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# THE EFFECT OF VISUAL ANGLE AND FRAME ON DELBOEUF ASSIMILATION-CONTRAST EFFECTS: A TEST OF THE POOL AND STORE MODEL

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by

Lucille Horn Spivak

A dissertation submitted to the Graduate
Faculty in Psychology in partial fulfillment
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of Philosophy, The City University of New York.

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## Abstract

# THE EFFECT OF VISUAL ANGLE AND FRAME ON DELBOEUF ASSIMILATION-CONTRAST EFFECTS: A TEST OF THE POOL AND STORE MODEL

by

Lucille Horn Spivak

Adviser: Professor Louis J. Gerstman

The pool and store model of Coren and Girgus proposes that the occurrence of assimilation and contrast distortions manifested by visual illusions is determined by the temporal distribution of information in the visual array during processing. According to the model, when the visual angle between the test and inducing elements of a configuration is approximately foveal and both can be seen simultaneously, assimilation occurs; when it is sufficiently large that the elements must be scanned in separate fixations the input is temporally distributed, and contrast occurs. The present studies manipulated the retinal size of the stimulus configuration in order to vary the visual angle between test and inducing elements (critical visual angle) while holding constant their size ratio. The pool and store model predicts that when the critical visual angle is large rather than small assimilation should tend to decrease and contrast should tend to increase. Five studies were performed to test these hypotheses. The first four were within subject designs, each utilizing 12 subjects, and the fifth was a separate groups design with 12 subjects per group.

In Experiments 1 and 2 the assimilation and contrast segments of the Delboeuf, Ebbinghaus and divided space illusions were presented on slides and size estimates made by adjusting the length of a variable line. Illusion magnitudes in this and subsequent studies were computed as percentage differences from control figure estimates. In both studies the illusion magnitude of the Delboeuf and Ebbinghaus varied with retinal size in the expected direction, but only one comparison was statistically significant.

In Experiments 3 and 4 the assimilation and contrast segments of the Delboeuf were presented on slides and size estimates made by selecting a comparison circle from a series presented in booklet form. Identical results were obtained in both studies. When retinal size was large rather than small, overestimation of the assimilation segment was significantly less and underestimation of the contrast segment significantly greater. Although both these results confirm the experimental hypotheses, they could be attributed to extraneous distortion induced by the size of the page framing the comparison figures.

*Experiment 5* tested both critical visual angle and framing effects using the assimilation and contrast segments of the Delboeuf. Illusion, control and comparison stimuli were reproduced on paper. Separate groups estimated each illusion segment using a method of limits procedure. In order to control for frame-induced distortion, the effect of visual angle was tested with the frame-figure ratio held constant across visual angle conditions. The effect of the frame was tested by comparing the illusion magnitude of identical figures when test and comparison stimuli were presented in a small, proximal frame and in a large, distant frame. For the assimilation variant, overestimation was significantly less when visual angle was large rather than small and when the frame was small and proximal rather than large and distant. For the contrast variant, visual angle had only a marginal effect, in the predicted direction, while the frame had no significant effect on illusion magnitude.

Taken together these studies suggest that Delboeuf assimilation and contrast effects are linked to the critical visual angle, although alternate interpretations are possible. The implications of the *pool* and *store* model and of the framing effect are discussed.

# ACKNOWLEDGMENTS

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# I

# ASSIMILATION AND CONTRAST: THE PROBLEM OF DEFINITION

In some geometric configurations there are systematic distortions such that the percept differs from the objective stimulus in a consistent fashion. Such figures are known as visual illusions. In general, visual illusions are manifested as distortions of size or of the direction of line elements. The present discussion will be concerned with the categorization and processing of illusory size distortions.

An illusion consists of a test figure surrounded by accessory elements. It is these surrounding or contextual elements which appear to induce the illusory distortion since, when the observer judges the test element in isolation, no systematic distortion ordinarily is obtained. In illusions of size, the distortion by the context is generally one of two different types. In one kind of distortion, the test figure is perceived as more similar to the contextual elements than it objectively is. This type of distortion is known as <u>assimilation</u> since the test element apparently is assimilated to the context instead of being clearly differentiated from it. The second type of distortion, <u>contrast</u>, seems to be obtained when the difference between test and contextual elements is accentuated.

On the basis of these observed distortions, a particular configuration is categorized either as an assimilation illusion or a contrast illusion. Let us consider some illusion figures that traditionally have been considered examples either of assimilation or contrast or a combination of the two.

In the Mueller-Lyer illusion (Figure 1 a), the shaft attached to the inward-pointing wings appears shorter and the shaft attached to the outward-pointing wings appears longer than a shaft without wings. Both these configurations usually are considered assimilation illusions, in which the shaft is assimilated to one of two extents in the figure. Since the wings-in figure is smaller in total extent than the wings out figure, the apparent size of the shaft may be assimilated to the entire figural extent. Alternatively, since the distance between the wing tips is smaller in the underestimated figure and larger in the overestimated figure, the shaft may be assimilated to these extents.

The Ebbinghaus illusion (Figure 1 b) usually is regarded as a contrast phenomenon since the central circle is perceived as larger in a context of small circles and as smaller in a context of large circles. Similarly, the divided line illusion (Figure 1 c) is considered a contrast illusion since the central section appears shorter when it is flanked by long lines while it appears longer when flanked by short lines.

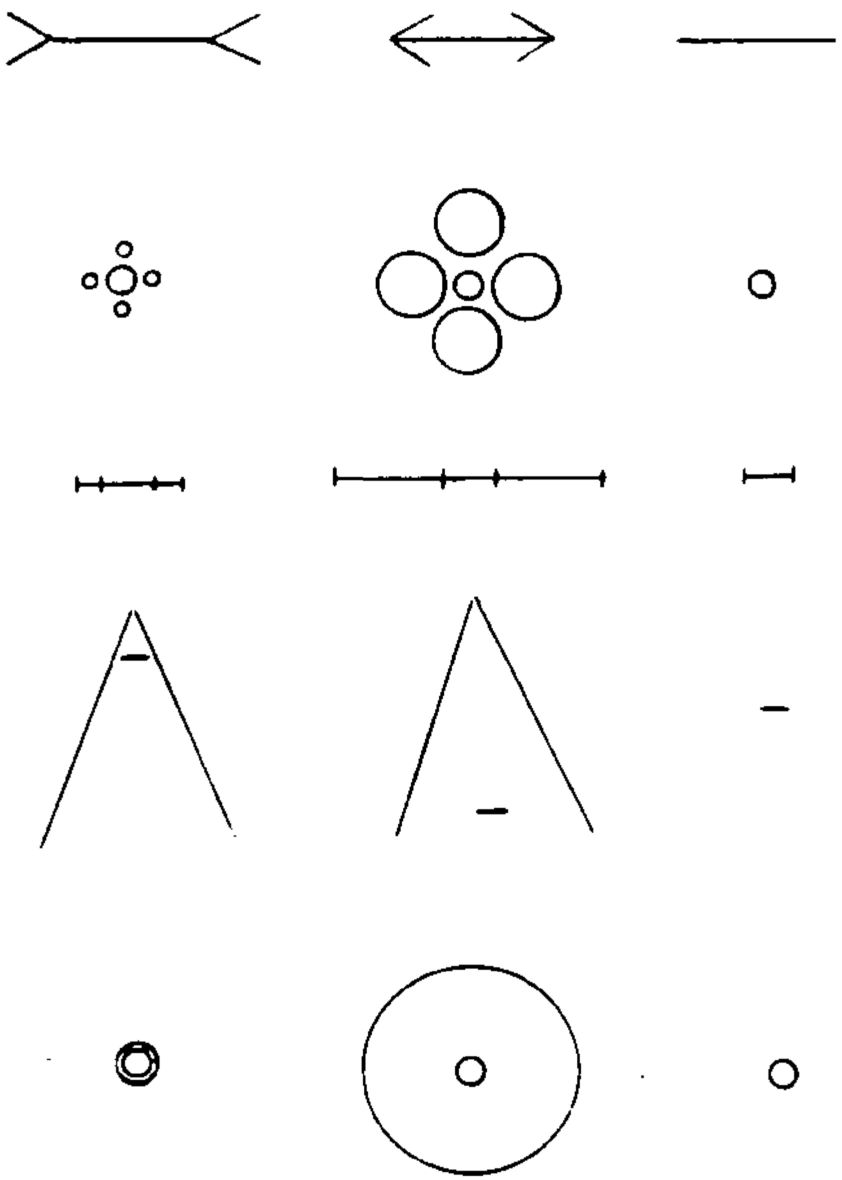


Figure 1. Assimilation and contrast illusions: a) Mueller-Lyer, b) Ebbinghaus. c) divided line, d) Ponzo, e) Delboeuf. Shown from left to right are the overestimated segment, underestimated segment, and control figure consisting of a test element with no inducing elements. The Mueller-Lyer is generally considered an assimilation illusion while the others may be considered as assimilation-contrast illusions or wholly contrast phenomena, depending upon the choice of relevant inducing context.

The two segments of the Ponzo illusion (Figure 1 d) are most frequently regarded as manifesting different types of distortion. The line closer to the apex of the angle, which appears longer than its actual size, is held to be assimilated to the narrow portion of the angle, while the lower line, which appears shorter than its actual size, is thought to be contrasted with the greater width of the surrounding angle.

There is also general agreement that each segment of the Delboeuf illusion (Figure 1 e) manifests a different type of distortion. When the central circle is surrounded by a slightly larger circle it appears larger than objective size, that is, it is assimilated to the outer circle. When the central circle is enclosed by a much larger circle it is presumably contrasted with the surrounding circle and thus is seen as smaller than objective size.

From the preceding examples it can be seen that the designation of a configuration as either an assimilation or a contrast illusion rests upon specification of the relevant context to which the test element is assimilated or with which it is contrasted. However, with the exception of the Mueller-Lyer illusion, each of these configurations has alternative contextual extents that can be seen as the context relevant to the illusion. When this alternative context is used, a figure usually seen as an assimilation illusion can be categorized as a contrast illusion and vice versa. Let us review the illusions described above (with the exception of the Mueller-Lyer), using the alternative context to categorize each.

The Ebbinghaus, traditionally held to be a wholly contrast phenomenon, can be viewed as an assimilation-contrast illusion similar to the Delboeuf (Girgus, Coren & Agdern, 1972). Just as the outer diameter of the Delboeuf is generally regarded as the critical contextual dimension, so the total figural expanse of the Ebbinghaus may be regarded as its relevant contextual extent. According to this interpretation, the center circle is overestimated when the surrounding circles are small because it is assimilated to the outer edges of the figure which extend only slightly beyond the test circle. Underestimation of the test element in the presence of larger surrounding circles continues to be viewed as a contrast phenomenon but the total figural extent rather than the surrounding circles is thought to be contrasted with the center circle.

The divided line illusion also may be interpreted as an assimilation-contrast illusion by assuming that, like the Delboeuf, the relevant context is the total figural extent. With this definition of the relevant context overestimation of the center segment, which is obtained when the flanks are short, would be attributed to the assimilation of the test element to the total figural extent. Underestimation, obtained when the flanks are long, continues to be seen as a contrast phenomenon but the center segment is held to be contrasted with the entire figural extent.

The Ponzo and Delboeuf illusions, which most frequently are viewed as assimilation-contrast phenomena, also can be seen as purely contrast illusions, similar to the usual interpretation of the divided line illusion. With respect to the Ponzo, Cleary (1966) notes that the line closer to the apex of the angle might appear longer because it is contrasted with the small spatial extents adjacent to it, much as the center segment of the divided line illusion is contrasted with the flanking segments. Similarly, Piaget (1969) maintains that the diameter of the central circle of the Delboeuf is contrasted with the extent between the two concentric circles. When the outer circle is not much larger than the central circle this extent is small and the diameter of the center circle is overestimated relative to this context. These alternate interpretations change only the categorization of the overestimated halves of the illusions. The underestimated segments continue to be viewed as contrast illusions although a different contextual extent is seen as relevant. In the case of the Ponzo, underestimation of the test line within the wide sector of the angle is held to result from contrast with the relatively large spatial extents flanking the line rather than with the width of the angle. Underestimation of the center circle of the Delboeuf is said to result, not from contrast with the larger surrounding circle but rather, from contrast of the diameter of the test circle with the relatively large extents between the two concentric circles.

The difficulty in categorizing illusions as assimilation or contrast phenomena seems to reside in an inability to identify the relevant context in each case. Since it is the context which induces the distortion, it should be possible to specify how an assimilation-inducing context differs from a contrast-inducing context. Only if the attributes that differentiate the two types of context can be specified, can unambiguous classification of illusion figures occur. Let us now turn to some of the data that have been collected on assimilation and contrast distortions and to the theoretical formulations that have been proposed to account for them to see whether any light can be shed on the contextual attributes that define each type of distortion.

# II

# ASSIMILATION AND CONTRAST: AN OVERVIEW OF DATA AND THEORY

Illusions have been studied extensively for more than 100 years. During that period a number of theoretical formulations have emerged, some of which are addressed to both assimilation and contrast phenomena while others are addressed to one or the other. This latter approach seems to suggest that the mechanisms underlying each type of distortion are sufficiently different from each other that it is difficult to encompass both in a single theoretical formulation. Let us see whether there are empirical data that support the suggestion that these are basically different phenomena.

## Empirical Findings

Although the assumption of a processing distinction between assimilation and contrast is widely held, a review of the literature reveals no concerted effort to validate this assumption. Very little research systematically compares one class of illusion with the other. In order to ascertain whether there are differences between assimilation and contrast illusions and similarities within each illusion category, it is necessary to draw upon the results of a variety of experiments which utilize quite different methodologies and subject populations. In addition to the usual difficulties which such comparisons entail, interpretation is hampered by some special problems which deserve mention. Frequently a manipulation is not performed on both segments of the same illusion. Thus, if the assimilation variant of one illusion behaves differently from the contrast variant of another, this can be interpreted as a difference either between illusion configurations or between assimilation and contrast phenomena. Also, possible differences between assimilation and contrast illusions are obscured when the composite form of the configuration is used. With this measurement technique, both variants of an illusion are presented in tandem, one segment serving as the standard stimulus and the other as the variable. Such a procedure makes it impossible to determine whether both variants of an illusion respond similarly or differently to a given manipulation.

With these difficulties in mind, let us examine the evidence from four different lines of research: the effect of temporal and spatial separation of test and inducing elements, age trends in illusion magnitude and the effect of practice on illusion magnitude. The results of these four kinds of parametric manipulation may help to determine whether there are processing differences between assimilation and contrast illusions and may even give some clues about the nature of these differences.

