf and Ebbinghaus illusions into their standard and negative forms clarifies the direction of their developmental trends.

Recall that the standard Delboeuf illusion reaches a maximum at an I/T ratio of 3/2 (Piaget, 1942; Keats, 1964) and then decreases in size until it becomes a negative (contrast) illusion (Piaget 1942). This suggests that the Delboeuf may contain some assimilation characteristics and some contrast characteristics. As the I/T circle ratio becomes larger than 3/2, the contrast characteristics become more prevalent until they finally produce a contrast illusion.

The Ebbinghaus illusion also seems to occur in both the standard contrast form as well as the negative assimilation form (Weintraub and Cooper, 1972). The negative illusion quickly decreases with increased I/T ratio and soon becomes the standard (contrast) form.

The data thus suggest that both the Delboeuf and Ebbinghaus illusions can occur as either contrast or assimilation illusions under appropriate I/T ratios and appropriate age levels. That is, when the Delboeuf illusion having a large I/T ratio is viewed by older children, the negative (contrast) form will occur. When an Ebbinghaus illusion having a small I/T ratio is viewed by younger children, the negative (assimilation) form will occur. If the I/T ratio and viewing subjects' age is changed from these levels, the standard form of both the Delboeuf and Ebbinghaus illusions will occur. It appears that these two illusions are not of a fixed type -- contrast or assimilation illusion alone -- but may occur as either type of illusion. Since the change from one form of the illusion to the alternate form occurs gradually, we may hypothesize that the two illusions always contain both contrast and assimilation properties, regardless of the I/T ratio used. That is, both the Ebbinghaus and Delboeuf consist of the same illusory characteristics but their physical parameters set the relative amounts of contrast and assimilation at different levels.

If our hypothesis is correct we would expect that both illusions should show similar, if not identical age changes. This does not imply that the "effect" of the Ebbinghaus must decrease with increasing age because the Delboeuf decreases. What it does suggest is that if contrast effects become stronger with age and assimilation effect weaker, either illusion, Delboeuf or Ebbinghaus, should produce a greater contrast effect with increasing age.

This effect can be demonstrated by a set of hypothetical developmental data for both the Delboeuf and Ebbinghaus illusions (see Figure 3.1, Appendix 3). Both illusions consist of a 20 mm T circle with either a 30 mm or 80 mm I circle(s). At age one the I = 30 mm Delboeuf illusion has its T circle judged as much larger than its 20 mm size. The judged size of the T circle decreases as age increases, but the negative form of the illusion does not occur. In the case of the I = 80 mm Delboeuf illusion the negative form of the illusion is perceived by subjects at age three, while the positive form of the illusion is still seen by the youngest subjects (age one).

The T circle for the I = 30 mm Ebbinghaus illusion is perceived by the age one subjects as larger than its physical size (negative form of the illusion). The subjects at age three, however, judge the T circle as smaller than its physical size (positive illusion). When the I = 80 mm Ebbinghaus is used, all subjects judge it as the positive form of the illusion, with older subjects showing a stronger illusory effect (a smaller T circle size judgement).

Briefly to recapitulate, there are three major propositions: first, both positive and negative forms of the Delboeuf and Ebbinghaus illusions can be produced; secondly, that both the Ebbinghaus and Delboeuf illusions are due to a mixture of varying amounts of contrast and assimilation effect; thirdly, if the two illusions both contain varying amounts of contrast and assimilation effect, we would expect the age trends for the Ebbinghaus and Delboeuf illusions to be similar.

The present study was designed to evaluate these hypotheses by presenting Delboeuf and Ebbinghaus illusions, having various I circle sizes, to children of different ages.

CHAPTER II

METHOD

Subjects

Subjects consisted of 120 children, equally divided among three age groups of five and one-half, seven and one-half, and nine and one-half years. All subjects were from the Winnipeg school system. They were all drawn from a single school so that they had roughly the same socio-economic level and ethnic background. Each age group consisted of 20 males and 20 females. Five and one half, seven and one half, and nine and one half year old groups were chosen since Cooper et al. (1972) and Murray (1965) have suggested that the major illusory developmental trends occur between five and nine years of age.

Apparatus

The stimulus materials were drawn with black ink on 10 x 10 inch white cards. There were four variations of the Delboeuf illusion and four variations of the Ebbinghaus illusion. Specifically, for each card, a standard test circle 20 mm in diameter was paired with an inducing circle which could be either 23, 29, 41 or 65 mm in diameter. In addition, four control cards were included which contained only the 20 mm test circle. All figures were drawn at the centre of the stimulus cards. For illustration of the control, Delboeuf and Ebbinghaus stimuli, see Figures 3, 4, and 5 respectively.

The apparatus for measuring illusory magnitude consisted of an oscilloscope which displayed a circle on the screen. The size

Fig. 3. The control stimuli (actual size).

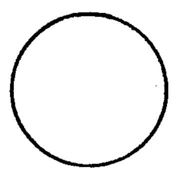


Fig. 4 The four Delboeuf Illusion stimuli
(1/3 actual size).

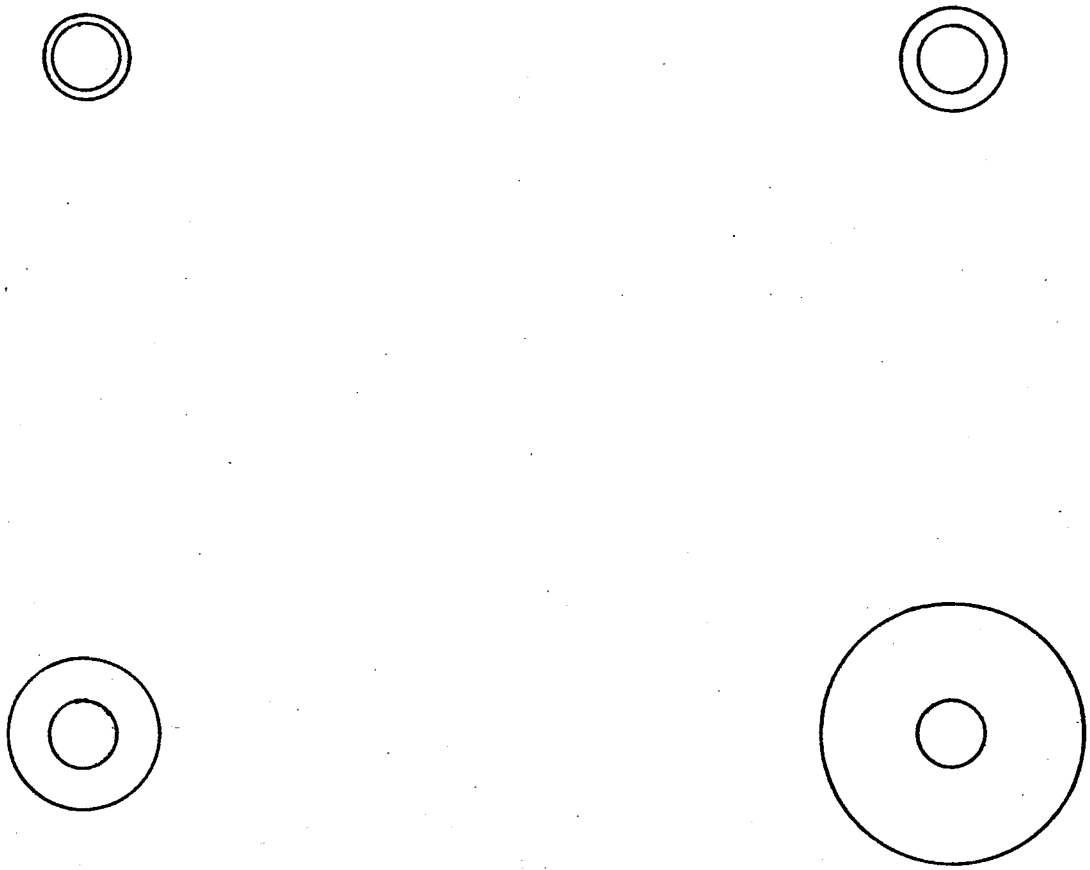
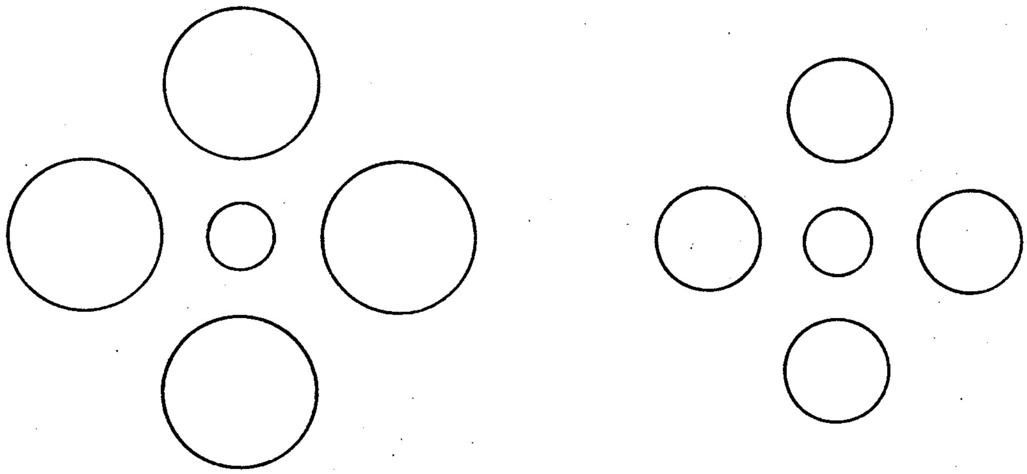
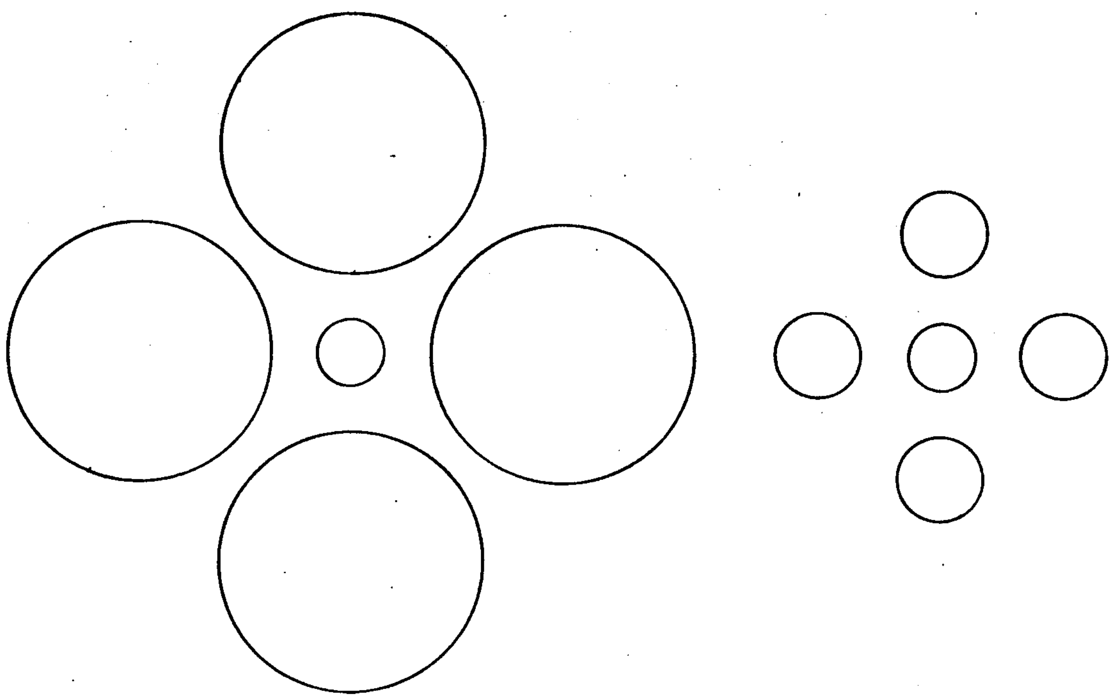