The most consistent evidence that assimilation and contrast illusions result from different mechanisms comes from experiments which present test and inducing elements successively. Overestimation of the inner circle of the Delboeuf assimilation figure is found with simultaneous presentation but, when the outer circle is presented prior to the inner circle, the latter is underestimated (Cooper & Weintraub, 1970; Morinaga, 1935; Piaget & Lambercier, 1944; Seltzer & Sheridan, 1965; Spitz, 1968). Ikeda and Obonai (1955), using a presentation duration of 500 ms for both the inducing and test stimuli, found that as the temporal delay between the onset of these elements was increased, underestimation grew, reaching a maximum with a 600 ms delay. Similarly, the wings-out segment of the Mueller-Lyer illusion is overestimated with simultaneous presentation and is underestimated when the wings are presented prior to the shaft (Clem & Pollack, 1975; Pollack, 1964). The effect is obtained with an onset asynchrony as great as 1000 ms when shaft and wings are each presented for 500 ms. The composite form of the Mueller-Lyer also exhibits a reversal in the direction of the illusion under conditions of successive presentation so that the shaft of the wings-in segment in perceived as longer than that of the wings-out segment (Fraisse, 1971).

This reversal in the direction of distortion with successive presentation has been reported only for assimilation illusions. Temporal separation of test and inducing elements of contrast illusions appears not to destroy the contrast effect. Ikeda and Obonai (1955) found that underestimation of the Delboeuf persisted with a 600 ms delay between the onset of the test and inducing elements, when each was presented for 500 ms. Cooper and Weintraub (1970), using a 1.5 second duration for inducing and test stimuli, observed underestimation of the Ebbinghaus with an onset asynchrony of 3 seconds.

In summary, these findings seem to indicate that temporal separation of test and inducing elements destroys the assimilation effect, resulting in a reversal to contrast. Contrast effects, on the other hand, continue to be obtained under conditions of temporal separation.

Manipulating the spatial separation between test and inducing elements also appears to affect assimilation and contrast illusions differently. As the size of the gap between the wings and the shaft of the Mueller-Lyer illusion is increased, the underestimation of the wings-in variant gradually decreases and then reverses to overestimation (Fellows, 1967; Ihara & Kido, 1934; Yanagisawa, 1939), while overestimation of the wings-out variant decreases but does not reverse (Yanagisawa, 1939). Although spatial separation does not affect both halves of the illusion identically, it does seem to decrease the assimilation effect for both variants.

For the Ponzo illusion separation between test and inducing context can be accomplished by enlarging the angle within which the test lines are situated. Fisher (1968) showed that distortion decreased as angle size increased from 45° to 90° but, since the lower line or contrast component of the illusion was estimated relative to the upper line or assimilation component, it is not possible to determine whether spatial separation affected the two segments of the illusion differently. In a study of the apparently larger segment of the Ponzo Pressey, Butchard, and Scrivner (1971) found that increasing the angle enclosing the test line resulted in a gradual decrease of overestimation and finally a reversal to underestimation.

Spatial separation of test and inducing elements appears to affect each segment of the Ebbinghaus illusion differently. Girgus et al. (1972) manipulated both the size of the context circles and their distance from the central circle. Regardless of the size of the surrounding circles, as their distance from the central circle increased, the apparent size of the test circle decreased. Thus the distortion of the overestimated variant reversed to underestimation while that of the underestimated variant increased still further. These findings appear consistent only if the Ebbinghaus is interpreted as an assimilation-contrast illusion. In that case, spatial separation of test and inducing elements appears to diminish or reverse the assimilation effect and to enhance the contrast effect.

Practice, or repeated judgments under conditions of free inspection, appears to diminish the magnitude of some illusions but not others. Early investigators reported that the magnitude of the Mueller-Lyer illusion decreases with free viewing over a period of time (Heymans, 1896; Judd, 1902, 1905; Lewis, 1908). This phenomenon, known as illusion decrement, has been confirmed by many others (Coren & Girgus, 1972; Day, 1962; Dewar, 1967; Festinger, White, & Allyn, 1968; Girgus, Coren, Durant & Porac, 1975; Girgus, Coren, & Horowitz, 1973; Hoenig, 1972; Koehler & Fishback, 1950; Mountjoy, 1958; Parker & Newbigging, 1963). However, decrement has not been observed for assimilation illusions other than the Mueller-Lyer. Girgus and Coren (Note 1) found that with free inspection the distortion magnitude of the underestimated segments of the Delboeuf, Ebbinghaus and Ponzo illusions showed significant decrement over time while that of the overestimated segments showed no change.

Practice appears, then, to have quite consistent effects on configurations which could be classified as assimilation-contrast phenomena. Decrement is observed for the contrast segments but not for the assimilation segments of such illusions. It remains to be explained why the Mueller-Lyer, unlike other assimilation illusions, is able to decrement with prolonged inspection.

The fourth and final line of research relevant to the assimilation-contrast distinction concerns age-related changes in illusion magnitude. Most studies have found that the distortion of the Mueller-Lyer, an assimilation illusion, decreases with age (Barclay & Comalli, 1970; Binet, 1895; Gaudreau, Lavoie, & Delorme, 1963; Girgus, Coren, & Fraenkel, 1975; Noelting, 1960; Piaget & von Albertini, 1950;

Piaget, Maire, & Privat, 1954; Pollack, 1964; Segall, Campbell, & Herskovitz, 1966; Weintraub, Tong, & Smith, 1973). A few investigators have found that the decrease is followed by an increase in adolescence (Walters, 1942; Wapner & Werner, 1957).

For the Delboeuf, a decrease in illusion magnitude with age was found for the overestimated segment by Giering (1905) and by Piaget, Lambercier, Boesch and Albertini (1942) for both segments of the figure. Santostefano (1963) observed a decrease with age only for the assimilation or overestimated segment and the opposite tendency for the contrast or underestimated segment. There is one instance of a failure to observe an age-related decline in the magnitude of the assimilation variant (Ruessel, 1934) but this study utilized an extremely small age range of 4 to 6 1/2 years. Aside from this study there seems to be good agreement that the illusion magnitude of the Delboeuf assimilation variant decreases with age but no consistent trend emerges for the contrast segment.

Each half of the Ponzo (Quina & Pollack, 1972) and Ebbinghaus (Coren & Porac, 1978) appears to exhibit a different curvilinear age trend. For both illusions the strength of the assimilation or apparently larger segment decreases with age and that of the contrast or apparently smaller segment increases with age, at least until adolescence, after which both trends tend to reverse. Studies of the composite form of the Ponzo (Farquhar & Leibowitz, 1971; Liebowitz & Judisch, 1967) and the Ebbinghaus (Wapner & Werner, 1957) report that illusion magnitude increases with age, which may reflect primarily the contribution of the underestimated segments of these illusions.

Further evidence that assimilation and contrast illusions may exhibit different developmental trends comes from studies which have utilized successive presentation of figural elements. With simultaneous presentation, overestimation of the Delboeuf assimilation figure decreases with age but, with successive presentation, the illusion reverses to underestimation and the contrast effect increases with age (Piaget & Lambercier, 1944). Similarly, the apparently longer half of the Mueller-Lyer illusion displays an age-related decline in the assimilation effect with simultaneous presentation while, with successive presentation, the illusion reverses to underestimation and the contrast effect increases with age (Pollack, 1964).

Taken together, these results seem to indicate that the magnitude of assimilation illusions tends to decrease and the magnitude of contrast illusions to increase as a function of chronological age, at least until adolescence.

Consideration of the evidence from all four types of research does seem to support the assumption of a processing difference between assimilation and contrast illusions, despite a number of anomalous findings which require explanation. Let us now consider the theories which have been proposed to account for these two types of distortion to see whether they are able to specify the mechanisms underlying this suggested processing difference which would explain the data described above.

## Assimilation Theories

### Confusion theories

Confusion theories or theories of "total impression" were among the earliest proposed to account for the Mueller-Lyer as well as a number of other assimilation illusions (Boring, 1942, pp. 244-245; Titchener, 1918, pp. 321-328). Although somewhat different in their details, all such theories postulate that the observer judges the size, not only of the target element, but also of the total figure. The apparent size of the target is therefore a compromise between these two quantities. According to this explanation the distortion of the overestimated segments of the Delboeuf, Ebbinghaus, Ponzo, and divided line illusions can be attributed to the inclusion of the total figural extent in the observer's size estimate of the test element. Accordingly, it would be expected that the larger the total figural size in relation to the target element, the greater its overestimation. However, when the total figural extent is sufficiently large it appears that a contrast effect is induced, for the test element is then underestimated rather than overestimated. Obviously one limitation of confusion theory is its inability to explain contrast effects.

Confusion theory seems to be more applicable to the Mueller-Lyer, which exhibits only assimilation. The overestimation of the wings-out segment relative to the wings-in segment is readily explained by the fact that its total extent is, in fact, greater. The illusion is enhanced when the figural extent is enlarged by decreasing the angle between the obliques (Dewar, 1967; Heymans, 1896; Lewis, 1908) and, within limits, by increasing the length of the obliques (Lewis, 1909; Nakagawa, 1958). However, since both these manipulations change the distance between the obliques as well as the figural extent, it is unclear which context is confused with the shaft.

Arguing that the relevant context is the distance between the obliques, Erlebacher and Sekuler (1969) point out that the wings-in figure is underestimated relative to a straight line although both are equal in total extent. They demonstrated that underestimation of the wings-in variant increased as the distance between the wing tips decreased. Further, when angle size was varied while holding intertip distance constant, illusion magnitude remained invariant. A subsequent study (Sekuler & Erlebacher, 1971) indicated that each half of the Mueller-Lyer behaves quite differently. The effect of intertip distance on the wings-in segment was confirmed but this variable had no significant effect on the wings-out figure. Overestimation of the wings-out figure was a nonlinear function of angle size, with distortion greatest when angle size was moderate. It appears therefore that confusion theory can account for the distortion of the tails-in figure more adequately than for the tails-out figure.

Unless it is able to specify which extents in the array distort the test element and the conditions under which this occurs, the utility of confusion theory is rather limited. Nevertheless, the basic concept that the sizes of contextual elements are inappropriately incorporated into the observer's estimate of a test element, continues to be an influential one, as we shall see in considering the next theory.

### Pressey's assimilation theory

Although the concept of assimilation is not a new one, Pressey (1967, 1970, 1971) has developed it in detail and shown how it might apply in a number of different situations. He begins with the observation that when judgments of a series of magnitudes are made, the extreme values tend to regress toward the mean so that the larger magnitudes are underestimated and the smaller ones are overestimated. Averaging occurs for the Mueller-Lyer illusion because the obliques force the observer to estimate, not only the length of the shaft, but also an indefinite number of lengths parallel to the shaft (Figure 2). In the case of the inward-pointing obliques the shaft is the longest extent in the array and when it is averaged together with the shorter extents it tends to be underestimated. When the obliques point outward, the shaft is the shortest extent among longer ones and averaging results in overestimation. This implies that the contextual extents within an array should be

Figure 2. Hypothetical extents averaged with the shaft of the Mueller-Lyer illusion, according to Pressey's assimilation theory. Underestimation of the shaft at left is attributed to context of shorter extents and over-estimation of the shaft at right to context of longer extents.

distorted in a direction opposite to that of the test element. In support, Mountjoy (1966) found that the distance between the wing tips is underestimated in the apparently longer portion of the Mueller-Lyer and overestimated in the apparently shorter portion. Similarly, when the inner circle of the Delboeuf is overestimated, the outer circle is underestimated (Ogasawara, 1952; Weintraub, Wilson, Green, & Palmquist, 1969).

Pressey stipulates that only the portion of the array within the _attentive field_, that is, the portion which receives the observer's focal attention, contributes to the estimate of the test element. Although the attentive field is not observable directly, Pressey (1974) has been able to demonstrate that overestimation of the Ponzo illusion varies with changes in the stimulus array which presumably shift the observer's focus of attention.

By postulating that the effectiveness of a contextual magnitude decreases as it moves from the center to the periphery of the attentive field, Pressey is able to account for the effects of spatially separating the wings and shaft of the apparently smaller segment of the Mueller-Lyer (Pressey & Bross, 1973). As the gap between the wings and the shaft increases, the contextual magnitudes become progressively larger, finally exceeding the length of the shaft, so that averaging results in overestimation, reversing the usual direction of the illusion. When the gap is sufficiently large that contextual magnitudes lie outside the center of attention, overestimation decreases to zero. This sort of explanation is less successful when applied to the assimilation segment of the Ponzo illusion. Overestimation decreases with increasing angle size but, contrary to expectation, a reversal to underestimation or contrast is observed when the angle is increased further (Pressey et al., 1971).

Pressey admits that assimilation theory is unable to account for contrast phenomena such as the Ebbinghaus illusion. Overestimation is observed when the surrounding circles are smaller than the test circle and underestimation when they are larger. An averaging mechanism would produce distortion in the opposite direction. Although an averaging process can account for the overestimation of the Ponzo, Delboeuf and divided line illusions, it cannot explain why these configurations exhibit underestimation when contextual magnitudes are large. If these contextual magnitudes are assumed to lie within the attentive field they should result in increased overestimation and, if they are assumed to lie outside the attentive field, they should cause no distortion.

Since Pressey's theory is explicitly addressed only to assimilation effects, it cannot be expected to account for contrast effects. However, its failure to differentiate the conditions which result in assimilation from those which result in contrast limits the predictive ability of the theory in that it is not possible to specify beforehand which situations would lie within the domain of the theory and which would not. Let us see whether contrast theories can rectify this deficiency.

## Contrast Theories

### Helmholtz and Obonai

Contrast phenomena seem to involve operations that are distinctly different from assimilation effects. Instead of negating differences between focal and contextual elements so that they appear to be more similar than they actually are, the observer apparently magnifies these differences. The formulations of Helmholtz and Obonai, although widely separated in time, are similar in that both are concerned with stimulus characteristics which might lead to such a pattern of perceptual judgments.

According to Helmholtz (1866/1962), sensory differences which are clearly perceived tend to be exaggerated. This description, while not addressed to underlying mechanisms, still carries some testable implications. The magnitude of the contrast effect would be expected to increase as the size difference between test and contextual elements increases. In support, overestimation of the central circle of the Ebbinghaus increases as the size of the context circles is diminished and underestimation increases as the size of the outer circles is enlarged (Girgus et al., 1972; Massaro & Anderson, 1971). Contrary to the contrast formulation, the distortion displayed by the divided line illusion and its variant, the divided space illusion (Figure 3) actually decreases when there are extreme size differences between test and contextual elements (Lewis, 1909; Morinaga, Note 2; Obonai, 1954; Wada, Note 3). The Delboeuf, usually considered an assimilation-contrast illusion, behaves in much the same fashion (Piaget et al., 1942).

Obonai (1954) considers the Delboeuf as well as the Ebbinghaus and divided line illusions to be contrast phenomena since all seem to exhibit distortion in accordance with the same general rule. Figures are seen as larger when adjacent to medium or small extents and smaller when adjacent to large extents. This descriptive statement, while accurate, remains vague since the size terms are not defined. Based on this statement it might be expected that when test and contextual elements are the same size no distortion would occur. However, under these conditions both the divided line and Ebbinghaus illusions manifest overestimation (Obonai, 1954; Zigler, 1960) and the Delboeuf manifests overestimation when the diameter of the center circle is equal to the interspace between the center and outer circles (Ogasawara, 1952).

Both Helmholtz and Obonai seem to imply that the observer compares the test element with surrounding figural elements. Therefore manipulations which emphasize the context or facilitate the comparison process should enhance the contrast effect. Consistent with this hypothesis, Morinaga (Note 4) and Massaro and Anderson (1971) have found that increasing the number of context circles in the Ebbinghaus

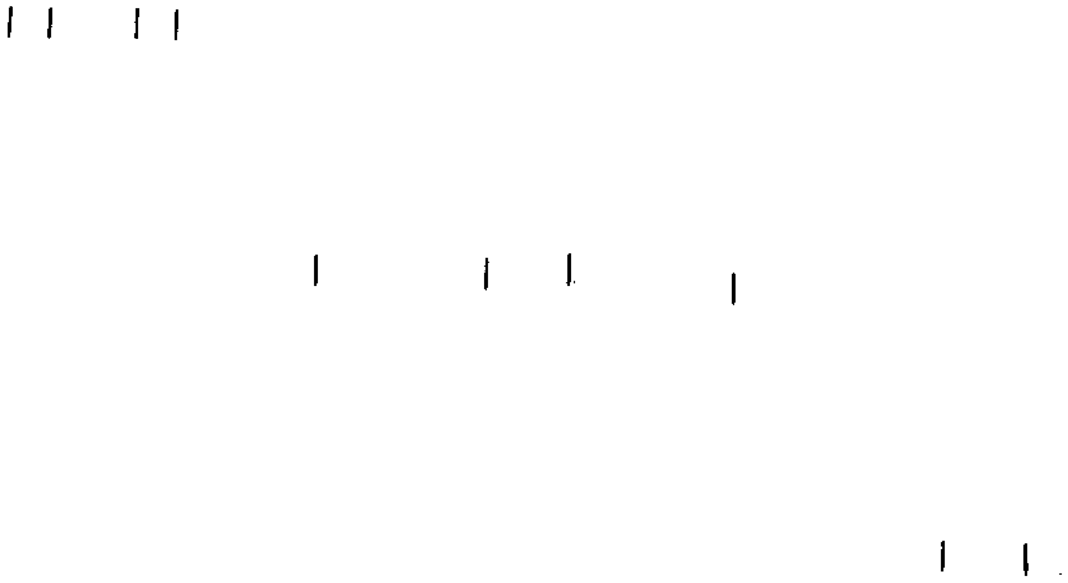


Figure 3. Divided space illusion, a variant of the divided line. Top, apparently larger central segment; middle, apparently smaller central segment; bottom, control.

configuration increases the magnitude of the distortion.

Increasing the distance between test and inducing elements or presenting the context prior to the test element should make the comparison process more difficult and thus reduce the magnitude of the contrast effect. However, contrary to expectation, Girgus et al. (1972), found that the greater the spatial separation between the center and surrounding circles of the Ebbinghaus, the greater the underestimation of the center circle. Ikeda and Obonai (1955) found that both the overestimated and underestimated Delboeuf variants were underestimated when the context circle was presented prior to the central circle and underestimation of both figures grew as the temporal delay between test and inducing elements increased. Cooper and Weintraub (1970) confirmed that under conditions of successive presentation the Delboeuf overestimation illusion reversed to underestimation and further, they observed no diminuition in the distortion of the underestimated segment of the Ebbinghaus with temporal delays up to 3 seconds.

The effects of spatial and temporal separation of test and inducing elements appear to be inconsistent with the contrast formulation of Helmholtz and Obonai. Although both suggest that contrast is a function of the size relationship between an element and its context, their statements are descriptive rather than explanatory. Further, they do not specify how a contrast-inducing context differs from an assimilation-inducing context. Thus, the classification of illusions as assimilation or contrast effects remains ambiguous. Let us therefore turn to formulations which are addressed to both forms of distortion to see whether these issues may be clarified.

## Assimilation-Contrast Theories

### The perceptual style hypothesis

It has been suggested that the tendency to assimilate test and contextual elements instead of clearly differentiating them might be characteristic of a global perceptual style, while the tendency to exaggerate or contrast the difference between figural elements might be related to an analytic perceptual style (Wapner & Werner, 1957). Witkin, Dyk, Faterson, Goodenough, and Karp (1962) characterize individuals who exhibit a global perceptual style as field dependent and those who exhibit a high degree of perceptual articulation as field independent. Tasks such as the Embedded Figures Test which measure the degree to which perception of a figure is influenced by contextual visual stimuli have been found to differentiate reliably between these two perceptual styles. Individuals who are field dependent have difficulty segregating a figure from its surround and thus might be more likely when viewing an illusion figure to confuse test and contextual elements or to employ an averaging strategy. Those who are field independent tend to articulate a figure from its background and thus when viewing an illusion figure might be expected to extract the salient features which differentiate the test element from its context and to enhance those which would increase figural differentiation.

This suggests that differences in susceptibility to assimilation and contrast illusions should covary with differences in perceptual style. Witkin et al. (1962) found that the magnitude of the Mueller-Lyer illusion was greater for field dependent than for field independent individuals. In addition, cross cultural studies (Berry, 1968; Dawson, 1967) have found that societal groups which are more field dependent tend to manifest a larger illusion magnitude on the Mueller-Lyer while there appears to be no relationship between field dependence-independence and the magnitude of the horizontal-vertical illusion (Figure 4), which cannot be explained in terms of assimilation or contrast.

Since children are known to become more analytic or field independent with age (Witkin et al., 1962; Witkin, Lewis, Hertzman, Machover, Meissner, & Wapner, 1954), one would expect the strength of assimilation illusions to diminish with age and the strength of contrast illusions to increase with age. These expectations are generally consistent with reported age trends in illusion magnitude. A decrease in illusion magnitude with age has been observed for the Mueller-Lyer by many investigators (Barclay & Comalli, 1970; Binet, 1895; Gaudreau et al., 1963; Girgus et al., 1975; Noelting, 1960; Piaget & von Albertini, 1950; Piaget et al., 1954, Pollack, 1964, 1970; Segall et al., 1966; Wapner & Werner, 1957; Weintraub, et al., 1973).

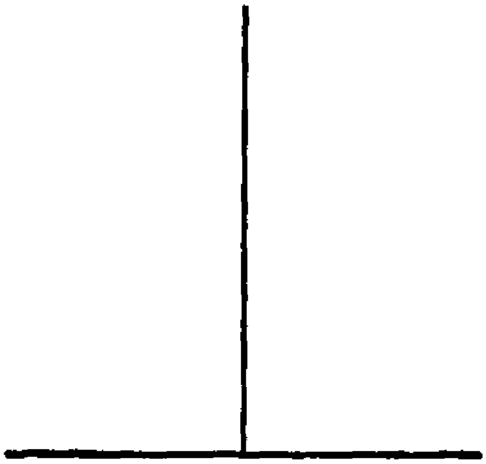


Figure 4. Horizontal-vertical illusion. The vertical line appears longer than the horizontal line.

Each segment of illusions which can be interpreted as assimilation-contrast phenomena seems to exhibit different age trends, the distortion of the overestimated or assimilation segments decreasing and that of the underestimated or contrast segments increasing with age, at least until adolescence. This has been observed for the Delboeuf (Santostefano, 1963), Ebbinghaus (Coren & Porac, 1978) and Ponzo (Quina & Pollack, 1972). The only contradictory finding is that of Piaget et al. (1942), who report a decline in illusion magnitude for both Delboeuf segments.

While the above results suggest that perceptual style may contribute to individual differences in susceptibility to illusions, it is nevertheless true that field dependent individuals experience contrast effects and field independent individuals experience assimilation effects. It would seem, then, that the illusion configurations themselves may induce wholistic or analytic viewing strategies which may be accentuated or diminished depending upon the perceptual style of the observer. Although the perceptual style hypothesis sheds no light on the configurational properties which might induce assimilation or contrast effects, one would expect both forms of distortion to decrease if the target element is isolated from its context. In support, differentiating the shaft from the wings of the Mueller-Lyer by making them different colors or by introducing a small gap between them reduces the magnitude of the illusion (Coren & Girgus, 1972b). A further implication of the perceptual style hypothesis is that segregating a target element from its context, either by increasing the distance between them or by presenting them successively, should eliminate the illusion. However, as noted previously, under these conditions assimilation effects reverse to contrast while contrast effects continue to be observed and may even be enhanced (Clem & Pollack, 1975; Cooper & Weintraub, 1970; Fellows, 1967; Girgus et al., 1972; Ikeda & Obonai, 1955; Jaeger, 1978; Oyama, 1960; Piaget & Lambercier, 1944; Pollack, 1964).

The perceptual style hypothesis is best able to account for individual differences in illusion magnitude and its principles are generally consistent with observed age trends in illusion magnitude. However, it has not approached the basic problem of why certain configurations seem to induce assimilation while others induce contrast.

### Oyama's feature analyzer theory

Oyama (1977) attributes assimilation and contrast effects to interactions among neural units which are selectively sensitive to size. The existence of such units in the visual cortex of animals has been demonstrated by microelectrode recordings (Hubel & Wiesel, 1965; 1968) which indicate that single units respond to a limited range of stimulus sizes and maximally to those of a preferred size. Still other stimuli appear to inhibit the response rate to a level below baseline. The presence of size detectors in the human visual system is hypothesized on the basis of psychophysical studies (Blakemore & Campbell, 1969; Campbell & Robson, 1968; Kulikowski & King-Smith, 1973) using as stimuli patterns of bright and dark striations known as gratings, which vary in spatial frequency or number of cycles of repetitive pattern per degree visual angle. Such studies have shown that inspection of a grating raises the contrast threshold for detecting subsequently presented gratings of a similar spatial frequency. No threshold elevation occurs for test gratings whose spatial frequency differs from that of the adapting grating by two or more octaves, an octave being a change in spatial frequency by a factor of two.

Theoretically, a stimulus of a given size would elicit responses from a population of neural units, with apparent size being determined by the location of the distribution peak, as shown in Figure 5 a. Oyama proposes that the test and inducing elements of an illusion configuration stimulate different populations of size detectors whose interaction shifts the position of the distribution peaks, producing distortions in apparent size. This idea is an expansion of a model proposed by Blakemore, Carpenter and Georgeson (1970) to account for distortions in perceived orientation. Drawing upon the lateral inhibitory model of Ratliff (1965), they suggest that summation of the activity of two simultaneously active response distributions would result in a mutual repulsion of their excitation peaks, as shown in Figure 5 b. In the size domain this would

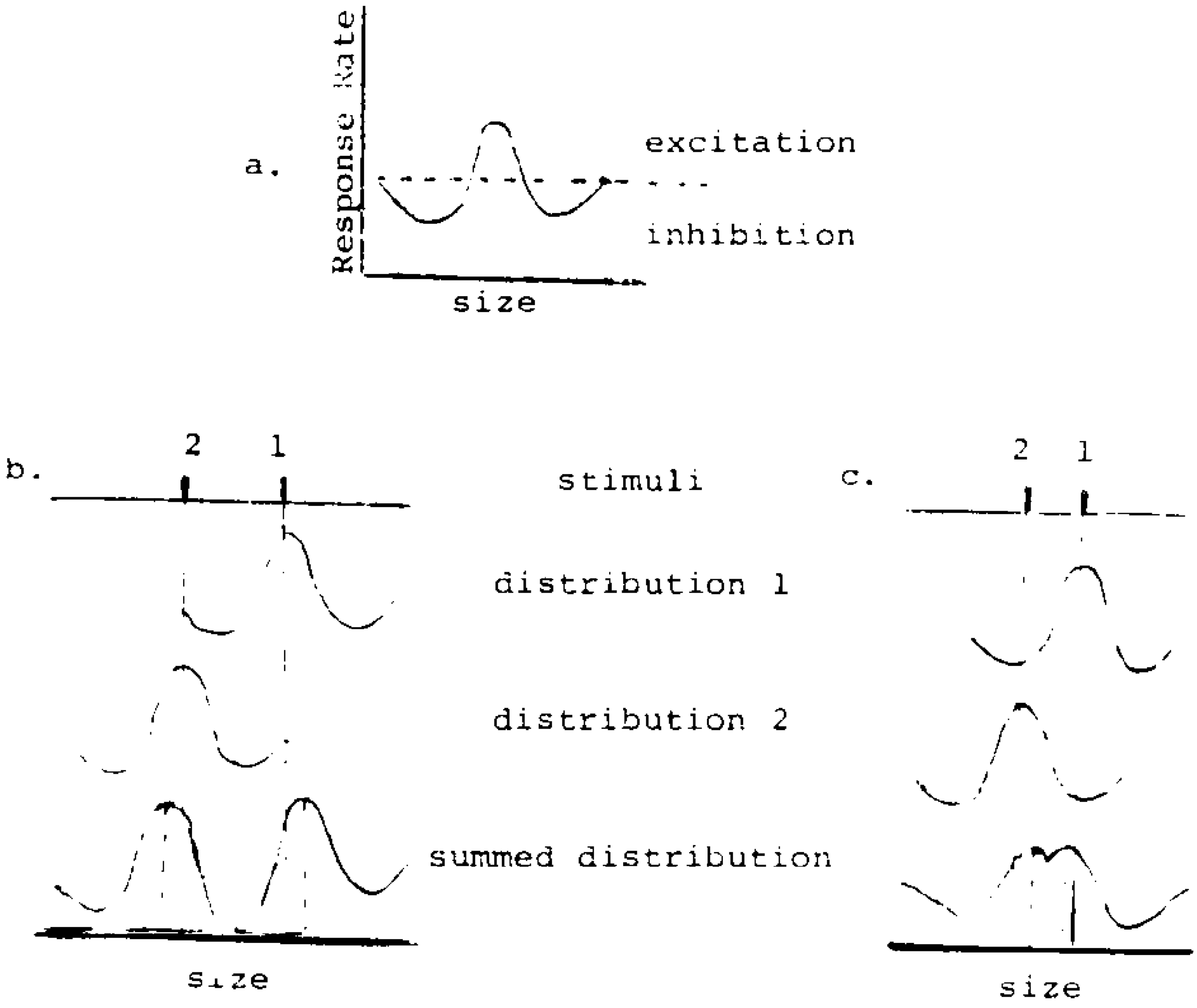


Figure 5. Response distributions of hypothetical size detectors. a) Response of a population of neural units to a single stimulus. Apparent size is determined by the location of the distribution peak. b) Two simultaneously presented stimuli activate different distributions which summate their activity, resulting in repulsion of excitation peaks or contrast. Apparent size difference of stimuli (dotted lines) is greater than objective size difference (solid lines). c) Summed distributions of two simultaneously presented stimuli results in attraction of excitation peaks or assimilation. Apparent size difference of stimuli (dotted lines) is less than objective size difference (solid lines).

correspond to a contrast effect since the apparent size difference between the test and inducing elements of the configuration is increased. According to Oyama, the model of Blakemore et al. (1970) also predicts the attraction of excitation peaks when their separation is small relative to the width of the distributions (Figure 5 c). This would correspond to an assimilation effect since the apparent size difference between the figural elements is decreased.