Fig. 5. The four Ebbinghaus Illusion stimuli
(1/3 actual size).





of the circle could be changed by changing the voltage supply to the oscilloscope from the audio generator. The subject adjusted the voltage by turning a potentiometer on the voltage supply. The actual size of the circle produced by the subject could be read directly from the potentiometer. The subject's distance from the screen was held approximately constant at a distance of 24 in. by having them sit straight in a chair which was placed at a fixed distance from the apparatus.

Procedure

Four independent variables were employed in this experiment. The variables were: age ($5\frac{1}{2}$ years, $7\frac{1}{2}$ years, and $9\frac{1}{2}$ years), sex, type of illusion (Delboeuf and Ebbinghaus), and size of inducing circles (23 mm, 29 mm, 41 and 65 mm). The type of illusion and size of the inducing circle were within subject variables, while age and sex were between subject variables. There were, then, three age groups, each with 20 male and 20 female subjects.

All subjects received 12 targets consisting of four control targets and four I variant targets for each of the two illusions. The targets were presented in a totally random order which varied from subject to subject. Presentation rate was subject-paced.

The instructions to subjects were uniform across age groups. It is known that analytic instructions[1] have an effect on illusion size (Virus, 1967). Since analytic instructions might be interpreted

[1]Analytic instructions are instructions where the subject is asked to make the C circle actually the same size as the T circle instead of making the two circles appear the same size.

differently by subjects of different age levels, they were avoided. Analytic instructions such as "make these two circles the same size", were avoided in favour of the instructions "make these two circles look the same size". The subjects were asked to repeat the instructions to ensure they had understood. They were also requested, after they had completed the task, to indicate which circle they had made look like the comparison (C) circle. This was done in order to avoid the possibility of the younger subjects making the C circle the same size as the I circle in the Delboeuf illusion.

Because previous experimentation with the present apparatus (Sigurdson, 1974) showed that a training procedure was required with young subjects a similar training procedure was used in the present study. The C circle was set at 20 mm and the experimenter demonstrated to the subject how turning the dial could make the C circle larger or smaller. The subject was allowed to practise turning the dial until he or she could execute four consecutive demands either to increase or decrease the circle size.

A transparent plastic template, consisting of a series of concentric circles, having diameters of 10, 15, 20, 25, 30 or 35 mm, was placed on the face of the oscilliscope. The subjects were required to adjust the dial for two ascending and two descending trials in order to match the produced circle to one of the circles on the plastic template.

The subjects were then required to make judgements of the control stimulus, with the experimenter providing feedback as to the accuracy of their performance. There was a maximum of six practice trials (three ascending and three descending).

The test stimuli were presented in a totally random fashion with the only restriction being that for any given subject not more than two control targets could appear in sequence.

For every trial the readout representing each subject's T circle estimate was recorded. Each dial reading constituted a raw score.

CHAPTER III

RESULTS

For each subject there were 12 raw scores, one for each of the eight test targets and four control targets. Each score consisted of the mean of an ascending and descending trial for each of the 12 targets. These 12 subjects' scores were then converted to eight derived scores by a two step process. First a constant was added to each of the 12 scores to correct for changes in equipment calibration due to heating. The constant was obtained just prior to experimentation with each subject by matching the C circle to the standard 20 mm template circle, and recording the dial value. The difference between this reading and the correct reading of 2.50 was added to each of the judgements made by that subject. That is, if the standard circle of 20 mm required a dial reading of 2.63, then a constant of -0.13 was added to each of the scores obtained for that subject.

A second constant was added to each of the eight test target scores. This constituted a correction for each subject's ability to reproduce the standard (control) circles correctly. The correcting constant was produced from a mean of the subject's four control target scores. The difference between this value and the actual 20 mm standard was added to each subject's judgements for the eight test target scores. That is, if the subject's mean score for the four control circles was 24 mm, -4 mm was added to the judgements for each of the test targets.

The conversion of dial readouts to mm judgements was left until after the analysis had been completed. This was done in order to minimize rounding error. The conversion from dial reading to circle size in mm was accomplished by use of a conversion table (see Appendix 4). This table was constructed from average dial readings required to produce standard size circles of 10, 20, 30 and 40 mm.

The mean judgement score for each of the 48 x sex x illusion type x I circle size cells is presented in Appendix 5 to provide the reader with an overview of the data prior to analysis. Main and supplementary analysis were conducted on these data as given below.

Main Analysis

A mixed factorial analysis of variance was conducted on the derived scores above. The design contained two between factors, age (three levels) and sex (two levels) and two within factors, illusion type (two levels) and inducing (I) circle size (four levels). There were 20 subjects in each of the age x sex cells. The results of the analysis are summarized in Table 2. It will be convenient to describe the results in terms of those factors which had either statistical or theoretical significance, as follows:

Size of inducing circle. Figure 6 demonstrates the effect of the I circle size on the judged magnitude of the T circle. The figure suggests that initially, as I circle size increased, apparent T circle size increased. Further I circle increases produced apparent decreases in the T circle size. The main

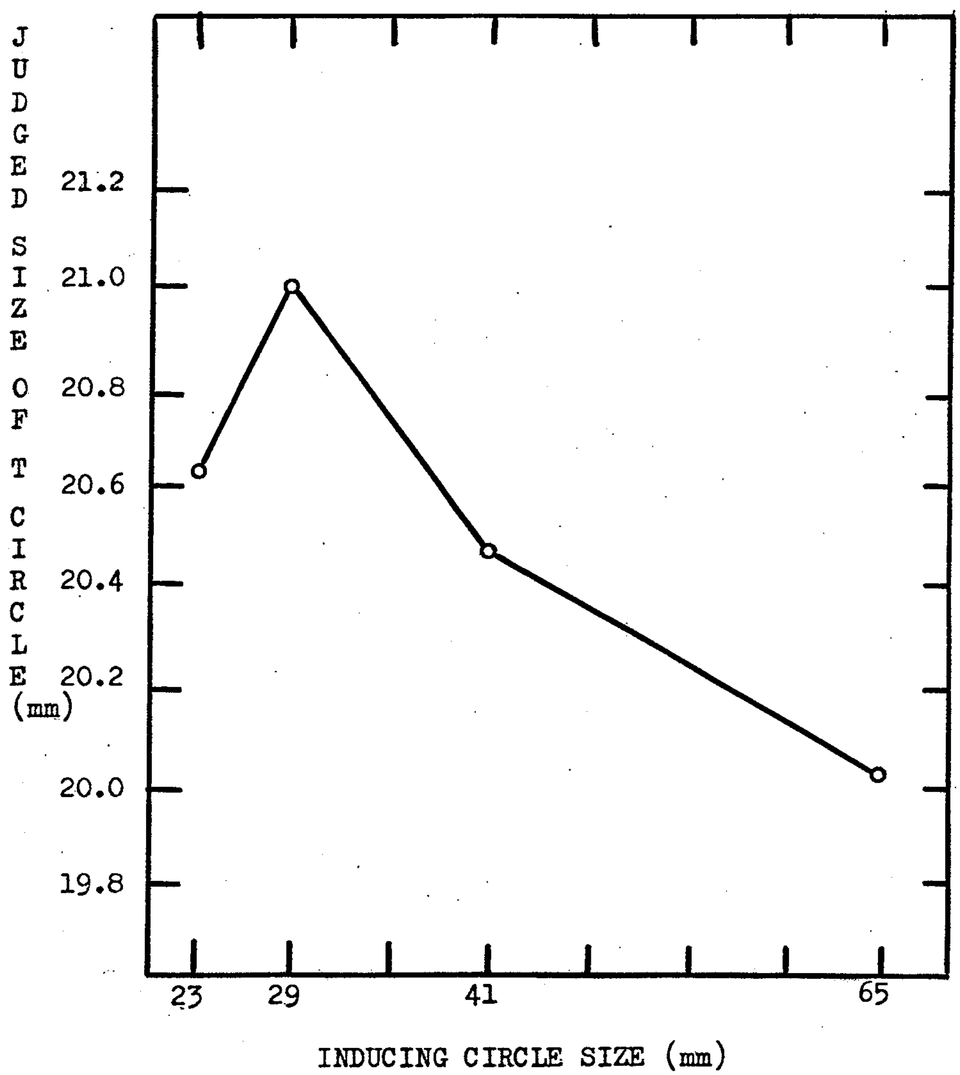
TABLE 2

MAIN ANALYSIS OF VARIANCE FOR ILLUSION SIZE

SOURCE	df	SS	MS	*F*
SEX (S)	1	0.0342	0.0342	0.368
AGE (A)	2	0.1074	0.0537	0.578
S x A	2	0.0049	0.0024	0.026
SUBJECTS WITHIN GROUPS	114	10.5981	0.0930	
ILLUSION TYPE (I)	1	1.1035	1.1035	44.601***
S x I	1	0.0582	0.0582	2.356
A x I	2	0.3174	0.1587	6.414**
S x A x I	2	0.1108	0.0554	2.243
I x SUBJECTS WITHIN GROUPS	114	2.8206	0.0247	
I CIRCLE SIZE (C)	3	1.7432	0.5811	18.249***
S x C	3	0.2217	0.0739	2.324
A x C	6	0.3369	0.0562	1.764
S x A x C	6	0.1318	0.0220	0.690
C x SUBJECTS WITHIN GROUPS	342	10.8892	0.0318	
I x C	3	0.6982	0.2327	6.408**
S x I x C	3	0.0244	0.0081	0.224
A x I x C	6	0.2344	0.391	1.076
S x A x I x C	6	0.0635	0.0106	0.291
I x C x SUBJECTS WITHIN GROUPS	342	12.4211	0.0363	

** $p < 0.01$
*** $p < 0.001$

Fig. 6. Judged size of T circle as a function of the size of inducing circle (Delboeuf and Ebbinghaus illusions combined).


JUDGED SIZE OF T CIRCLE (mm)
21.2
21.0
20.8
20.6
20.4
20.2
20.0
19.8
23
29
41
65
INDUCING CIRCLE SIZE (mm)

analysis of variance showed that the main effect for I circle size was highly significant ($F = 18.249$, $p < 0.001$).

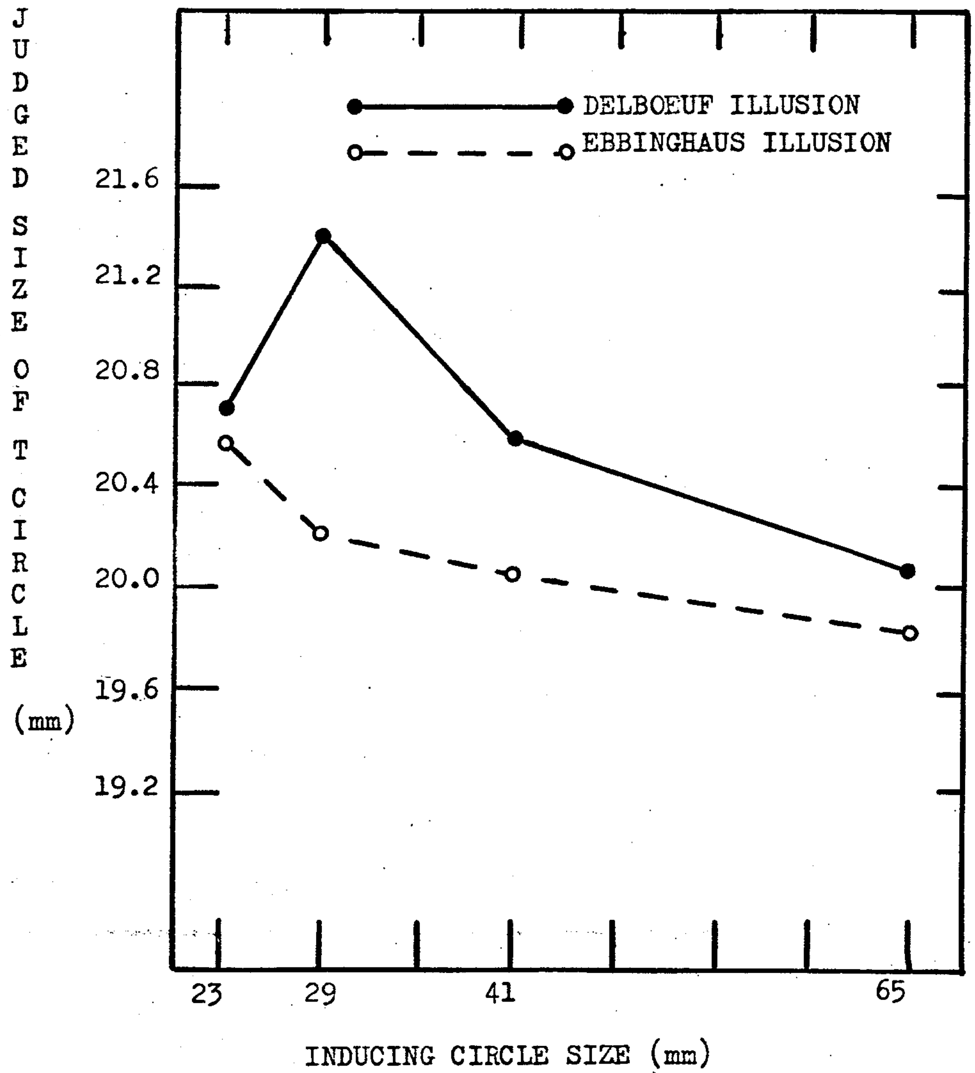
Age. The mean judgement of the T circle was 20.42, 20.43, and 20.36 mm for the five and one-half, seven and one-half, and nine and one-half age groups, respectively. This suggests that increasing age was associated with a very slight decrease in the perceived size of the T circle. More precisely, the perceived size of the T circle for the two younger age groups was virtually identical, while the oldest age group showed a slight decrease from the level of the first two points. The fact that such small differences occurred among these points suggests that the main effect for age would not be significant. These small decreases in fact yielded a non-significant main effect for age in the analysis of variance ($F = 0.578$, $p > 0.10$).

Sex. Inspection of the data suggested that no sex effect had occurred. The analysis of variance corroborated this impression ($F = 0.368$, $p > 0.10$). Any sex-related effects have not been presented graphically and will not be discussed further.

Type of Illusion. The difference in judged size of the T circle for the two illusions is graphically presented in Figure 7. As can be seen from the figure, the judged size of the T circle for the Delboeuf was higher in value for all I circle sizes than for the Ebbinghaus. This difference seemed to be both consistent and large. In support the main analysis yielded a highly significant main effect for illusion type ($F = 44.60$, $p < 0.001$).

The figure further suggests that there was a difference in

Fig. 7. Judged size of T circle as a function of inducing circle size for the Delboeuf and Ebbinghaus illusions.


JUDGED SIZE OF T CIRCLE (mm)
21.6
21.2
20.8
20.4
20.0
19.6
19.2
DELBOEUF ILLUSION
EBBINGHAUS ILLUSION
23
29
41
65
INDUCING CIRCLE SIZE (mm)

either the shapes or the slopes of the curves, for the Delboeuf and Ebbinghaus illusions. In general support the analysis yielded a significant illusion by I circle size interaction ($\underline{F}$ = 6.414, $\underline{p} < 0.001$). Supplementary analysis to determine if the interaction reflected a difference in shape or slope of the curves is considered a little below.