Oyama's account of a reversal from assimilation to contrast under conditions of successive presentation is most easily understood from a consideration of Figure 5 c. The overlap in the excitation portions of the two distributions indicates those neural units which are activated by both the test and the inducing stimulus. According to Oyama, prior inspection of the inducing element reduces the sensitivity of those detectors which are within the distribution of the test stimulus, causing the peak of the latter distribution to shift away from that of the inducing stimulus. No reversal would be expected for a contrast effect under conditions of successive presentation since, as shown in Figure 5 b, the excitation portions of the two distributions do not overlap.

Oyama asserts that, whether the figural elements are presented simultaneously or successively, the magnitude of the distortion is a function of the size ratio between test and inducing elements. A logarithmic distribution of size tuning curves is hypothesized so that regardless of the retinal size of a configuration, identical ratios between test and inducing elements would correspond to a constant separation on the logarithmic scale and thus result in identical illusion magnitudes.

In support, there is a good deal of Japanese work (reviewed by Oyama, 1960) to indicate that the overestimation of the Delboeuf and divided line illusions varies systematically with the ratio between test and inducing elements. There seems to be good agreement that maximal overestimation of the Delboeuf occurs when the diameter of the outer and inner circles is in the ratio 3:2 and that maximal overestimation of the divided line is obtained when each flank is one-half the length of the center segment. Similar results have been obtained for the Delbouef by Piaget et al. (1942) and for the divided line by Lewis (1912) and Obonai (1954). However, there seems to be no general agreement on the figural ratio which yields maximal underestimation of these illusions.

Oyama's theory receives only partial support from studies of the effect of retinal size on illusion magnitude. Consonant with the theory, the ratio producing maximal overestimation of the Delboeuf remains constant with variations in the retinal size of the illusion figure (Ogasawara, 1952; Piaget et al., 1942). Also, the illusion magnitude of the Ponzo appears to be unaffected by retinal size (Farquhar & Leibowitz, 1971). Contrary to the theory, a number of investigators have observed a decrease in illusion magnitude as the retinal size of the figure is increased. This has been found for the overestimated segment of the divided line illusion (Obonai, 1954) and for the Mueller-Lyer illusion (Binet, 1895; Heymans, 1896; Kido, 1927; Obonai, 1935).

A further difficulty with Oyama's model is that a simple summation of the distributions in Figure 5 c would result, not in attraction of the excitation peaks but rather, a distribution with a single peak. The integrity of the two distributions might be retained if summation were nonlinear, as suggested by Carpenter and Blakemore (1973) but a model of such interaction has not been formulated. Furthermore, the relationship between spatial frequency detectors and size perception has not yet been established. Despite these difficulties Oyama's theory is attractive because it proposes that illusions result from physiological mechanisms which are basic to all perception.

### Adaptation level theory

Helson's adaptation level theory (Helson, 1964a, 1964b), a far-ranging theory of perceptual-judgmental phenomena, was not formulated specifically to explain illusions, although Helson suggested that it might be able to do so. The theory is basically quantitative but can be understood also in non-quantitative terms. According to the theory a stimulus is always judged relative to the observer's current adaptation level, which is determined not only by the stimulus currently in the visual field, but also by previously presented stimuli as well as a number of organismic variables. Essentially the adaptation level is computed by averaging three different classes of stimuli: focal stimuli, background stimuli, and residual stimuli. Focal stimuli are those which occupy the observer's focal attention, such as those being judged; background stimuli consist of the contextual elements surrounding the focal stimulus; residual stimuli include stored representations of previously presented stimuli, learned perceptual strategies, constitutional predispositions and the current physiological state of the observer. These three classes of stimuli are appropriately weighted, focal stimuli most heavily and residual stimuli least heavily, and their geometric mean is computed to arrive at the adaptation level. Helson has proposed that stimuli which are close to the adaptation level are perceived as if they were at the adaptation level, in other words, they are assimilated to the adaptation level. On the other hand, he has proposed that stimuli which are quite distant from the adaptation level appear either smaller or larger than their objective size by contrast. This formulation accounts for assimilation and contrast in a general way but it does not specify how close to the adaptation level a focal stimulus must be in order for assimilation to take place and how distant it must be for contrast to occur.

Mathematical formulations of the theory have not been widely applied but they seem capable of fairly precise quantitative description of at least a limited number of illusions. Merryman and Restle (1970) and Restle and Merryman (1968) use an equation of the general form:

$$\text{judged size} = \text{physical size}/\text{adaptation level}$$

The equation states that apparent size is shifted away from the adaptation level, increasing when the adaptation level is small and decreasing when it is large. Since the adaptation level will increase when contextual elements are large and decrease when they are small, an equation of this form predicts only contrast and cannot be applied to assimilation effects.

Using a different mathematical formulation, Massaro and Anderson (1971) are able to predict the magnitude of the Ebbinghaus illusion as a function of the size, number, and distance of the surrounding circles. The general form of the equation is as follows:

$$\text{judged size} = ws + (1 - w)s^*$$

Applied to the Ebbinghaus illusion, the term $s^*$ is the apparent size of the central circle in the presence of a single context circle and thus represents a contrast effect. This term is combined with the apparent size of the central circle with no context circles ($s$) and each is weighted, with the stipulation that the weights sum to unity.

While this mathematical formulation differs from that of adaptation level theory, the general principles are quite similar. Perceived size is a function of the size of the inducing elements and the value of the weighting parameter is determined by their number and distance from the test element, in much the same fashion as these factors affect the adaptation level. Increasing the number of context circles increases the weight of the background stimuli, thus increasing the magnitude of the illusion. On the other hand, increasing the distance between inducing and test stimuli decreases the weight of the background stimuli and so should decrease illusion magnitude. Contrary to this formulation, increasing the distance between the test and inducing elements of the Ebbinghaus decreases the illusion magnitude only of the overestimated segment while the illusion magnitude of the underestimated segment increases (Girgus et al., 1972).

A similar difficulty is encountered in applying adaptation level theory to temporal separation phenomena. According to the theory, background stimuli, which are presented simultaneously with the test element, should affect perceptual estimates more than residual stimuli, which are presented prior to the test stimulus. The expectation that illusion magnitude should decrease under conditions of successive presentation is contradicted by the reversal from assimilation to contrast manifested by the Delboeuf (Cooper & Weintraub, 1970) and Mueller-Lyer (Pollack, 1964).

Although adaptation level theory can, in principle, be applied to assimilation as well as contrast phenomena, in practice it has been applied only to contrast. It has difficulty specifying when stimuli would be assimilated to the adaptation level and when they would be contrasted with it. Let us, therefore, consider still another theory of assimilation-contrast.

### Piaget's theory

Piaget (1969) hypothesizes specific mechanisms to account for illusion formation and attempts to identify the relevant inducing context, incorporating both of these factors into quantitative statements that describe the magnitude of many illusions quite successfully. Piaget's basic assumption is that *centrations* or acts of attention are not distributed equally over all parts of a figure and that the portion which receives the greatest density of centrations tends to be overestimated relative to other portions of the figure. By monitoring eye movements Piaget has shown that observers spend more time fixating the larger of two unequal extents and that this extent tends to be overestimated. Although foveal fixation and attention are generally correlated, each can be varied independently. When observers are instructed to attend to an element in peripheral vision, it, rather than the foveally fixated element, is overestimated (Fraisse, Ehrlich & Vurpillot, 1956). Centrations are composed of many *encounters* between the elementary units of a display and the elementary units of the visual system. These encountering elements within the perceiver are not neural units but rather hypothetical and abstract. Piaget maintains that perception of an array involves active comparison or <u>coupling</u> of its various elements by progressive exploration of the configuration. Distortion ordinarily is obtained when coupling is incomplete and diminishes progressively with more complete exploration of figural relationships.

Piaget uses the following general equation to obtain illusion magnitude:

$$\text{illusion magnitude} = nL(L_1 - L_2)L_2/SL_{max}$$

where $L_1$ is the greater of two lengths compared, $L_2$ is the shorter length, $L_{max}$ is the greatest length of the entire figure, S is the surface or area of the configuration, n is the number of separate comparisons and L is a reference length which is not clearly defined but may be equal to $L_1$ or $L_2$. In practice this formula has had to be modified separately for each illusion to which it has been applied in order for the functions to be accurate. Therefore, in fact, each equation is derived empirically.

According to Piaget, there are two varieties of illusion. Primary illusions, those which decrease in magnitude with age, are said to result from an "interaction of elements perceived together in one single field of centration". Secondary illusions, those which increase in magnitude with age, are presumed to result from perceptual activities which bring distant portions of the array into relationship with one another. The suggestion that such perceptual activities develop with age is consistent with the observation that adults tend to scan a display more completely than children (Zaporozhets, 1965).

Piaget notes that the same perceptual mechanisms can result in either an increase or a decrease in illusion magnitude. Up to a point exploration of an array increases illusion magnitude, particularly when its elements are widely separated. On the other hand, more thorough exploration increases the probability that the number of couplings will approach the maximum and therefore, would result in a diminution of distortion. Obviously a theory which proposes an explanatory mechanism which can have quite opposite effects must be able to specify the conditions under which each would obtain. Although the theory is able to explain certain illusion phenomena after they have occurred, it is not sufficiently specific to allow prediction in advance.

This difficulty may be inherent in any theory which postulates central attentional processes as an explanatory mechanism. In order to validate such a theory it must be possible to observe the viewer's deployment of attention by a method which is objective and independent of illusion magnitude. While Piaget has indicated that eye fixations are sometimes an index of the observer's attention he has stipulated quite clearly that this is not always the case. Thus, when observers were shown variants of the divided line illusion they overestimated the longer segment in Figure 6 a and underestimated the shorter segment in Figure 6 b, displaying the usual distortion observed for this illusion. In each case gaze fixations were more numerous for the segment being

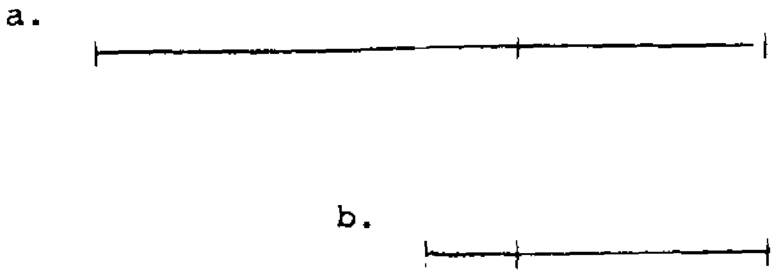


Figure 6. Variants of the divided line illusion. In a) the longer segment is overestimated, in b) the shorter segment is underestimated.
B = visual angle
retinal size

judged. Since the theory predicts that the element receiving the greatest density of centrations should be the one overestimated, overestimation of the longer segment is consistent with expectation but underestimation of the shorter is not. In order to account for the latter distortion Piaget postulates a reduced number of encounters for the shorter segment in comparison to the longer (Piaget, 1969, p. 103). This after-the-fact explanation is not very convincing since, had the opposite result been found, the theory could have accommodated it equally well. Since centrations, encounters and couplings are hypothetical processes which are never measured independently of illusion magnitude, the theory is as impossible to disprove as it is to prove. Thus nearly any experimental result can be explained after it has occurred but the theory has little predictive power.

## Pool and Store Model

All of the theories described so far have difficulty specifying the conditions necessary for the occurrence of assimilation or contrast and the underlying processing mechanisms involved. None provides definitive criteria for classifying illusions as assimilation or contrast phenomena. In the main these theories are descriptive rather than explanatory. Such theories can be useful if they clearly delineate a relevant phenomenon from other similar phenomena and describe the conditions under which it occurs. Unfortunately even the level of description provided is often so vague and ill defined that only a few testable hypotheses can be generated.

A more recent theory, known as the pool and store model (Coren and Girgus, 1978), attempts to define the antecedent conditions necessary for the occurrence of assimilation and contrast. According to this model different processing mechanisms are responsible for assimilation and contrast phenomena and the temporal distribution of incoming information determines which processing mode will tend to prevail. Coren and Girgus point out that when a stimulus configuration subtends a visual angle greater than the foveal width of about 2°, only that portion of the array in foveal vision is apprehended clearly. In order to see the entire configuration clearly, the observer must scan the array so that first one part is in foveal vision and then another. This means that although all parts of a stimulus display may be present simultaneously, they are taken in simultaneously only if the stimulus subtends a visual angle of not much more than 2°. Otherwise, the various parts of the display are actually apprehended in temporal succession by a series of separate fixations.

Coren and Girgus point out that psychophysical studies of line length and loudness (Ward & Lockhead, 1970, 1971) indicate that stimuli presented in close temporal proximity tend to be averaged or assimilated while those which are more separated in time tend to be perceived so that their differences are accentuated or contrasted. They suggest a parallel between these results and the assimilation-contrast effects of the classical illusions. Although all parts of an illusion figure may be presented simultaneously, the spatial proximity between the inducing context and the test element determines the temporal proximity of their entry into the visual system. If inducing and test elements are sufficiently close they can be seen in a single glance and hence enter the sensory register simultaneously. Under these conditions, Coren and Girgus suggest that test and inducing elements are pooled or averaged, resulting in assimilation. On the other hand, when the test element and inducing context are sufficiently distant from each other, they must be scanned in a series of glances and so they enter the visual system separated by an interval of time. Under these conditions each piece of visual information must be stored in memory to await integration of the final percept. Coren and Girgus speculate that temporally distributed information must be stored in a manner that will permit current visual input to be clearly differentiated from both prior and subsequent input. This leads to an accentuation of differences which results in contrast. According to this formulation, the terms assimilation and contrast reflect clearly different processing mechanisms and the temporal distribution of information determines which mechanism will be employed.

Using the pool and store model Coren and Girgus are able to account for a number of classical illusions and much of the illusion data described earlier in this chapter. For example, in the overestimated half of the Delboeuf illusion, the inner and outer circles are spatially proximate so that they tend to be seen simultaneously. According to the model, this would result in the pooling of their extents and the overestimation of the inner circle. In the underestimated variant of the Delboeuf the visual angle separating the two concentric circles tends to be extrafoveal, the outer circle being much larger than the inner one. Because the circles are spatially separated, they must be scanned in a series of temporally discrete fixations. The information contained in each fixation must be encoded and compared with information which arrives at a later point in time. The encoded memory representations tend to enhance the differences between the two circles. This contrast effect results in underestimation of the inner circle.

The Ponzo illusion can be explained in a similar fashion. The test line, when placed within the narrow portion of the angle near the apex, is so close to the sides of the angle that it cannot be glimpsed alone without the inducing context. Therefore the test line is pooled with the total horizontal extent between the converging sides of the angle, and the line is overestimated. When the test line is placed within the wide portion of the angle both cannot be seen together clearly in foveal vision and their entry into the visual system is temporally separated. The test line is contrasted with the total horizontal extent between the sides of the angle and is underestimated.

For both the overestimated and underestimated halves of the Mueller-Lyer illusion there is no separation whatever between the test and inducing elements. Since the shaft cannot be viewed without simultaneously viewing the wings, its length is pooled with the average locus of the points that make up the wings, resulting in assimilation.

In addition to being able to explain the above illusions as well as several others, the pool and store model is also able to account for a number of empirical findings which were previously shown to be difficult for other theories to integrate. Let us re-examine some of these within the context of the pool and store model.

The model implies that the effect of presenting the contextual elements prior to the test element should be similar to the effect of separating them spatially, provided that the spatial separation is sufficiently great that the elements must be scanned in discrete glances. According to the model, when the elements of an assimilation illusion are temporally separated, assimilation should be impossible and the illusion should reverse to contrast. On the other hand, since temporal separation of the elements is a necessary precondition for the occurrence of contrast, further temporal separation of the elements of a contrast illusion should not destroy the illusion. Consistent with this line of reasoning, the overestimated segments of the Mueller-Lyer and Delboeuf illusions manifest assimilation when the figural elements are presented simultaneously and contrast when the inducing elements are presented prior to the test element (Clem & Pollack, 1975; Cooper & Weinbraub, 1970; Fraisse, 1971; Morinaga, 1935; Pollack, 1964; Sagara & Oyama, 1960; Seltzer & Sheridan, 1965). On the other hand, the underestimated segments of the Delboeuf and Ebbinghaus illusions exhibit contrast effects whether the figural elements are presented simultaneously or successively (Cooper & Weintraub, 1970; Ikeda & Obonai, 1955; Jaeger, 1978).

The effects of spatial separation of test and inducing elements seem to be quite similar to those of temporal separation. Increasing the gap between the wings and the shaft of the underestimated portion of the Mueller-Lyer illusion results in a gradual weakening of assimilation and finally a reversal to contrast (Fellows, 1967; Ihara & Kido, 1934; Yanigasawa, 1939). Similarly, the overestimated segment of the Ponzo exhibits a gradual decrease in the strength of the assimilation effect and a reversal to contrast with increasing distance between the test line and its enclosing angle (Pressey et al., 1971). As the distance between the central and surrounding circles of the Ebbinghaus increases, the distortion of the overestimated variant gradually decreases and reverses to assimilation, while that of the underestimated segment is enhanced (Girgus et al., 1972). Although the Ebbinghaus is traditionally regarded as a wholly contrast phenomenon, this result suggests that one component of this illusion may be an assimilation-contrast factor which is related to the distance and hence the visual angle between the central and surrounding circles.

Although there is considerable supporting evidence for the pool and store model, its assertions have not been tested directly. Most investigations of the stimulus parameters associated with assimilation-contrast distortions have manipulated the size relationship between the test and contextual elements of a configuration. Generally assimilation, or overestimation, is observed when contextual elements are small and contrast, or underestimation, is observed when they are large, relative to the test element. However, when contextual elements are large their distal edges are further from the test element than when they are small. Thus, the size ratio between test and inducing elements and their visual angle proximity tend to be confounded.

By varying the visual angle of an entire configuration it is possible to manipulate the proximity between test and inducing elements while holding constant their size ratio (see Figure 7). If size ratio alone is the effective variable, this manipulation should not affect illusion magnitude. If the visual angle separating test and inducing elements is critical--let us call this factor the critical visual angle--illusion magnitude should vary despite the invariance of the size ratio. The pool and store model implies that the same figural ratio which induces an assimilation effect when the critical visual angle is approximately foveal, allowing test and inducing elements to be seen simultaneously, should tend to induce a contrast effect when

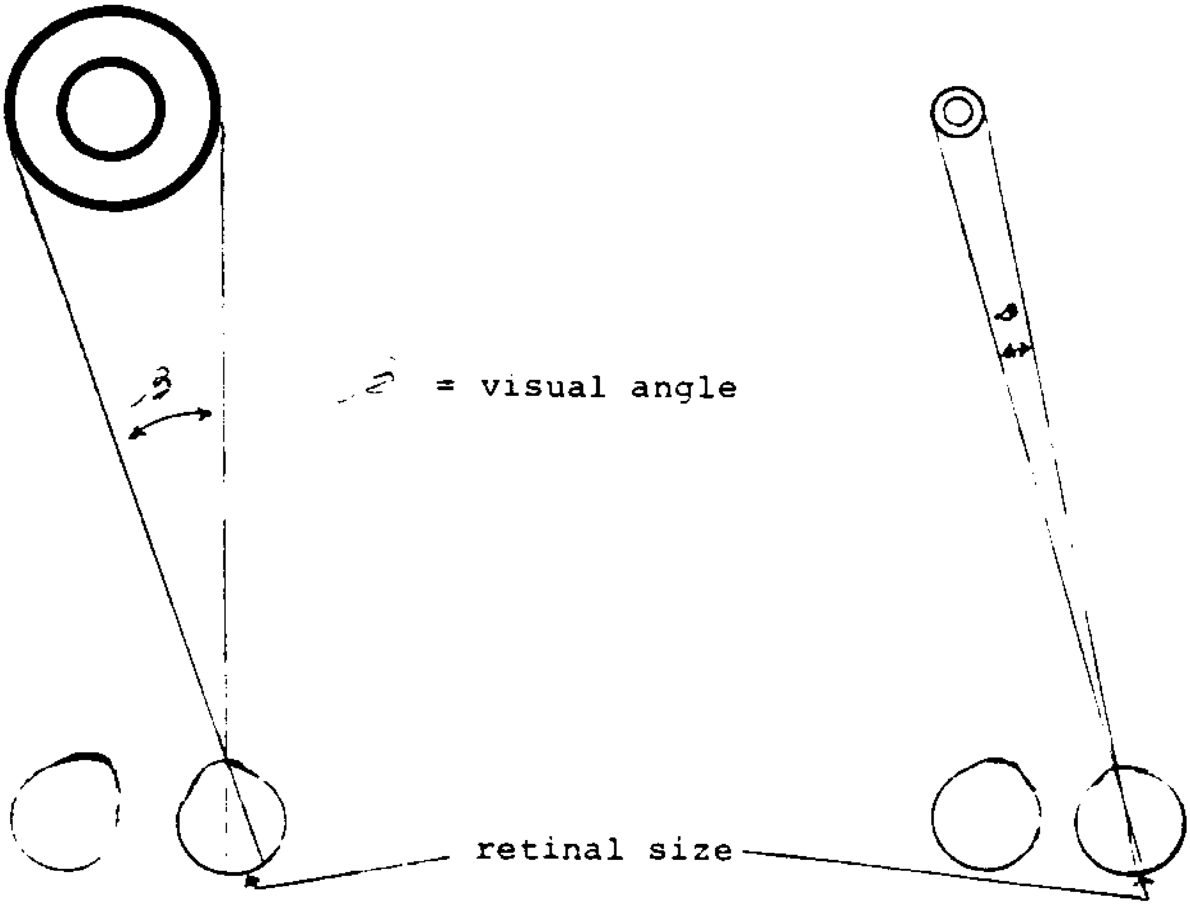


Figure 7. Illusions with identical figural ratios but subtending different visual angles. The critical visual angle, related to the absolute distance between the two concentric circles, increases with visual angle.

the critical visual angle is sufficiently large that the observer must scan test and inducing elements successively. Similarly, the model implies that the same figural ratio which induces a contrast effect when the critical visual angle is clearly suprafoveal should tend to induce an assimilation effect when the critical visual angle is approximately foveal. Thus, the _pool_ and _store_ model implies that assimilation and contrast effects are not linked to specific figural ratios but rather to the critical visual angle between test and contextual elements.

This view presents a problem with respect to terminology. On the one hand it seems inconsistent with the _pool_ and _store_ model to designate particular figural ratios as assimilation or contrast figures. On the other hand, it would be confusing as well as premature to abandon the usual terminology at this point. Therefore the designations assimilation and contrast _figures_, and assimilation and contrast _illusions_, will be used to refer to the figural ratios which ordinarily manifest over- and underestimation, respectively. The terms assimilation and contrast _segments_ and assimilation and contrast _variants_ will be used interchangeably with these terms. When referring to specific distortions and their assumed underlying processes, the terms _assimilation_ and _contrast_ will be used. The designations assimilation _effect_ and contrast _effect_, and assimilation _phenomenon_ and contrast _phenomenon_, will be used interchangeably with these terms. Thus, according to the _pool_ and store model, an assimilation illusion may manifest a contrast effect (underestimation) if its critical visual angle is sufficiently suprafoveal.

Since the critical visual angle covaries with the figural ratio, evidence which might support the pool and store hypotheses must be sought from studies which varied ratio over a range of test figure sizes or studies which used a single ratio and varied the size of the configuration. Ogasawara (1952) varied the figural ratio of the overestimated segment of the Delboeuf as well as the retinal size of test circles. Regardless of retinal size, maximal overestimation occurred when the ratio between the diameter of the outer and inner circles was 3:2. At this ratio the magnitude of the illusion was similar for all figure sizes, leading Ogasawara to conclude that illusion magnitude varied with the ratio between the circles rather than with their separation. However, if the critical visual angle is calculated it is apparent that at the 3:2 ratio test and inducing circles were separated by no more than 1° even for the largest figure used. Piaget et al. (1942) also found maximal overestimation of the Delboeuf when the figural ratio was approximately 3:2, regardless of retinal size. The contrast segment of the illusion behaved somewhat erratically and it was not possible to determine a ratio for maximal underestimation. At the optimal ratio for overestimation the separation between inner and outer circles was approximately 2° visual angle and no contrast ratio was tested employing a separation this small. It is apparent that neither Piaget nor Ogasawara manipulated retinal size over a sufficiently wide range to determine whether assimilation-contrast effects are related to the critical visual angle.

A number of studies have manipulated the retinal size of a configuration while holding ratio constant. The magnitude of the overestimated or assimilation variant of the divided line and divided space illusions is reported to increase as the size of the configuration is decreased (Obonai, 1954). Whether the contrast variant fails to respond to the size manipulation or whether such manipulation has not been attempted is unclear. Farquhar and Leibowitz (1971) found no difference in the magnitude of the Ponzo illusion as a function of the size of the configuration. Unfortunately they used a variant of the illusion containing lines radiating from the apex of the angle to its foot. Since the test lines were superimposed on this background of radiating lines both were viewed together whatever the size of the configuration. Moreover they measured the composite form of the illusion, the contrast segment serving as the standard and the assimilation segment as the variable. Even if the assimilation effect had decreased with size, if the contrast effect increased by an equal amount the total illusion magnitude would be unchanged. Therefore measurement of the composite form of an assimilation-contrast illusion could obscure the different effect of size on each segment of the illusion.

A number of investigators have studied the effect of size on the magnitude of the Mueller-Lyer illusion. Reports of a decrease with retinal size are most frequent (Binet, 1895; Heymans, 1896; Kido, 1927; Obonai, 1935), while an increase with retinal size is reported by Waite and Massaro (1970). Measuring each segment of the illusion separately, Bayer and Pressey (1972) found that the distortion of the tails-in segment remained invariant while that of the tails-out segment decreased with retinal size. This suggests that in the earlier studies, which used the composite form of the illusion, the observed decrease in distortion with retinal size may have been due principally to a change in the tails-out segment. In support, Benussi (1906), who studied only the underestimated segment of the Mueller-Lyer, found that illusion magnitude remained constant with variations in retinal size.

The studies reviewed offer scant evidence that illusion magnitude may be affected by the visual angle between test and contextual elements. However, no investigator has systematically manipulated the critical visual angle over a sufficiently wide range to adequately test the implications of the _pool_ and _store_ model. The studies in this dissertation were carried out in order to provide such a test.

## Rationale of the Present Studies

Five studies were carried out in which the critical visual angle was manipulated by varying the retinal size of the illusion configuration while holding its size ratio constant. The critical visual angle was defined as the separation between the edge of the test element and the distal edge of the context. Based on the _pool_ and _store_ model it was expected that with a separation of not more than about 2° visual angle an assimilation process should predominate because both elements would always be seen simultaneously in foveal vision. A contrast process should predominate with a separation sufficiently large so that the observer always would have to scan the configuration in order to see all parts of it clearly. It was reasoned further that with a separation of 4° to 5° the elements might be seen sometimes separately and sometimes simultaneously, depending upon where the observer fixated the configuration. With the gaze centered on the test element, the distal edge of the context element would be sufficiently peripheral so that both could not be seen clearly at the same time. With the gaze fixated midway between the test and inducing elements both might be seen simultaneously since there is a band of 1° to 2° of relatively clear vision surrounding the fovea (Woodworth & Schlosberg, 1954, p. 384). In support, Kaufman and Richards (1969) found that in a free viewing situation fixations tend to cluster about the center of arrays subtending up to 5° visual angle, suggesting that the complete figure could be seen fairly clearly without scanning. Therefore, both assimilation and contrast processes should be induced by an illusion configuration with a critical visual angle of 4° to 5°. Thus, enlarging an assimilation figure so that its critical visual angle is 4° to 5° should weaken the assimilation effect and, reducing a contrast figure so that its critical visual angle is 4° to 5° should weaken the contrast effect.

This is the rationale for the visual angle manipulations in the current studies. The illusions used each have one segment which is generally overestimated and one which is generally underestimated.

## Hypotheses

Based on the pool and store model the following predictions were made:

1. The overestimated segment of each illusion should manifest less overestimation when the figure subtends a large visual angle than when it subtends a small visual angle. In other words, the distortion manifested by the overestimated variant of each illusion should decrease with retinal size.

2. The underestimated segment of each illusion should manifest greater underestimation when the figure subtends a large visual angle than when it subtends a small visual angle. Therefore, the distortion manifested by the underestimated segment of each illusion should increase with retinal size.