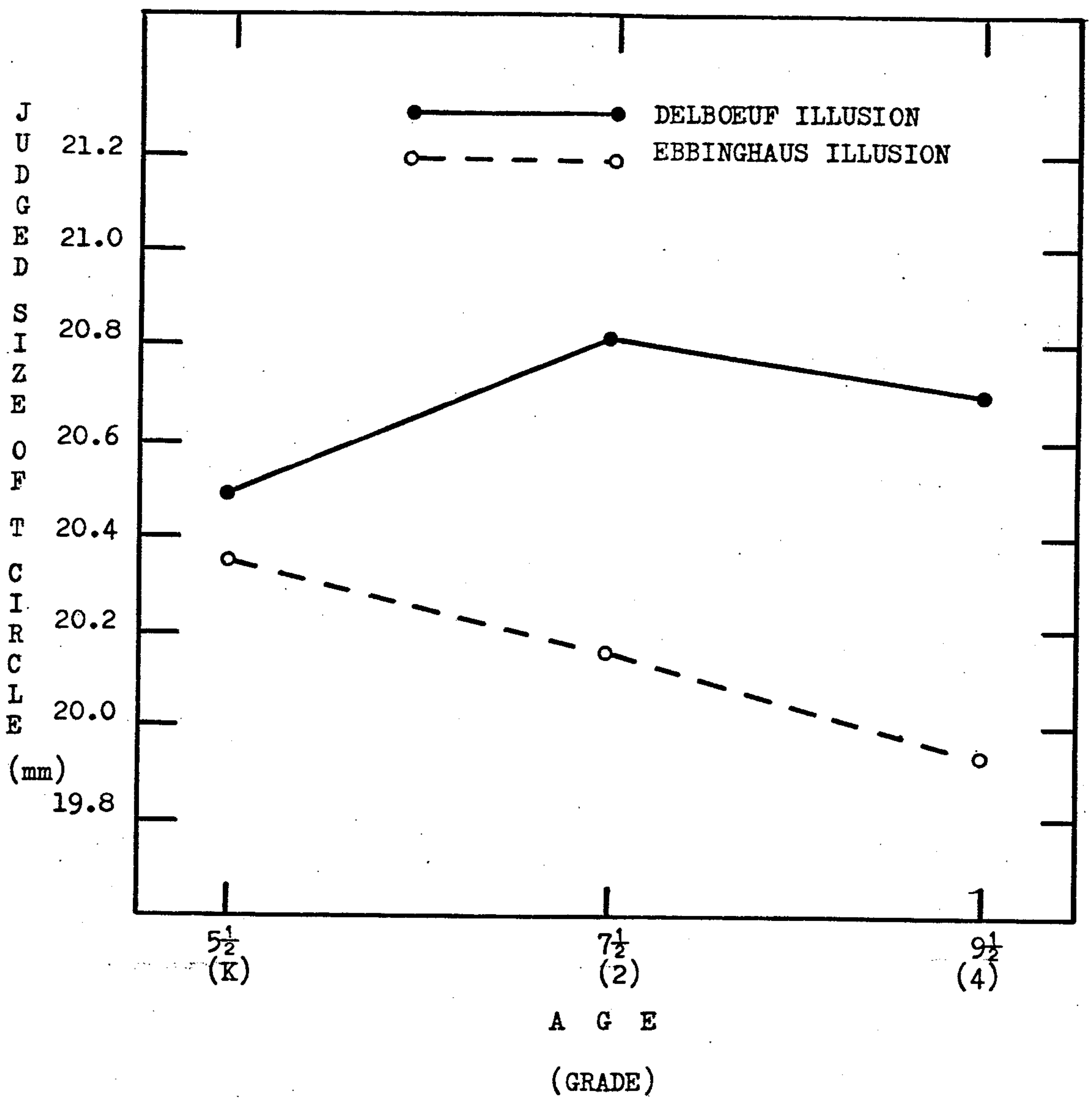
Figure 8 shows the judged size of the T circle as a function of the three age levels, for each of the two illusions. The figure suggests that increasing age affected the strength of the two illusions differently. This was corroborated by a significant age x illusion type interaction ($\underline{F}$ = 6.414, $\underline{p} < 0.001$). Since this interaction was of theoretical importance for the present study, subsequent analysis, reported below, was conducted to determine what type of differences accounted for the interaction.

It was also decided _a priori_ to do a Dunn multiple t-test with respect to the largest and smallest T circle estimates for both types of illusions, in order to determine if each illusion showed both its positive and negative form.

Supplementary Analysis

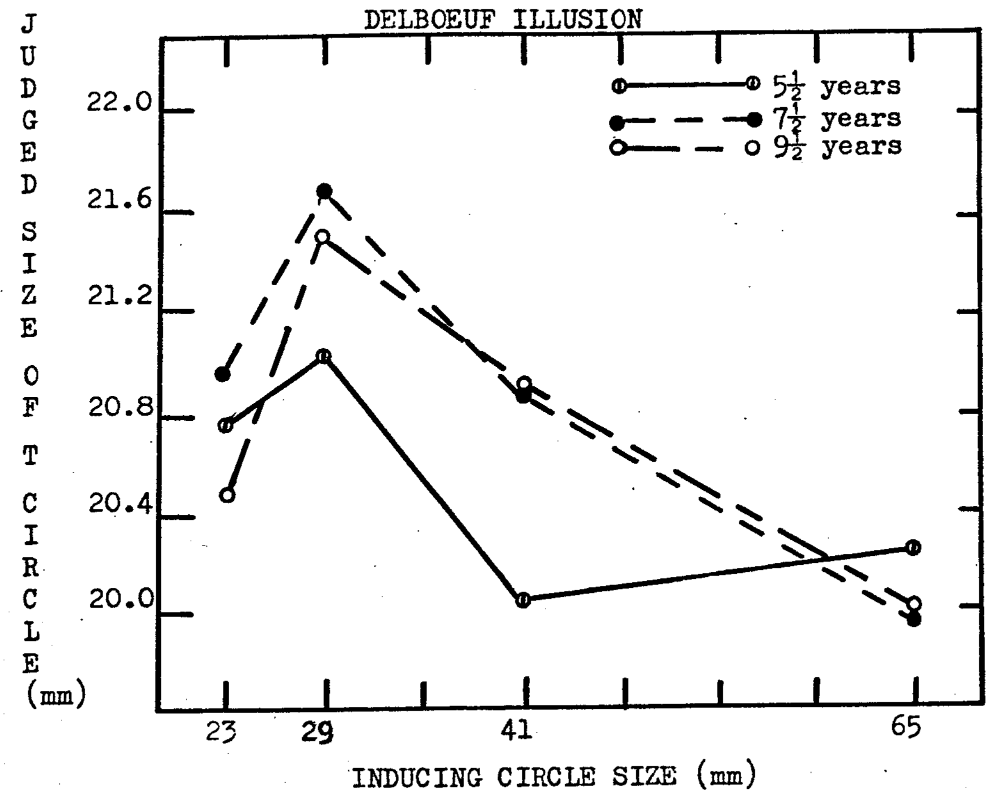
Illusion type x I circle size interaction. The main analysis of variance (Table 2) yielded a significant illusion type effect, a significant I circle size effect, and a significant interaction between these two variables. Figure 9 illustrates these effects graphically. It appears that the magnitude of the Ebbinghaus linearly decreased as the I circle size increased. The Delboeuf, however, appeared to be an inverted U function of the judged size

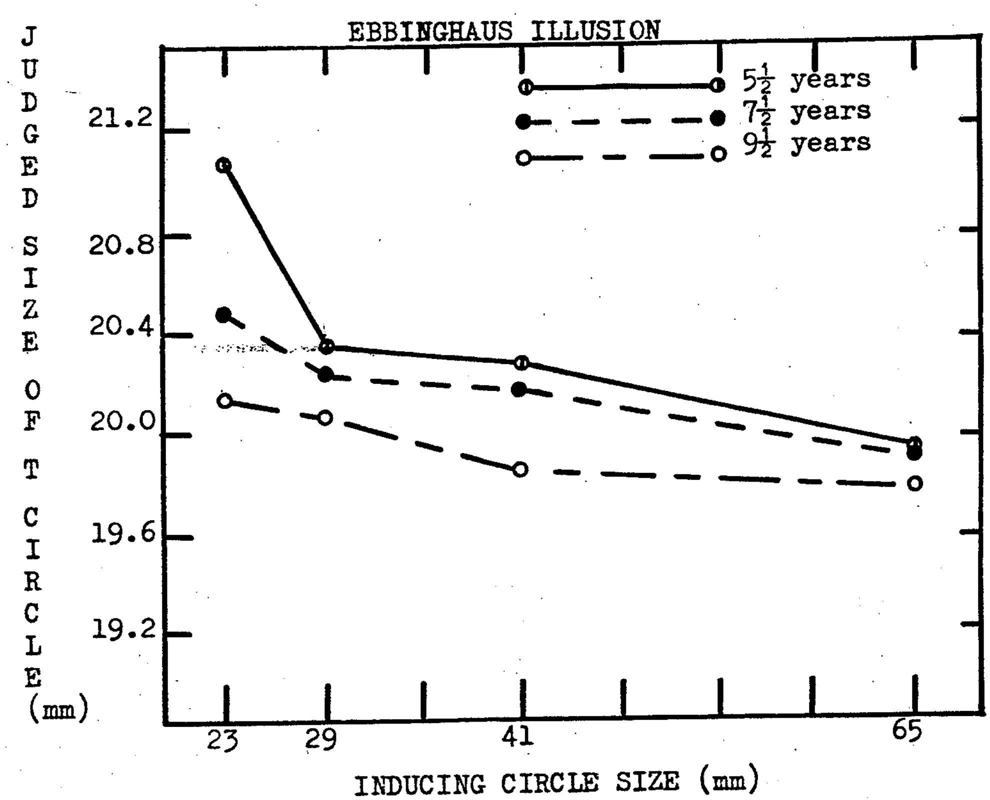
Fig. 8 . Judged size of T circle as a function of age for the Delboeuf and Ebbinghaus illusions.



DELBOEUF ILLUSION
EBBINGHAUS ILLUSION
JUDGED SIZE OF CIRCLE (mm)
21.2
21.0
20.8
20.6
20.4
20.2
20.0
19.8
5½ (K)
7½ (2)
9½ (4)
AGE
(GRADE)

Fig. 9. Judged size of T circle as a function of age and inducing circle size for the Delboeuf and Ebbinghaus illusions.


DELBOEUF ILLUSION
JUDGED SIZE OF T CIRCLE (mm)
22.0
21.6
21.2
20.8
20.4
20.0
5½ years
7½ years
9½ years
23
29
41
65
INDUCING CIRCLE SIZE (mm)


EBBINGHAUS ILLUSION
JUDGED SIZE OF T CIRCLE (mm)
21.2
20.8
20.4
20.0
19.6
19.2
5½ years
7½ years
9½ years
23
29
41
65
INDUCING CIRCLE SIZE (mm)

of T circle by size of I circle. Since both illusions produced an apparent decrease in the perceived size of the T circle with increasing I circle size, it was hypothesized that the significant interaction was due to the differing shape of the two curves. In order to understand the trend components of each of the illusion curves, a trend analysis was performed on both illusion types. Table 3 summarizes the results. The Ebbinghaus showed a significant linear component ($F = 5.530$, $p < 0.05$) but non-significant cubic or quadratic components. The Delboeuf in contrast had both significant linear and cubic components ($F = 9.560$, $p < 0.01$, $F = 5.832$, $p < 0.05$, respectively), while the quadratic component was non-significant ($F = 3.586$, $p > 0.05$).

These results indicate that changing I circle size affected the two illusions differently with respect to the shape of the T circle - I circle function each illusion produced. This differential effect of equal I circle size changes may have been due to the fact that the Ebbinghaus had four surrounding I circles, while the Delboeuf had only one.

Age x illusion type interaction. Recall that the significant age x illusion type interaction ($F = 6.414$, $p < 0.05$) indicated that increasing age affected the magnitude of the two illusions differently. Figure 8 suggests that the magnitude of the Delboeuf illusion increased from kindergarten to grade two, but remained virtually constant from grade two to four. The Ebbinghaus, however, seemed to show a linear decrease from kindergarten to grade four. In order to determine if these particular effects had occurred,

TABLE 3

TREND ANALYSIS FOR THE DELBOEUF ILLUSION

SOURCE	SS	df	MS	F
LINEAR	0.9271	1	0.9271	9.560**
CUBIC	0.5655	1	0.5655	5.832*
QUADRATIC	0.3477	1	0.3477	3.586
SS Age x Ss w groups	11.0580	114	0.0970	

TREND ANALYSIS FOR THE EBBINGHAUS ILLUSION

SOURCE	SS	df	MS	F
LINEAR	0.5363	1	0.5363	5.530*
CUBIC	0.0060	1	0.0060	0.062
QUADRATIC	0.0029	1	0.0029	0.030
SS Age x Ss w groups	11.0580	114	0.0970	

*$p < 0.05$
**$p < 0.01$

a split plot analysis of variance was conducted on the six age x illusion type cells (Table 4).

As hypothesized, the estimated T circle sizes for the Delboeuf and Ebbinghaus were not significantly different at the kindergarten level ($\underline{F} = 0.781$, $\underline{p} > 0.10$) but were significantly different for both grades two and four ($\underline{F} = 24.253$, $\underline{p} < 0.001$, and $\underline{F} = 29.419$, $\underline{p} < 0.001$, respectively).

An apparent anomoly is worth discussing at this point. Although the overall age effect for each illusion was not significant, a significant age x illusion interaction did occur. The significant interaction was due to the significant difference between the values of Ebbinghaus illusion and the Delboeuf illusion for grade two and grade four. It may seem discrepant that the difference between the Delboeuf and Ebbinghaus illusions at grades two and four were significant while the difference between the Delboeuf at kindergarten and at grade two or four was not significant, since both of these differences were of approximately equal value. However, the difference between the two illusions was a within subjects factor, while the age differences for the Delboeuf (kindergarten compared to grade two or four) was a between subjects factor. The between subjects variance was much larger than the within subjects variance. This produced a situation in which differences of the same magnitude caused a significant interaction effect, but not a significant age effect.

<u>T-tests</u>. As previously noted, it was <u>a priori</u> decided to do four t-tests to determine if both positive and negative forms of

TABLE 4

SPLIT PLOT ANALYSIS OF VARIANCE OF AGE BY ILLUSION TYPE INTERACTION

SOURCE	SS	df	MS	F
BETWEEN AGE FOR DELBOEUF	0.12768	2	0.06384	1.085
BETWEEN AGE FOR EBBINGHAUS	0.18824	2	0.09412	1.599
WITHIN CELL			0.05885	
WITHIN SUBJECTS				
WITHIN ILLUSION @ AGE 1	0.01530	1	0.01530	0.781
WITHIN ILLUSION @ AGE 2	0.47526	1	0.47526	24.263***
WITHIN ILLUSION @ AGE 3	0.57624	1	0.57624	29.419***
AGE x ILLUSION	0.31740	2	0.15870	8.102**
ILLUSION x SUBJECTS WITHIN GROUPS	2.83060	144	0.01959	

** $p < 0.01$
*** $p < 0.001$

each illusion occurred. This was accomplished by performing a t-test on both the largest and smallest T circle estimates obtained for the levels of I circle size and age. Figure 9 shows the three age-related curves for each of the illusions. The two points picked for t-tests on the Delboeuf were nine and one-half years, I circle size = 65 mm for the lowest point, and seven and one-half years, I circle size = 29 mm for the largest value. For the Ebbinghaus the largest value used was at five and one-half years, I circle size = 23 mm, while the largest value was at nine and one-half years, I circle size = 65 mm. The overall significance level was set at 0.05, dictating a significance level of 0.0125 for each of the four t-tests.

The t-test for the highest value of the Delboeuf was significant ($t = 35.508$, $p < 0.01$) indicating that the positive form of the Delboeuf was produced. The t-test for the lowest value was not significant ($t = 1.401$, $p > 0.10$). Since the T circle was not judged to be significantly smaller than its physical size, the negative form of the Delboeuf was not found in the present study.

The t-test for the highest value of the Ebbinghaus was significant ($t = 20.801$, $p < 0.01$) as was the t-test for the lowest value ($t = 6.726$, $p < 0.01$). Since the highest value was larger than the physical size of the I circle and the lowest value was smaller than the physical size of the T circle, both the positive and negative forms of the illusion were produced.

In summary, the following results were obtained: a significant decrease in the judged T circle size with increasing I circle size; a significantly larger T circle size estimate for the Delboeuf than for the Ebbinghaus; and a significant difference between the T circle size estimates for the Ebbinghaus and Delboeuf at the seven and one half and nine and one half year levels. All of the remaining main effects and interactions were non-significant. Among the non-significant results special attention was given to the main effects for age and sex since they were of theoretical importance for the present study. It is of interest to note that neither the main effect for sex nor any of the sex interactions were significant. Also it should be noted that as predicted, with the exception of the age x illusion type and I circle size x illusion type interactions, none of the interactions were significant.

CHAPTER IV

DISCUSSION

The discussion of the results is presented in three distinct sections. The first section is concerned with the changes in the Delboeuf illusory effect as a function of physical parameters and age. The second section is concerned with the Ebbinghaus illusory effect as a function of the same two variables. The final section attempts to integrate the results from the two previous sections as they relate to the hypothesis, that both illusory effects represent one underlying process and, therefore, have a single age trend.

The Delboeuf Illusion

Physical parameter effects for the Delboeuf illusion. The literature on the Delboeuf illusion reviewed in the Introduction suggested three predictable outcomes with respect to the effects of increasing the I circle size. These outcomes were with respect to (1) the shape of the curve produced by plotting amount of illusion by I circle size, (2) the I/T circle ratio at which the maximum illusion was obtained, and (3) the I/T circle ratio which produced a negative illusion. Each of these three predictions are discussed in turn by examing the results from the present study, clarifying the predicted outcome on the basis of other studies in the area, and then reconciling any differences between the expected and actual results.

First consider the shape of the curve produced by plotting amount of illusion by I circle size (Figure 7). Initially the judged size of the T circle (amount of illusion) increased significantly with increased I circle size. With further increases of the size of the I circle, the judged size of the T circle decreased, finally falling slightly below the zero illusion point of 20 mm. The shape of the curve was very similar to that predicted and reported by Piaget (1942) and that found by Keats (1962). Both Piaget and Keats used the method of comparison while the method of adjustment was used in the present study. Despite the use of a different method in this study, the same effect on the perceived size of the T circle was found over the full range of I circle sizes.

Sigurdson (1970), using the same method as was used in the present study, found a straight line decrease in T circle size with decreasing I circle size. This straight line function is not, however, in conflict with the present results since only two I circle sizes were used in her study.

It is evident that the results for the judged size of T circle as a function of I circle size (T circle - I circle function), found in the present study, are in full accord with the other results mentioned above, despite the use of different methods.

Now consider the I/T circle ratio that produced a maximum illusory effect in the present study. The maximum illusion occurred at an I/T ratio of approximately 3/2.5. This estimate is only an approximate interpolation made from a visual inspection of the T circle - I circle function for the Delboeuf. Nevertheless, this ratio is very close to the 3/2 I/T ratio found by Keats (1964), Weintraub *et al*., Weintraub and Cooper (1972) and Morinaga (1935). Although the method of paired comparisons was used in all of these studies their results are similar to those of the present study.

Finally consider the present results with respect to the I/T ratio which produced a negative Delboeuf illusion. A negative illusion was not found in the present study. The most negative point was not statistically different from 20 mm (zero illusion). The I/T ratio for this particular point was 2.6/1.

Numerous other researchers have found the negative form of the Delboeuf illusion. Keats (1964) found that the negative illusion occurred with I/T ratios of 3/1 to 4/1, while Ikeda and Ohonai (1955) found a negative illusion for an I/T ratio of 3/1. These two studies considered together suggest that an I/T ratio of 3/1 is necessary to produce a negative Delboeuf illusion.