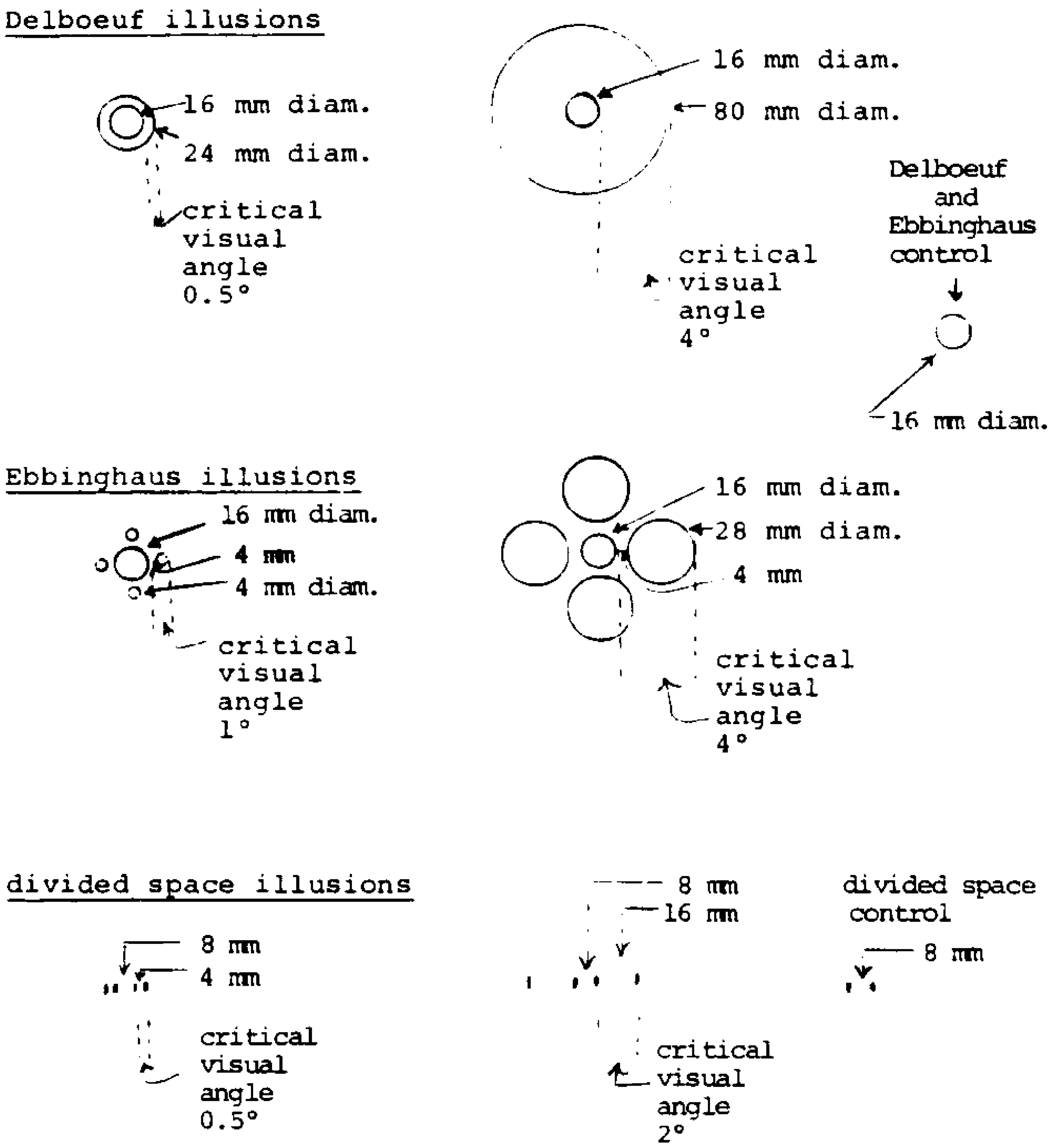
# III

# EXPERIMENTS 1 AND 2

The stimuli in both experiments consisted of the over- and underestimated segments of the Delboeuf, Ebbinghaus and divided space illusions, presented on slides. By changing the size of the on-screen image the identical figure could subtend either a large or a small visual angle. Size estimates were made using a variable line apparatus.

## Experiment 1

Subjects. Twelve City College students served as subjects. Stimuli. The stimuli were the over- and underestimated segments of the Delboeuf, Ebbinghaus and divided space illusions and control figures, consisting of the test element with no inducing elements. Stimulus dimensions and visual angles shown in Figure 8 and enumerated in the text following are for figures in the small visual angle condition. The analagous values for figures in the large visual angle condition are ten times as large. Delboeuf. The ratio of outer to inner circle diameter chosen for the assimilation figure was 3:2 since it has been shown to result in maximal overestimation (Oyama, 1960; Piaget et al., 1942). Since no optimal ratio has been reported for the contrast figure, but underestimation has been reported with a ratio as small as 4:1 (Girgus & Coren, Note 1; Piaget et al., 1942), a ratio of 5:1 was chosen. In the small visual angle condi-



8 mm = approximately $1^0$ visual angle

Figure 8. Illusion and control stimuli, Experiment 1 and 2. Overestimated segment of each illusion appears at left, underestimated segment at right. Dimensions and critical visual angles shown are for figures subtending a small visual angle. Analogous values for figures subtending a large visual angle are 10 times as large.

tion the diameter of the inner circle of both illusion variants and of the control circle was 16 mm and subtended 2.0° visual angle. The diameter of the outer circle of the assimilation figure was 24 mm (3.0° visual angle) and that of the contrast figure was 80 mm (10.0° visual angle). The critical visual angle of the assimilation figure was 0.5° and of the contrast figure was 4.0°. Ebbinghaus. Both variants of the illusion consisted of a central circle surrounded by four context circles. The stimulus parameters chosen were similar to those found by Girgus et al. (1972) to yield maximal distortion. In the small visual angle condition the diameter of the central circle of both variants of the illusion was 16 mm (2.0° visual angle). The same control circle was used for both the Ebbinghaus and Delboeuf illusions. The distance between the edge of the central circle and the proximal edge of surrounding circles was 4 mm (0.5° visual angle) for both variants of the Ebbinghaus. The diameter of the context circles was 4 mm (0.5°) for the overestimated variant and 28 mm (3.5°) for the underestimated variant. The critical visual angle was the distance between the edge of the central circle and the distal edge of the surrounding circles, 1.0° for the overestimated variant and 4.0° for the underestimated variant. Divided space illusion. The figural ratios chosen were those found to produce maximal distortion by Obonai (1954). For the overestimated segment the ratio of the length of the total figure to the length of the center segment was 2:1 and for the underestimated segment was 5:1. In the small visual angle condition the length of the center segment of both illusion variants and of the control figure was 8 mm (1.0° visual angle). The length of the total figure was 16 mm (2.0°) for the overestimated segment and 40 mm (5.0°) for the underestimated segment. The critical visual angle was the visual angle subtended by each flanking segment, 0.5° for the overestimated variant and 2.0° for the underestimated variant.

Presentation Method and Apparatus. The illusion and control stimuli were slides, prepared by photographing drawings made with black ink on white paper. The slides were white-on-black negatives, back-projected on a 4 ft x 4 ft screen using a Kodak Carousal projector. Viewing distance was held constant at 450 mm. Visual angle was manipulated by varying the distance between the projector and the screen and by using a zoom lens (focal distance adjustable from 102 - 152 mm) to reduce the image, and a 2 1/2 in lens to enlarge it. Apparently equal brightness of large and small images was achieved by inserting a collar in the reduction lens. Manipulating retinal size optically allowed the same slides to be used in the two visual angle conditions, and insured that frame size and line width were proportional to visual angle. Visual angle was varied by a factor of 10, which was the largest variation that could be obtained using the same slides for both visual angle conditions. Stimuli were blocked by size and order of blocks counterbalanced within and between subjects. Order of stimuli within blocks was reversed for half the subjects.

Estimation Procedure. Each observer made a single estimate of each stimulus. The diameter of the central circle of the Delboeuf and Ebbinghaus illusions and the length of the central extent of the divided space illusion were estimated by adjusting a variable line apparatus constructed of oak-tag (see Figure 9) which had millimeter tape affixed to the reverse of the line. The apparatus used to judge stimuli subtending a small visual angle contained a line of Chartpak tape 1.6 mm wide and measured 30 cm x 8.5 cm when the line was fully retracted. The apparatus used to judge stimuli subtending a large visual angle contained a line of Chartpak tape 3.2 mm wide and measured 35 cm x 8.5 cm when the line was fully retracted. Half the subjects always received the variable line set obviously too short and half always received it set obviously too long. The height of each observer's seat was adjusted so that the center of all stimuli was approximately at eye level. In order to be certain that observers did not deliberately avoid looking at the contextual elements of the larger figures it was stressed that they were always to look at the entire figure before making a judgment.

Results and Discussion. Illusion magnitude was computed as a percentage by taking the difference between the illusion figure estimate (I) and the control figure estimate (C), dividing by the control figure estimate and multiplying by 100, as follows:

Figure 9. Variable line apparatus used to make size estimates in Experiments 1 and 2. Length of line is varied by sliding it in and out of sleeve.

$$\text{Percentage illusion magnitude} = \frac{I - C}{C} \times 100$$

A positive illusion magnitude indicates that the illusion figure was overestimated relative to the control figure and a negative illusion magnitude indicates that it was underestimated relative to the control figure. The illusion magnitudes for all three illusions are shown in Table 1.

Differences in illusion magnitude between large and small visual angle figures were analyzed using t tests for correlated means. A statistically significant difference was manifested only by the underestimated variant of the Ebbinghaus illusion ($t = 2.34$, df = 11, $p < .05$, 2 tailed). However, the differences were in the expected direction for all comparisons. Since subjects may have experienced some difficulty in estimating the size of a circle by judging the horizontal extent of its diameter, it it possible that subject variability may have prevented these differences from reaching statistical significance. Therefore, it was decided to replicate the study, this time asking subjects to make two estimates of each figure and allowing them pre-experimental practice with the variable line apparatus.

## Experiment 2

Subjects. Twelve City College students served as subjects.

Stimuli and Procedure. Stimuli and method of presentation were the same as in the previous study except that each figure was presented twice, in random order, and the mean of the two estimates was used in analyses. In order to

## Table 1

### Mean Percentage Illusion Magnitudes in Experiment 1

| | Overestimated Variant | | | | Underestimated Variant | | | |
|---|---|---|---|---|---|---|---|---|
| | Visual Angle | | | | Visual Angle | | | |
| Illusion | Large | Small | Diff. | *t* | Large | Small | Diff. | *t* |
| Delboeuf | 4.12 | 11.40 | -7.28 | 1.17 | 1.00 | 12.20 | -11.20 | 1.11 |
| Ebbinghaus | 3.96 | 10.97 | -7.01 | 1.18 | -6.59 | 12.34 | -18.93 | 2.34* |
| Divided space | 2.08 | 5.71 | -3.63 | 0.44 | -3.65 | 0.52 | - 4.17 | 0.56 |

*$p < .05$, 2 tailed, df = 11.

familiarize observers with the variable line apparatus they were given pre-experimental practice, estimating the size of circles and extents similar to the control figures. Practice stimuli were drawn on white paper with black ink and were presented vertically against the projection screen. Eight stimuli were used: four circles of 12, 20, 140, and 200 mm diameter and four extents measuring 5, 11, 50, and 110 mm. Thus, each set of four consisted of one pair similar in size to the control figures in the small visual angle condition and one pair similar to those in the large visual angle condition and, within each pair, one was smaller than the control figure and one was larger. Each of the eight practice figures was estimated twice and immediate feedback was given by placing the variable line apparatus against the figure so that the subject could see the extent of his error. Each experimental and each practice estimate was made once with the variable line set obviously too short and once with it set obviously too long.

Results and Discussion. Illusion magnitudes, computed in the same manner as in the previous study, are shown in Table 2. Analyses, using $t$ tests for correlated means, with df = 11, indicate that none of the figures manifests a statistically significant difference in illusion magnitude between large and small visual angle conditions.

However, the fact that the Delboeuf and Ebbinghaus illusions manifest differences in the predicted direction in

Table 2

Mean Percentage Illusion Magnitudes in Experiment 2

| | Overestimated Variant | | | | Underestimated Variant | | | |
|---|---|---|---|---|---|---|---|---|
| | Visual Angle | | | | Visual Angle | | | |
| Illusion | Large | Small | Diff. | *t* | Large | Small | Diff. | *t* |
| Delboeuf | 2.32 | 7.81 | -5.49 | 1.61 | -6.08 | -3.32 | -2.76 | 0.55 |
| Ebbinghaus | 1.04 | 2.95 | -1.91 | 0.64 | -4.10 | -3.09 | -1.01 | 0.39 |
| Divided space | 7.06 | 1.22 | 5.84 | 1.13 | -0.75 | -7.49 | 6.74 | 2.10 |

both this study and the previous one suggests that the experimental effect may have been obscured. This might occur if the response measure yields results which are so variable that the effect of interest is difficult to detect. In a comparison of different methods of illusion measurement Coren and Girgus (1972a) found that the method of average error, using the same type of variable line apparatus used in the present experiments, was the most efficient method of measurement for the Mueller-Lyer illusion while choice from a graded series was the most efficient measurement method for the Ebbinghaus illusion. Although the difference between the two methods was not very great, it may be that the extreme visual angles utilized in the present studies added to the variability of estimates of circle size obtained using the variable line apparatus. Therefore, in the next study the response measure was choice from a graded series of comparison stimuli and only a single illusion, the Delboeuf, was used.

# IV

# EXPERIMENTS 3 and 4

The stimuli in both experiments were slides of the assimilation and contrast segments of the Delboeuf illusion which subtended either a large or a small visual angle. Observers made their size estimates by choosing a comparison circle from a graded series presented in booklet form, one circle to a page.

## Experiment 3

Subjects. Twelve City College students served as subjects.

Stimuli and Apparatus. The test stimuli were the assimilation and contrast segments of the Delboeuf illusion and control circles with no surrounding circle, identical to the stimuli used in the previous experiments. Viewing distance, visual angles and method of presentation were also the same. Size estimates of the central circle of the illusion figures and of the control figures were made using a graded series of comparison circles presented in booklet form, one circle to a page. Two booklets were prepared, one for each visual angle condition, consisting of reproductions of drawings (black on white) on paper 8 1/2 x 11 in. Comparison circles for the small visual angle condition ranged in diameter from 11.5 mm to 20.5 mm in 0.5 mm steps and had a line width of about 0.5 mm. Comparison circles for the large visual angle condition ranged in diameter from 124 mm to 196 mm in 4 mm steps and had a line width of about 1.0 mm.

Procedure. Each of the three stimuli (two illusions and one control figure) was presented twice in random order at each visual angle and the mean of the two estimates was used in subsequent analyses. Stimuli were blocked by size and order of blocks counterbalanced within and between subjects. Order of stimuli within blocks was reversed for half the subjects. The two estimates of each stimulus were made by entering the comparison booklet once beginning with the smallest circles and once beginning with the largest circles. Order of entry was reversed for half the subjects. Once the entry point had been established, observers were free to look back and forth among the circles in the booklet.

Results and Discussion. Illusion magnitudes, computed as percentage differences from control figure estimates as described previously, are shown in Table 3. Statistical analysis was carried out using t tests for correlated means. Overestimation of the assimilation variant was 8.49% when the figure subtended a small visual angle and 5.19% when the figure subtended a large visual angle, a significant difference ($t = 2.706$, df = 11, $p < .05$, 2 tailed). The contrast variant was underestimated 1.86% when it subtended a large visual angle and was overestimated 2.81% when it subtended a small visual angle, and this difference also was significant ($t = 3.032$, df = 11, $p < .02$, 2 tailed). Both these results confirm the predictions of the pool and store model.

## Table 3

Experiment 3: Mean Percentage Illusion Magnitude, Delboeuf Illusion

| Assimilation Variant | | | | Contrast Variant | | | |
|---|---|---|---|---|---|---|---|
| <u>Visual Angle</u> | | | | <u>Visual Angle</u> | | | |
| Large | Small | Diff. | *t* | Large | Small | Diff. | *t* |
| 5.19 | 8.49 | -3.30 | 2.706* | -1.86 | 2.81 | -4.67 | 3.032** |

*$p < .05$, 2 tailed, df = 11

**$p < .02$, 2 tailed, df = 11

Since the stimuli used in this study were identical to the Delboeuf figures in the previous studies and only the response method was changed, it would appear that the use of a graded series of comparison figures is a more sensitive measure of circle size than the use of a variable line apparatus. However, in light of the fact that two previous studies failed to confirm the experimental hypotheses, a replication seemed in order.

## Experiment 4

The present experiment was carried out to replicate and extend the results of the previous study, using a contrast configuration with a larger outer to inner circle ratio.

Subjects. Twelve City College students served as subjects.

Stimuli and Apparatus. The stimuli were the assimilation and contrast segments of the Delboeuf illusion and control circles with no surrounding circle. Viewing distance and method of presentation were the same as in the previous studies. The ratio of outer to inner circle diameter was 3:2 for the assimilation segment and 8:1 for the contrast segment. The use of a large ratio for the contrast configuration necessitated a smaller center circle than used in the previous experiments so that the figure would not extend beyond the projection screen when its retinal size was large. The retinal size of the contrast figure was varied by a factor of 10 and identical slides were used in both visual angle conditions. The retinal size of the assimilation figure was varied by a factor of 15 so that the critical visual angle would be comparable to that used in the previous studies. This necessitated using different slides in each visual angle condition. In the small visual angle condition the central circle of both illusion variants and the control circle had a diameter of 12 mm (1.5° visual angle). The assimilation segment had an outer circle diameter of 18 mm (about 2.2°) and the critical visual angle was about 0.4°. The contrast segment had an outer circle diameter of 96 mm (12.0°) and the critical visual angle was about 5.2°. In the large visual angle condition the assimilation segment had a central circle diameter of 180 mm, an outer circle diameter of 270 mm, and the critical visual angle was about 5.6°. The contrast figure had a central circle diameter of 120 mm, an outer circle diameter of 960 mm and the critical visual angle was about 52.5°. Two control circles were presented, one with a 180 mm diameter and one with a 120 mm diameter. Slides were prepared from drawings made in black ink on clear acetate. Each sheet of acetate contained a single circle, either a test circle or one of the inducing circles. Each illusion figure was constructed by superimposing two sheets of acetate and photographing them on a light box. The control circle was photographed with a blank sheet of acetate. This method produced sharper slides than drawings made on paper. In addition, it ensured that the test circle of the illusion and the control circle were identical in size since they were in fact the same circle. This control feature was helpful because at the larger magnification any small errors in drawing became sizeable on-screen errors. Two booklets of comparison figures were prepared in the same manner as in the previous study. The booklet in the small visual angle condition was 8 1/2 x 11 in and contained circles ranging in diameter from 7.5 mm to 16.5 mm in 0.5 mm steps with a line width of about 0.5 mm. The booklet in the large visual angle condition was 11 x 11 in and contained circles ranging in diameter from 84 mm to 216 mm in 4 mm steps with a line width of about 1.0 mm. This booklet contained a larger range of circle sizes because, since the comparison figures for assimilation test figure (180 mm) and the contrast figure (120 mm) overlapped, the same booklet was used for both.

Procedure. The procedure was identical to that used in Experiment 3, each observer making two estimates of each test figure at each visual angle, with the mean used in subsequent analysis.

Results. Illusion magnitudes, computed as percentage differences from control figure estimates as previously described, are shown in Table 4. Statistical analysis was carried out using $t$ tests for correlated means with df = 11. For the assimilation variant overestimation was significantly less when the critical visual angle was large ($\bar{X} = 4.37\%$) than when it was small ($\bar{X} = 12.05\%$), $t = 3.749$, $p < .01$, 2 tailed. For the contrast variant underestimation was significantly greater when the critical visual angle was large

## Table 4

Experiment 4: Mean Percentage Illusion Magnitude, Delboeuf Illusion

| Assimilation Variant | | | | Contrast Variant | | | |
|---|---|---|---|---|---|---|---|
| Visual Angle | | | | Visual Angle | | | |
| Large | Small | Diff. | *t* | Large | Small | Diff. | *t* |
| 4.37 | 12.05 | -7.68 | 3.749* | -7.63 | -0.20 | -7.43 | 4.572** |

*$p < .01$, 2 tailed, df = 11

**$p < .001$, 2 tailed, df = 11

($\bar{X} = -7.63\%$) than when it was small ($\bar{X} = 0.20\%$), t = 4.572, $p < .001$, 2 tailed.

Discussion. The present results are identical to those of Experiment 3. When the critical visual angle was large rather than small, significantly greater underestimation of both illusion variants was obtained. Increasing the critical visual angle served to decrease the illusion magnitude of the assimilation or overestimated variant, while it increased the illusion magnitude of the contrast or underestimated variant, confirming the predictions of the pool and store model.

However, before these results can be accepted it is necessary to consider whether they may have been due to uncontrolled factors. The data indicate that in Experiments 3 and 4 the control figure estimates behaved in much the same fashion as the illusion estimates. That is, both control and illusion figures subtending a large visual angle were significantly underestimated relative to those subtending a small visual angle. Since control figure estimates should not be systematically distorted, such errors suggest the presence of extraneous variables which also may have distorted illusion estimates, independent of any illusion effects.

It is generally assumed that any distortion induced by extraneous variables is nullified by the use of a control figure since such variables presumably induce a constant error which is identical for both illusion and control figures. Therefore, by computing illusion magnitude in terms of the difference between illusion and control figure estimates, a relatively uncontaminated measure should be obtained. However, if extraneous factors have different effects on illusion and control figures or different effects in each visual angle condition, such estimates of illusion magnitude would be erroneous.

It seemed possible that in the course of manipulating retinal size, extraneous variables having such differential effects might have been introduced inadvertently. When visual angle is varied and size ratio held constant, other factors such as line width and frame size should be proportional to figure size in order to maintain the same size relationships in the two visual angle conditions. The frame enclosing test figures in the large visual angle condition was the edge of the projection screen and in the small visual angle condition was the edge of the slide. By using the same slide for test figures in each visual angle condition and manipulating retinal size by optical techniques line width, frame size, and figure size were varied simultaneously.

However, the frame surrounding comparison circles, provided the edge of the booklet page, was not proportional in the two visual angle conditions. In the large visual angle condition the booklet page which framed the comparison figures was smaller than the projection screen which framed the test figure; in the small visual angle condition the booklet page which framed the comparison figures was larger than the edge of the slide which framed the test figures.

Kuennapas (1955) found that the apparent size of a figure varies with the size of the page which frames it. He presented a standard line in a frame of fixed size and varied the size of the frame enclosing comparison lines. As the frame size of the comparison lines increased, observers chose a longer line to match the standard, indicating that the apparent size of the comparison line decreased as the frame was enlarged. Kuennapas noted that phenomenal line length appeared to be a logarithmic function of the area or side of the square enclosing it. Since the length of the standard was not varied, apparent size might be a function of either the ratio between the frame and the line or the visual angle separating them.

In any case, Kuennapas' results imply that the frame may distort the apparent size of a figure in much the same manner that the contextual elements of an illusion configuration distort the test element. That is, a figure enclosed in a relatively small, proximal frame might tend to be overestimated and one enclosed in a relatively large, distant frame might tend to be underestimated. A frame which is sufficiently large and distant might cease to exert any distortion on apparent size.

This line of reasoning can be applied, for example, to the framing conditions of Experiment 3. In the large visual angle condition test figures were framed by an extremely large, distant projection screen while comparison figures were framed by a relatively small, proximal booklet page. The size ratio between the frame and the control circle was 7.6 while the ratio between the frame and the physically identical comparison circle was 1.3. The visual angle between the frame and the control circle was approximately 65° while the visual angle between the frame and the physically identical comparison circle was about 3°. These frame-figure relationships, whether considered in terms of ratio or visual angle proximity, should result in comparison figures being overestimated relative to control figures. In support, underestimation of large visual angle control figures in Experiments 3 and 4 ranged from about 8% to 12%.

In the small visual angle condition the frame-figure relationships of test and comparison figures were exactly the reverse of those in the large visual angle condition. The frame surrounding test figures, provided by the edge of the slide on the screen, was relatively smaller and more proximal than that of the booklet page framing the comparison figures. However, control figures were not overestimated relative to comparison figures but rather, were underestimated, about 5% in Experiment 3 and 4% in Experiment 4. This result can be explained if it is assumed that the frame surrounding the comparison circles was sufficiently large and distant that it did not affect their apparent size and that underestimation of the control was induced by its frame.

In Experiment 3 the control figure was approximately 6.5° from the frame and the frame-figure ratio was 7.6. This frame-figure relationship, whether viewed in terms of proximity or ratio, might be expected to induce a contrast effect which would result in underestimation of the control.

In summary, the greater underestimation of control figures subtending a large rather than a small visual angle suggests that framing effects were not equal in the two conditions. If such extraneous distortion is nullified by computing illusion magnitude relative to control figure estimates, the results of the previous studies can be accepted with confidence. If it is not, then these results are open to question.

The next study was carried out to test the predictions of the *pool* and *store* model while controlling for framing effects. In addition, the frame was manipulated to determine its effect on illusion magnitude.

## V

## EXPERIMENT 5

The present study tested both visual angle and framing effects using the assimilation and contrast segments of the Delboeuf illusion. To permit convenient control of frame size, the illusion, control, and comparison stimuli were reproduced on paper. The frame was defined as the edge of the page on which the stimuli were presented.

The effect of visual angle was tested by varying the retinal size of the configuration while holding constant the ratio between test and inducing elements as well as the frame-figure ratio. Thus, any effects of the frame due to the relationship between frame size and figure size should be controlled. The effect of the frame was tested by comparing the illusion magnitude of identical figures when test and comparison stimuli were enclosed in a small, proximal frame and in a large, distant frame. Framing effects were tested only for figures subtending a small visual angle because manipulation of the frame enclosing large visual angle figures would have resulted in a comparison figure page that was extremely large and unwieldy.

If illusion and control figures are equally distorted by the frame, illusion magnitude, computed relative to the control figure estimate, should remain invariant. However, if they are distorted unequally, illusion magnitude should vary with the frame. This might occur if the outer circle of the Delboeuf inhibited direct interaction between the center circle and the frame while the control and comparison circles, lacking an outer context, were more readily subject to frame-induced distortion. In such a case, control and comparison figures, enclosed in identical frames, should be equally distorted, resulting in control figure estimates that are relatively veridical. The distortion of comparison figures, however, should result in erroneous illusion estimates.

Based on the results of Experiments 3 and 4 the distant frame would be expected to have no affect on the apparent size of comparison circles. However, the relationship between the proximal frame and the comparison circles is quite similar, in terms of both proximity and ratio, to the relationship between the two concentric circles of the illusion configuration. Therefore, in this experiment comparison circles should be distorted in the same direction as the central circle of the illusion. This should reduce the apparent size difference between a comparison circle and the illusion test circle, reducing the obtained illusion magnitude.

Separate groups of subjects estimated the assimilation and contrast segments of the illusion. Visual angle and frame were within subject factors, each observer estimating the following three figures and their controls:

1. A large visual angle figure in a relatively proximal frame.

2. A small visual angle figure in a relatively proximal frame, having a frame-figure ratio identical to that of Figure 1.

3. A small visual angle figure identical to Figure 2 but enclosed in a relatively large and distant frame.

The effect of visual angle was tested by comparing the illusion magnitude of Figures 1 and 2. If the results of the previous studies were due to framing effects, these figures should not differ in illusion magnitude. If illusion magnitude varies with retinal size as predicted by the _pool_ and _store_ model, overestimation of the assimilation illusion should be greater when the figure subtends a small rather than a large visual angle and, underestimation of the contrast illusion should be greater when the figure subtends a large rather than a small visual angle.

The effect of the frame was tested by comparing Figures 2 and 3. If the frame does not affect apparent size or, if the frame affects test and comparison figures equally, varying the frame should have no affect on illusion magnitude. If the proximal frame reduces the apparent size difference between comparison circles and the illusion test figure, the illusion magnitude of both Delboeuf segments should be less in the proximal than in the distant frame.

_Subjects_. Twenty-four City College students served as subjects, half judging the assimilation variant and half judging the contrast variant.

Stimuli and Apparatus. The test stimuli were the assimilation and contrast variants of the Delboeuf illusion and control circles with no surrounding circle. Test and comparison figures were reproduced on paper and the edge of the page defined the frame. The ratio between the side of the square page and the diameter of the test circle was the frame-figure ratio. Viewing distance was held constant at 450 mm. Three assimilation figures all with a 3:2 ratio and three contrast figures all with a 5:1 ratio were presented, one subtending a large visual angle and two subtending a small visual angle. The two configurations subtending a small visual angle were identical except that one was enclosed in a small, proximal frame and one in a large, distant frame. The small visual angle figure in the proximal frame had the same frame-figure ratio as the large visual angle figure. The frame size of comparison figures was identical to that of the test figures they were used to judge.

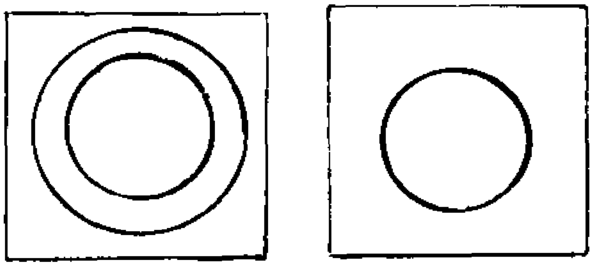
The three assimilation illusions and controls are schematically illustrated in Figure 10 which also shows figure and frame dimensions and visual angles. Large visual angle figures were 10 times the size of small visual angle figures. The diameter of the central circle of the large visual angle illusion and of the control circle was 160 mm (20°) and that of the analogous small

## Assimilation Illusion, Ratio 3:2

frame-figure ratio = frame width/test circle diameter

8 mm = approximately $1^0$ visual angle

Illusion Control



proximal frame: 280 x 280 mm
frame-figure ratio = 1.75

LARGE VISUAL ANGLE

central circle
of illusion: 160 mm diam.

control circle: 160 mm diam.

outer circle
of illusion: 240 mm diam.

critical visual angle: 5°

proximal frame: 28 x 28 mm
frame-figure ratio = 1.75

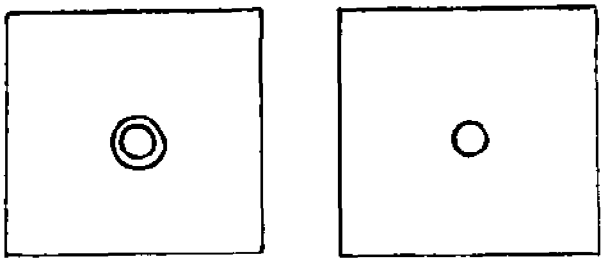
SMALL VISUAL ANGLE

central circle
of illusion: 16 mm diam.

control circle: 16 mm diam.

outer circle
of illusion: 24 mm diam.

critical visual angle: 0.5°



distant frame: 280 x 280 mm
frame-figure ratio - 17.5

Figure 10. Delboeuf assimilation stimuli, Experiment 5.