In the present study a maximum I/T ratio of 2.6/1 was as large as could be produced within the confines of the design, in which the prime concern was a comparison of the Delboeuf and Ebbinghaus illusions. A larger ratio than 2.6/1 would have caused the I circles in the Ebbinghaus illusion to overlap. Under these circumstances it is not surprising that a significant negative illusion was not produced. Although the most negative Delboeuf was not significant, it is of interest to note that the Delboeuf showed a tendency towards the negative direction. This tendency, along with the above mentioned design restrictions suggest that the present results in no way contradict previous evidence with respect to the possible production of a negative Delboeuf illusion.

Generally then, all three outcomes for the physical parameters showed adequate agreement with the results of other studies. The only point of any real divergence was the lack of production of the negative illusion and this has been easily explained as above.

Developmental trends for the positive Delboeuf. In the present study two important age-related results occurred. The first result was that the T circle - I circle function was the same for each of the three age levels (Figure 9). That is, since neither the age levels x I circle size interaction or the age x I circle x illusion type interaction was significant, we may conclude that there were no real differences in the shape of the T circle - I circle function curves for the three age levels.

Piaget (1942) has suggested that there should be no difference in the shape of the I circle size by amount of illusion curves for the differing ages and has presented data to support this claim. The present study showed no such differences, thereby clearly supporting Piaget's contention.

The second age-related result in the present study was that the judged size of the T circle was not statistically different for the three age levels. That is, there was no real effect of the age of the subjects on the amount of illusion seen.

Piaget (1942) has suggested that the magnitude of the positive Delboeuf should decrease with age. In an attempt to validate this suggestion, he performed several studies designed to examine the effects of age on the magnitude of the Delboeuf illusion. These studies, in which he used the method of comparison, supported his contention that the effect of the illusion should decrease with age.

Marginal support for Piaget's position was supplied in a study performed by Santostefano (1963). He reported that the amount of Delboeuf illusion decreased as the age of the subjects increased. The effect was, however, not statistically significant. Weintraub and Cooper (1972) found results similar to those of Santostefano (1963) in that the magnitude of the Delboeuf decreased as the subjects' age increased. Their results varied with those of Santostefano in that they were significant.

Sigurdson (1972) performed a study using the same method (adjustment) as in the present study. She found a non-significant decrease in the amount of Delboeuf illusion with increasing age.

Clearly the results of the present study fail to correspond to the data which suggest that the Delboeuf illusion should decrease with age. It is difficult to reconcile the difference between the expected and produced results. One possible explanation for this discrepancy is that the present study was performed using a different method (adjustment) than the method used in other studies (comparison). This argument is apparently weakened by Sigurdson's (1972) results which were obtained using the same method as the present study. She found a non-significant decreasing function for the effects of age on the Delboeuf illusion. A careful inspection of her study suggests some inappropriate procedures which may account for the apparent similarity between her results and those of other studies.

The most important procedural error was that Sigurdson did not take into account her unequal Ns when she considered her age effects. One of her significant factors (rural-urban) was unequally distributed between the two age groups. The urban children as a group showed a much stronger Delboeuf illusion than the rural children. Also, a greater percentage of the younger age group (six-seven year olds) came from urban areas. These two facts taken together suggest that a stronger illusion should have occurred in the younger age group since it contained more urban children and these children showed a stronger Delboeuf illusion. That is, the apparent age effect could simply have been due to the fact that there were more urban children in the younger age group. It could be argued that the reverse was true and the age effect produced the rural-urban distinction. This is very unlikely since the rural-urban difference was highly significant while the age difference was only a non-significant trend. Because of this inappropriate procedure, Sigurdson's results are clearly questionable, and it is probably reasonable to conclude that the difference between the results of the present study and those of other studies was due to the use of different methods.

It might be argued that the present method distorted the actual trends which occur with the Delboeuf illusion. That is, the method of adjustment may for some reason mask the effects of different manipulations on the size of the illusion. If this was the case, though, these masking effects would have distorted not only the age trend, but also the effects for the I circle size changes.

This was clearly not the case since the result obtained for shape of curve (T circle - I circle function) was the same as that predicted by the other studies in which the method of comparison was used. It appears that if the method of adjustment masked illusory effects, it did so in a very selective manner.

A second alternative, to explain the discrepancy between expected and observed results, is that the method of comparison may produce artifactual Delboeuf age trends. It has been suggested (Pressey, 1975) that children may confuse the meaning of instructions when asked whether the T circle is bigger than the C circle and respond periodically not to the T circle - C circle comparison, but to the I circle - C circle comparison. That is, when they are asked if the 25 mm I circle is bigger than the 20 mm I circle, they may say "no" because they are looking at the 28 mm I circle, not the 20 mm T circle. In the present study this problem was avoided by using a design in which each subject was required to demonstrate which of the two circles (T circle or I circle) the C circle matched.

A second possible problem with the method of comparison as it has been used in other studies is that subjects are not trained in the use of the method. That is, younger subjects being less adept at the method, would show higher variance in their estimates. The younger subjects do in fact show this higher variance (Piaget, 1943; Weintraub and Cooper, 1972).

Piaget (1942) has suggested that the Delboeuf illusion decreases slightly with practise in adult subjects. It is possible that this effect was due either to learning to compensate for the illusion or to becoming more efficient with the comparison technique. If increasing efficiency in the use of the comparison technique produces decreased illusion, and if younger subjects are less efficient with the technique, then the fact that they start at a less efficient point means they will show a greater illusion. In the present study each subject's ability to use the method of adjustment was brought to a common level. Thus, a possible artifactual decrease in the magnitude of the Delboeuf illusion may have been removed.

It seems that at this point further study is required in order to clarify the effects of misunderstood instructions and differing starting levels of efficiency with the comparison technique. Until this has been accomplished the reason for the discrepancy between the present results and those of Piaget (1942), Santostefano (1963) and Weintraub and Cooper (1972), remains unclear.

The Ebbinghaus Illusion

Physical parameters affecting the Ebbinghaus illusion.

Physical parameter changes in the Ebbinghaus illusion produced two effects of present interest. The first of these was the shape and direction of the curve for the T circle - I circle function. The second was the occurrence of a negative (assimilation) Ebbinghaus illusion.

Consider the results with respect to the shape and direction of the curve for the T circle - I circle function (Figure 7).

Increased I circle size caused a significant linear decrease in the estimated T circle size (increase in amount of illusion). This finding is congruent with results of a study by Morinaga (1956). Massaro and Anderson (1971) also found that increasing the I circle size caused a linear increase in the Ebbinghaus illusion. The present study clearly supports the findings of these two previous studies with respect to the change in the amount of illusion as a function of changing I circle size.

The second expected effect was the production of a negative (assimilation) illusion (Figure 9). The largest judged T circle size was found to be significantly larger than 20 mm. That is, a negative Ebbinghaus illusion was produced since the T circle was judged significantly larger than its physical size. This supports the finding of a negative Delboeuf illusion by Weintraub and Cooper (1972).

Overall, then, the present results obtained for both the effects of increasing I circle size and the formation of a negative illusion corresponded to the results of previous studies.

Developmental trends for the positive Ebbinghaus illusion. The effect of increasing age on the Ebbinghaus illusion was represented by plotting the judged T circle size against age. The plot showed that with increased age the T circle appeared to have been judged smaller than its physical size. This decrease in the judged T circle size, however, was very small and non-significant. This non-significant effect was in sharp contrast to the results of several other studies concerned with the effects of age on the

Ebbinghaus illusion.

Wapner and Werner (1956) and Weintraub and Cooper (1972) both found an increase in the illusion (decrease in judged T circle size) with age. In both of these studies the method of comparison was used. Sigurdson (1972) using the same method as in the present study (adjustment) found a decreased illusion with age. Her findings appear contradictory to both those of the present study and those of Wapner and Werner (1957) and Weintraub and Cooper (1972). Sigurdson's results, however, should probably be discarded because of the methodological problems discussed previously.

Why an effect of age for the Ebbinghaus illusion did not occur in the present study is clearly open to speculation. The possibilities presented for the Delboeuf illusion (misunderstood instructions or method-produced results) also apply in this instance, since the three studies available, discounting Sigurdson, were conducted using the method of comparison.

Developmental trends for the negative Ebbinghaus illusion. The age trend for the negative Ebbinghaus illusion was represented by plotting judged size of the T circle by age. An apparent decreasing age trend was produced; however, the effect was not significant. This non-significant result did not support Weintraub and Cooper's (1972) finding that the negative Ebbinghaus illusory effect decreases with increasing subject's age. Again it is possible that a difference between the methods of adjustment and comparison was responsible for the disparity between the two sets of results.

Theoretical Implications

In the present study an attempt has been made to reconcile apparent contradictions in the literature with respect to the effects of age on the magnitude of the Ebbinghaus and Delboeuf illusions. This attempt has been based on the following suppositions about the illusions involved. First, it was supposed that both the Delboeuf and Ebbinghaus illusions can occur in their positive and negative forms. That is, by manipulating subjects' age and I circle size, either a positive (assimilative) or negative (contrast) Delboeuf may be produced. Similarly, manipulation of subjects' age and I circle size will produce either a positive (contrast) or negative (assimilation) Ebbinghaus illusion. Since the change from the positive to negative form of the illusions occurs gradually, it was hypothesized that both illusions contain a balance between contrast and assimilation effects. That is, the Delboeuf and Ebbinghaus illusions are hypothesized to be the same except for their relative amount of contrast and assimilation effects. If the two illusions are functionally the same we would expect that their age-related trends would be the same.

The results of the present study partially support the stated hypotheses. As suggested both the positive and negative forms of the Ebbinghaus occurred, as well as the positive form of the Delboeuf. The fact that the negative Delboeuf did not occur does not suggest that it cannot be produced, because, as pointed out earlier, the present results may have been restricted by the use of a maximum I/T ratio of 2.6/1. Results from other studies

(Keats, 1964; Ikeda and Ohonai, 1955) suggest that if a large enough I/T ratio is used the contrast form of the Delboeuf may be produced. The production of the positive and negative forms of the illusion provides support for the hypothesis that the Delboeuf and Ebbinghaus illusions are both a function of the same process.

Unfortunately no age trends were found in the present study. That is, the magnitude of the two illusions did not change with increasing age. This eliminates the possibility of making any conclusive statement with respect to the hypothesis that the two illusions represent a single process, since if the hypothesis was correct, both the production of the positive and negative forms of the illusions, as well as significant and similar age trends, were expected. It does, however, raise a second unexpected question. Are the age trends in the present literature a function of the methods being used as suggested in the discussion of developmental trends for the positive Delboeuf illusion, above? Clearly, further study is necessary to clarify which method--adjustment or comparison--is appropriate for the study of age changes in illusions. When the question of the appropriate method is clarified, further testing of the hypothesis, that a single underlying process is responsible for both the Delboeuf and Ebbinghaus illusions, should be done.

CHAPTER V

SUMMARY AND CONCLUSIONS

In the present study it was hypothesized that both the Delboeuf and Ebbinghaus illusions have a single underlying process. This suggested that both the positive and negative forms of the illusions could be produced and that the age trends for the Delboeuf and Ebbinghaus should be the same or similar.

In order to evaluate these suppositions the effects of age and physical parameters on the Delboeuf and Ebbinghaus illusions were measured.

Subjects consisted of 40 five and one-half year old children, 40 seven and one-half year old children, and 40 nine and one-half year old children. Each age group contained an equal number of males and females.

There were 12 targets consisting of four Delboeuf illusory targets, four Ebbinghaus illusory targets, and four control targets. Each of the four Delboeuf and four Ebbinghaus targets had I circle sizes of 23, 29, 41, or 65 mm. A method of adjustment was employed in which an oscilloscope was used to provide a variable comparison circle. After a training procedure each subject received an ascending and descending trial for each of the 12 targets.

Analysis of the results showed a significant decrease in the amount of illusion as a function of I circle size, a significantly larger T circle size, a significantly larger T circle size estimate for the Delboeuf than for the Ebbinghaus, and a significant difference between the T circle size for the estimates for the Delboeuf and Ebbinghaus at two age levels. Analysis also showed that the positive and negative form of the Ebbinghaus as well as the positive form of the Delboeuf occurred.

Contrary to expectation, no age trends were found. The absence of an age trend may have been due to the use of the method of adjustment instead of the more commonly used method of comparison. The question now arises as to which method, adjustment or comparison is most appropriate for the study of age trends in illusions.

Although partial support for the suppositions was obtained, further experimentation with respect to the hypothesis of a single underlying process will have to be delayed until the problem of the appropriate method has been clarified.

REFERENCES

Cooper, L.A., and Weintraub, D. J. Delboeuf-type circle illusions: Interactions among luminance, temporal characteristics, and inducing-figure variations. Journal of Experimental Psychology, 1970, 85, 75 - 82.

Coren, S. A size contrast illusion without physical size differences. American Journal of Psychology, 1971, 85, 565 - 566.

Cornsweet, T. M. The staircase method of psychophysics. American Journal of Psychology, 1962, 75, 485 - 491.

Dressler, B. American Journal of Psychology, June 1894, 3. Cited from Binet (1895).

Eisner, D. and Apfeldorf, M. Verbal intelligence and suseptibility to visual illusions. Perceptual and Motor Skills, 1971, 33, 3 (Pt 2), 1298.

Eisner, D. and Schaie, K. Age changes in response to visual illusions from middle to old age. Journal of Gerontology, 1971, 26, 146 - 150.

Hanley, C. & Zerbolio, D. Developmental changes in five illusions measured by the up-and-down method. Child Development, 1965, 36, 437 - 457.

Helson, H. Adaptation Theory: an experimental and systematic approach to behaviour. New York: Harper and Row, 1964.

Ikeda, H. and Ohonai, T. The studies in figural after effects: IV The contract - confluence illusion of concentric circles and the figural after effect. Japanese Psychological Research, 1955, 2, 17 - 23.

Keats, J. A. An application of the method of paired comparisons to the study of the Delboeuf illusion. Australian Journal of Psychology, 1964, 16, 169 - 174.

Massaro, D. W. and Anderson, N. E. Judgemental model of the Ebbinghaus illusion. Journal of Experimental Psychology, 1971, 89, 147 - 150.

Morinaga, S. Conditions of the size-assimilation and size-contrast. Masuda Hakushi Shaon Saiki n Shinrigaku Renbunshy. Tokyo; cited in Iwanami, 1935.

Morinaga, S. An examination of the conditions determining size-contrast. Reported at the 20th Annual Meeting of J. F. A. 1965. Cited in Ikeda, H. and Ohonai, T. (1955).

Murry, F. Conservation of illusion--distorted lengths and areas by Primary School Children. Journal of Educational Psychology, 1965, 56, 65 - 66.

Oyama, T. Japanese studies on the so-called geometrical optical illusion. Psychologica, 1960, 7 - 20.

Piaget, J. The mechanisms of perception. New York: Basic Books, 1969.

Piaget, J., Lambercier, M., Boesch, E., von Albertini, B. Introduction a l'etude des perceptions chez l'enfant et analyse d'une illusion relative a la perception visuelle des cercles concentriques (Delboeuf). Arch. Psychol., 1942, 29, 1 - 107.

Pollack, R. H. Contour detectability thresholds as a function of chronological age. Perceptual and Motor Skills, 1963, 17, 411 - 417.

Pollack, R. H. Muller-Lyer illusion: Effect of age, lightner contrast and hue. Science, 1970, 170, 93 - 95.

Pollack, R. & Zetland, F. A translation of "the measurement of visual illusions in children" by Alfred Binet. Perceptual and Motor Skills, 1965, 20, 917 - 930.

Pressey, A. W. A theory of the Muller-Lyer illusion. Perceptual & Motor Skills, 1967, 25, 569 - 572.

Pressey, A. W. An extension of assimilation theory to illusions of size, area, and direction. Perception & Psychophysics. 1971, 9, 172 - 176.

Pressey, A. W., Butchard, N., & Scrivner, L. Assimilation theory and the Ponzo illusion: Quantitative predictions. Canadian Journal of Psychology. 1971, 25, 486 - 497.

Santostefano, S. A developmental study of the Delboeuf illusion, Perceptual and Motor Skills, 1963, 17, 23 - 29.

Schiller, P. and Wiener, M. Binocular and Steroscopic viewing of geometric illusions. Perceptual and Motor Skills, 1962, 15, 739 - 747.

Sigurdson, E. The effects of culture and environment on assimilation and contrast illusions. Unpublished Masters Thesis, University of Manitoba, 1974.

Stostrom, K. and Pollack, R. The effects of simulated receptor aging on two illusions. Psychonomic Science, 1971, 23, 1947 - 1948.

Virsu, V. Geometric illusions 1. Effects of figure type, instruction and pre and intertrial training on magnitude and decrement of illusions. Scandinavian Journal of Psychology, 1967, 8, 161 - 172.

Wapner, S. and Werner, H. Perceptual Development. Worcester, Mass.: Clark University Press, 1957.

Wapner, S., Werner, H. and Comalli, P. Perception of part-whole relations in middle and old age. Journal of Gerontology, 1960, 15, 412 - 416.

Weintraub, D. J. and Cooper, L. A. Coming of age with the Delboeuf illusion: Brightness contrast, cognition, and perceptual development. Developmental Psychology, 1972, 6, 187 - 197.

Weintraub, D., Wilson, B., Green, R. and Palmquist, M. Delboeuf illusions. Displacement versus diameter, arc deletions and brightness contrast. Journal of Experimental Psychology, 1969, 80, 505 - 511.

Wohlwill, J. Developmental studies of perception. Psychological Bulletin, 1960, 54, 249 - 288.

Wohlwill, J. Some characteristics of psychological data obtained with a group version of the up-and-down method. Perception and Psychophysics, 1968, 3, 54 - 56.

APPENDICES

APPENDIX 1

Assimilation Illusions

The portions of each figure marked "T" are physically the same size, but appear to be different because of the effect of the remaining portion of the figure.

Figure 1.1

The Muller-Lyer Illusion

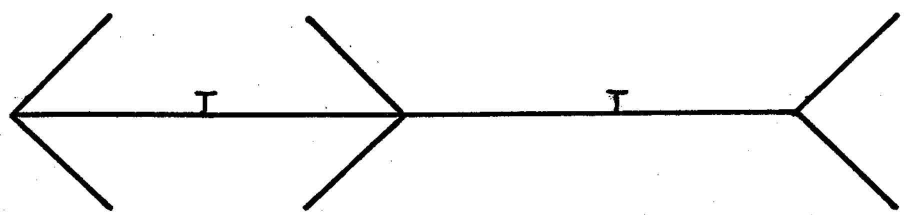
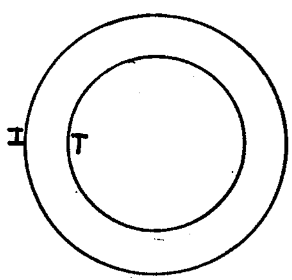


Figure 1.2

The Delboeuf Illusion


I
T

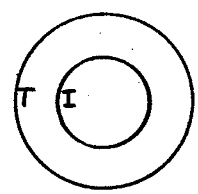

T
I

Figure 1.3

The Sander Parallelogram Illusion

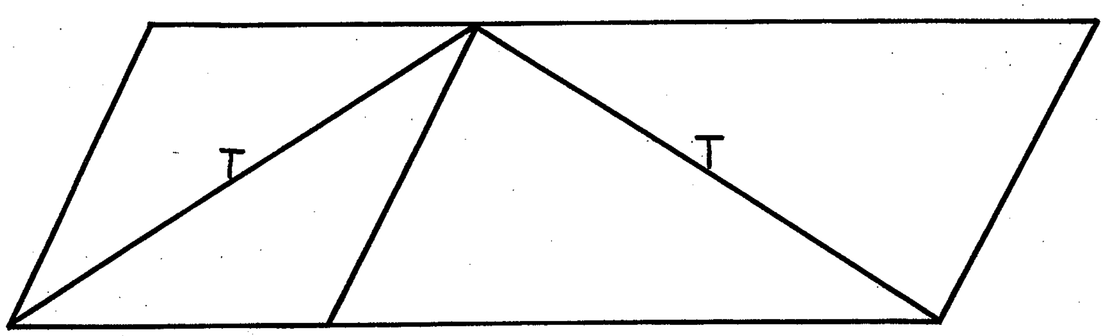
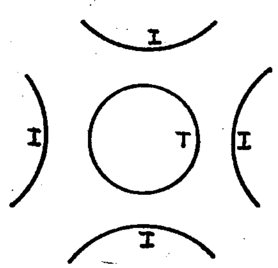


Figure 1.4

The "Arc" Delboeuf Illusion


I
I
T
I
I

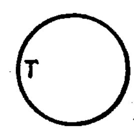

T

Figure 1.5

The Filled Space Illusion


T
T

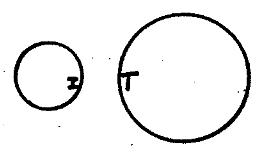
APPENDIX 2

Contrast Illusions

The portions of each figure marked "T" are physically the same size, but appear to be different because of the effect of the remaining portion of the figure.

Figure 2.1

The Oppel-Kundt Illusion


H
T

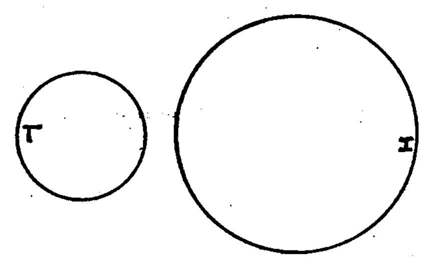
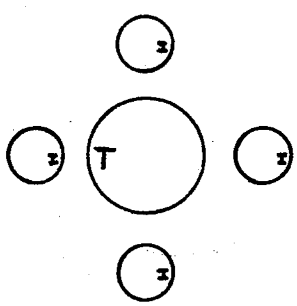
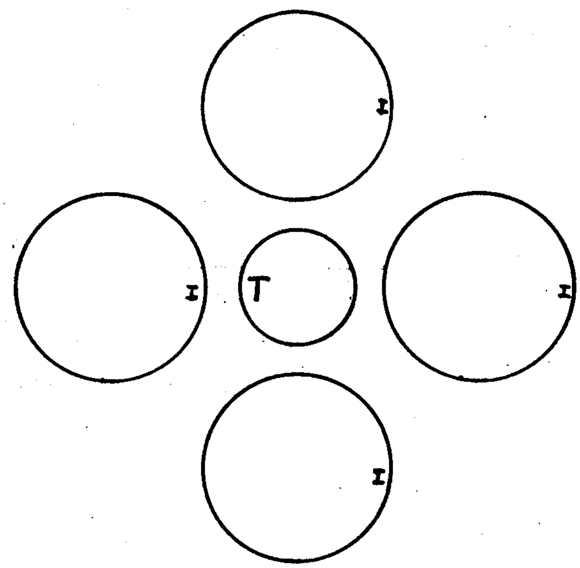

T
H

Figure 2.2

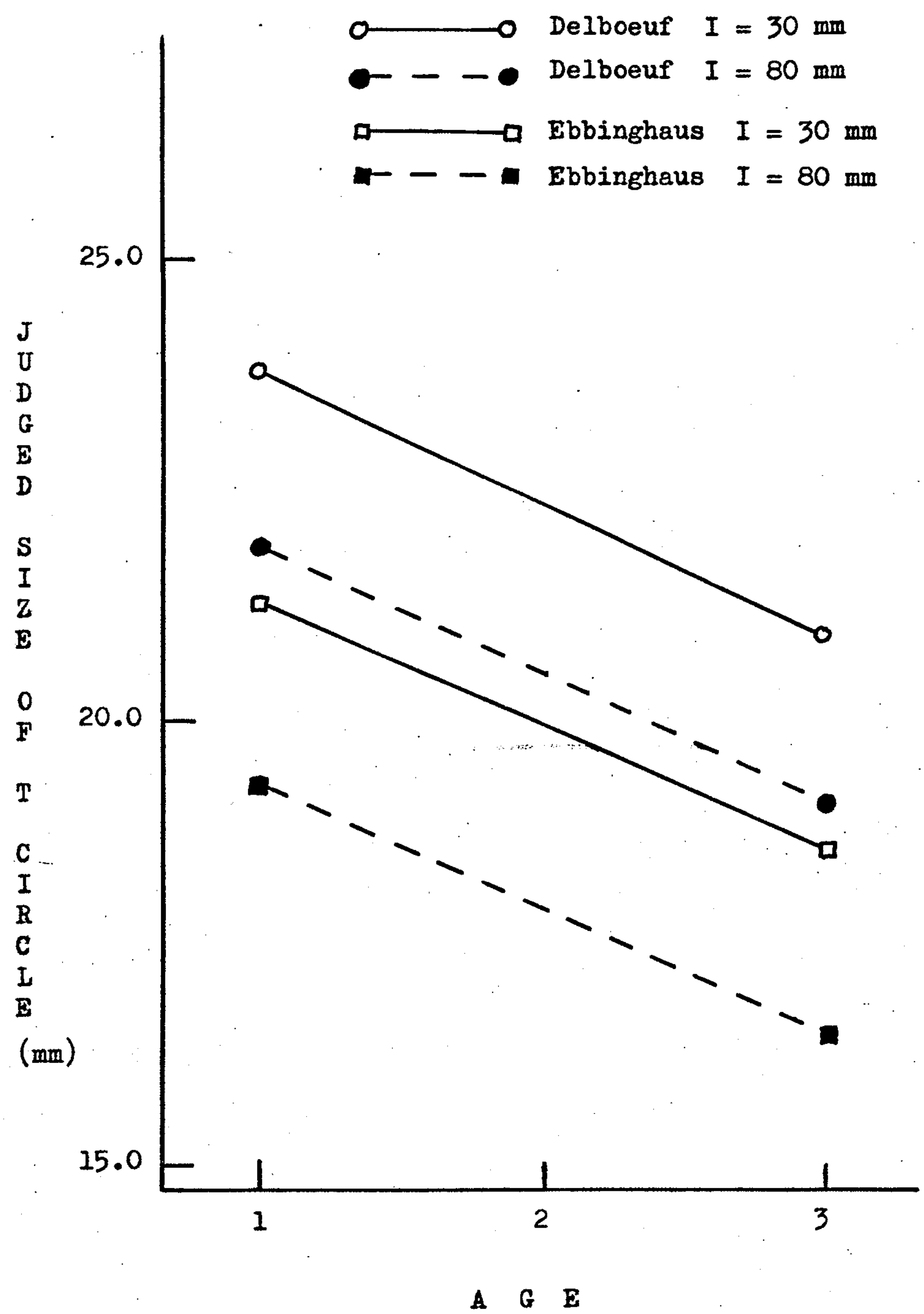
The Ebbinghaus Illusion


T


T

APPENDIX 3

Hypothetical Data for Age Changes in the Delboeuf and Ebbinghaus Illusions.



Delboeuf I = 30 mm
Delboeuf I = 80 mm
Ebbinghaus I = 30 mm
Ebbinghaus I = 80 mm
25.0
20.0
15.0
JUDGED SIZE OF T CIRCLE (mm)
1
2
3
AGE

APPENDIX 4

Conversion Table for Changing Dial Readings to Circle Size (mm)

CONVERSION TABLE

Dial Readout	Circle Size (mm)
2.370	18.0
2.396	19.2
2.422	19.4
2.448	19.6
2.474	19.8
2.500	20.0
2.526	20.2
2.552	20.4
2.578	20.6
2.604	20.8
2.630	21.0
2.656	21.2
2.682	21.4
2.708	21.6
2.734	21.8
2.760	22.0

APPENDIX 5

Raw Mean Score for Each of the 48
Age x Sex x Illusion Type x I Circle Size Cells

ILLUSION TYPE		Circle size	MALE AGE 5½	MALE AGE 7½	MALE AGE 9½	FEMALE AGE 5½	FEMALE AGE 7½	FEMALE AGE 9½
	DELBOEUF	23	2.578	2.603	2.522	2.605	2.640	2.592
		29	2.687	2.683	2.684	2.573	2.752	2.703
		41	2.542	2.622	2.652	2.463	2.509	2.579
		65	2.529	2.491	2.509	2.537	2.490	2.480
	EBBINGHAUS	23	2.565	2.538	2.489	2.713	2.580	2.546
		29	2.534	2.532	2.501	2.550	2.526	2.514
		41	2.516	2.545	2.480	2.544	2.488	2.470
		65	2.425	2.482	2.463	2.536	2.479	2.474