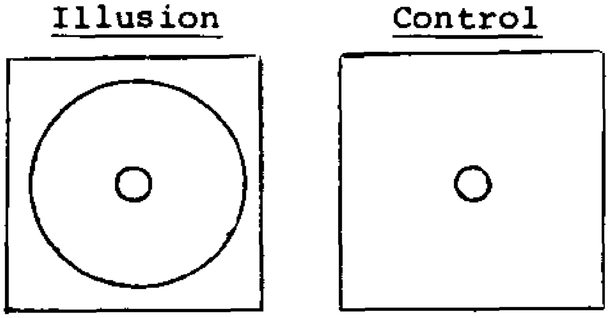
visual angle figures was 16 mm (2°). The critical visual angle of the large visual angle illusion was 5° and of the small visual angle illusions was 0.5°. Test and comparison figures subtending a large visual angle were enclosed in a frame 280 x 280 mm. Test and comparison figures subtending a small visual angle were enclosed in a frame 28 x 28 mm or 280 x 280 mm. Comparison circles subtending a large visual angle ranged in diameter from 110 mm to 210 mm in 10 mm steps and those subtending a small visual angle ranged in diameter from 11 mm to 21 mm in 1 mm steps.

The three contrast illusions and controls are schematically illustrated in Figure 11 which also shows figure and frame dimensions and visual angles. Large visual angle figures were five times the size of small visual angle figures. The diameter of the central circle of the large visual angle illusion and of the control circle was 50 mm (about 6.25°) and that of the analogous small visual angle figures was 10 mm (about 1.25°). The critical visual angle of the large and small illusions was, respectively, about 12.5° and 2.5°. Test and comparison figures subtending a large visual angle were enclosed in a frame 280 x 280 mm. Test and comparison figures subtending a small visual angle were enclosed in a frame 56 x 56 mm or 280 x 280 mm. Comparison circles subtending a large visual angle ranged in diameter from 34mm to 65 mm in 3 mm steps and those subtending a small

## Contrast Illusion, Ratio 5:1

frame-figure ratio = frame width/test circle diameter

8 mm = approximately $1^0$ visual angle



proximal frame: 280 x 280 mm
frame-figure ratio = 5.6

LARGE VISUAL ANGLE

central circle of illusion: 50 mm diam.

control circle: 50 mm diam.

outer circle of illusion: 250 mm diam.

critical visual angle: 12.5°

proximal frame: 56 x 56 mm
frame-figure ratio = 5.6

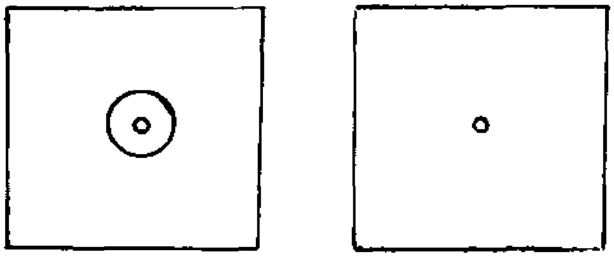
SMALL VISUAL ANGLE

central circle of illusion: 10 mm diam.

control circle: 10 mm diam.

outer circle of illusion; 50 mm diam.

critical visual angle: 2.5°



distant frame: 280 x 280 mm
frame-figure ratio = 28.

Figure 11. Delboeuf contrast stimuli, Experiment 5.

visual angle ranged in diameter from 7 mm to 13 mm in 0.6 mm steps.

Test and comparison stimuli were reproductions of drawings made with black ink on white paper. Stimuli subtending a small visual angle were reduction copies of those subtending a large visual angle so that line width was reduced proportionally to figure size. Large visual angle figures were recopied, same size, to be certain that any loss in clarity and contrast would be equal in the two visual angle conditions. Test and comparison figures were viewed side by side, nearly vertical, against a stand of heavy cardboard 670 x 670 mm covered with paper of a medium green tone (Coloraid GT2). Stimuli were positioned so that the center of test and comparison circles was centered within the vertical dimension of the stand. The center to center horizontal distance between test and comparison figures was held constant at 305 mm.

<u>Procedure</u>. Observers judged the size of the central circle of either the three assimilation illusions or the three contrast illusions and their respective controls by choosing a matching comparison circle from a series presented using a method of limits procedure. Observers made 12 estimates in all, judging each of the six test figures (3 illusions and 3 controls) twice, once with an ascending and once with a descending series. The mean of the two judgments was used in subsequent analyses. Stimuli were presented in random order and the order reversed for half

the subjects. Test figures were positioned on the left and comparison figures on the right for half the subjects and the positions reversed for the other half.

Results. As previously, illusion magnitudes were computed as percentage differences from control figure estimates. The assimilation and contrast variants were each analyzed separately by means of a randomized blocks analysis of variance, and two planned comparisons were performed for each variant with df =22. Illusion magnitudes are shown in Table 5.

Comparisons performed on the assimilation variants indicated that illusion magnitude was significantly affected both by visual angle and frame. The visual angle comparison involved the small visual angle figure in the proximal frame with a frame-figure ratio of 1.75, identical to the frame-figure ratio of the large visual angle figure. The small visual angle illusion was overestimated 5.06% while the large visual angle illusion was underestimated 1.26%, a significant difference ($\underline{t} = 2.46$, $p < .05$). Comparison of the small visual angle figures, identical except for frame, indicated that overestimation of the figure enclosed in a large, distant frame was 11.52%, significantly greater than the 5.06% overestimation displayed by the figure enclosed in a small, proximal frame ($\underline{t} = 4.187$, $p < .001$).

Comparisons performed on the contrast variants indicated that visual angle had only a marginal effect on

Table 5

Experiment 5: Mean Percentage Illusion Magnitude, Delboeuf Illusion

Assimilation Variant (N = 12)

| Visual Angle | Large | Small | |
|---|---|---|---|
| Frame | Proximal | Proximal | Distant |
| | -1.26 | 5.06 | 11.52 |

Contrast Variant (N = 12)

| Visual Angle | Large | Small | |
|---|---|---|---|
| Frame | Proximal | Proximal | Distant |
| | 0.91 | 3.54 | 2.32 |

illusion magnitude and frame conditions had no effect. The small visual angle figure entering the visual angle comparison was the one in the proximal frame with a frame-figure ratio of 5.6, identical to the frame-figure ratio of the large visual angle figure. The 3.54% overestimation of the small visual angle figure was greater than the 0.91% overestimation of the large visual angle figure, but this difference just failed to reach statistical significance ($t$ = 1.99, $p < .10$). Comparison of the small visual angle figures, identical except for frame conditions, indicated that the one in a small, proximal frame was overestimated 3.54% and the one in a large, distant frame was overestimated 2.32%, a difference which was not significant ($t$ = 0.92).

Discussion. The results indicated that the two segments of the Delboeuf behaved somewhat differently. In the case of the assimilation segment both experimental hypotheses were confirmed. Overestimation was significantly less when retinal size was large rather than small and when the frame was small and proximal rather than large and distant. In the case of the contrast segment the difference between visual angle conditions was in the expected direction but only marginally significant and there was no significant difference between frame conditions.

Considering first the framing effect, the behavior of the assimilation figure is consistent with the hypothesis that comparison circles enclosed in a small, proximal frame were, like the illusion figure, overestimated, thus decreasing the apparent magnitude of the illusion. Although the contrast variant failed to exhibit a significant framing effect, it is possible that if the frame enclosing comparison circles were somewhat larger and more distant, comparison circles might be underestimated. If an underestimated illusion figure is judged using underestimated comparison circles, the apparent magnitude of the illusion should decrease. On the other hand, if comparison circles which are underestimated are used to judge an overestimated illusion figure, the apparent magnitude of the illusion should increase.

It would appear, then, that the distant frame had no effect on the illusion magnitude of the contrast figure. If these comparison circles had been underestimated, the contrast figure, which manifested slight overestimation, would have displayed greater overestimation in the distant than in the proximal frame. The difference, although nonsignificant, is in the opposite direction.

Considering next the effect of retinal size, the obtained differences in illusion magnitude are consistent with the predictions of the _pool_ and _store_ model and, since the frame-figure ratios were invariant in each visual angle condition, it is unlikely that these differences were due to the effect of the frame. Nevertheless, these results appear to offer only equivocal support for the model in that the decrease in overestimation with retinal size was statistically significant for the assimilation variant but only marginally significant for the contrast variant. Furthermore, the large visual angle contrast variant failed to manifest underestimation although its critical visual angle was 12.5°.

One factor which may be relevant to these results is the visual angle subtended by the illusion figures. Kaufman and Richards (1969) suggest that figures subtending less than 5° visual angle can be seen in their entirety without scanning while larger figures cannot. The contrast figure in the small visual angle condition subtended slightly more than 6° and, therefore, it is likely that this figure could not be seen in its entirety without scanning. Although it was thought that the critical visual angle of the figures in the two retinal size conditions were sufficiently disparate to elicit a processing difference, it may be that there is little difference between the temporal separation of elements which are spatially separated by 2.5° and those which are separated by 12.5°. The linear relationship between the duration of a saccadic eye movement and its magnitude is such that the duration increases by about 2 ms for every 1° increase in magnitude (Ditchburn, 1973). This means that it should take about 20 ms longer to complete an eye movement of 12.5° than to complete one of 2.5°, a difference which might have a negligible effect on apparent size. On the other hand, there should be a large difference between the temporal separation of the elements of a configuration which is clearly extra‹foveal and one which is clearly subfoveal, since the time necessary to complete an eye movement is about 250 ms. The assimilation figure in the small retinal size condition subtended about 3° visual angle and therefore probably could be seen in its entirety in a single glance. There should be a clear difference between the processing mode of this figure and the one in the large retinal size condition, which subtended about 30° visual angle. This would explain why the illusion magnitude of the assimilation figures varied significantly with retinal size while the illusion magnitude of the contrast figures did not. In future studies it would be desirable to use a small contrast figure which can subtend less than 5° visual angle.

If both contrast figures elicited scanning it is puzzling that neither figure displayed underestimation. This result might be explained by illusion decrement, a phenomenon which is known to occur with prolonged viewing. In the present study, a method of limits procedure was employed so that each configuration was viewed for a considerably longer period of time than in the previous studies which used choice from a series or a method of adjustment procedure. Girgus and Coren (Note 1) have shown that with free viewing over time the illusion magnitude of the contrast segments of the Delboeuf, Ebbinghaus and Ponzo illusions decrements over time while the illusion magnitude of the assimilation segments remains unchanged. If the contrast figures in the present experiment were subject to decrement it would explain why the figures subtending a large visual angle failed to manifest underestimation. Coren and Girgus have suggested that contrast illusions may be subject to cognitive recalibration because the spatial separation of test and contextual elements allows them to be perceived successively rather than simultaneously. This implies that an assimilation figure subtending a large visual angle might display decrement although one subtending a small visual angle would not. If this were true, the decrease in illusion magnitude manifested by the large visual angle assimilation figure could have been due to illusion decrement rather than retinal size. This argument is, at present, highly conjectural since it has not yet been demonstrated that this figure is able to decrement but, in order to eliminate the possibility of decrement, it would be desirable in future work to use a quick estimation procedure.

# VI

# GENERAL DISCUSSION

Although all five experiments exhibited a similar pattern of results, only Experiments 3 and 4 yielded statistically significant findings for both the assimilation and contrast segments of the Delboeuf. It is unclear whether these results were due entirely to the effects of retinal size or whether they were contaminated by extraneous distortion.

Experiment 5 demonstrated that the frame affects illusion magnitude when test and comparison figures are in identical frames but it has not been demonstrated that this would occur also when test and comparison figures are in different size frames, as they were in Experiments 3 and 4. It might be argued that keeping frame size constant actually produces rather than controls for a framing effect. Under these conditions frame-induced distortion of comparison circles results in erroneous illusion estimates but, since control and comparison circles are equally distorted, control figure estimates tend to be veridical. Illusion magnitude, computed as the difference between illusion and control figure estimates, is therefore erroneous. On the other hand, if test and comparison figures are enclosed in different size frames the distortion of comparison figures might be reflected in distorted estimates of control as well as illusion figures. Assuming that this error is constant, computing illusion magnitude relative to control figure estimates might yield a relatively undistorted estimate of illusion magnitude. Although it is unclear whether framing effects may have confounded Experiments 3 and 4, it is suggestive that Experiment 5, which controlled for this source of extraneous distortion, yielded essentially similar findings.

While the pattern of results in all five studies is consistent with the predictions of the <u>pool</u> and <u>store</u> model, it is necessary to ask whether these results could be accounted for equally well by other theories. A decrease in the illusion magnitude of an assimilation figure with a decrease in retinal size is consonant with a number of other theories, but an increase in the illusion magnitude of a contrast figure is difficult for most theories to explain.

Assimilation theories assume that an observer is more likely to incorporate the size of contextual elements into his estimate of the test element when they are spatially proximate than when they are spatially distant. Since the absolute separation between test and contextual elements increases with the retinal size of the figure, a decrease in assimilation would be expected. Assimilation theories imply that when the context is quite distant from the test element it should have no effect on the apparent size of the test element. Therefore, neither confusion theory nor Pressey's assimilation theory would predict an increase in contrast with retinal size.

Contrast formulations imply that the observer compares the test element with the surrounding context. One might propose that increasing the absolute separation between test and contextual elements would hinder comparison and thus decrease the illusion magnitude of both the over- and underestimated segments of an illusion. On the basis of this formulation the illusion magnitude of the underestimated segment would not be expected to increase with retinal size.

The perceptual style hypothesis suggests that a tendency to assimilate test and contextual elements might be enhanced by a global viewing strategy while a tendency to contrast or exaggerate the difference between these elements might be enhanced by an analytic viewing strategy. Increasing the retinal size of an illusion configuration and hence the absolute distance between test and contextual elements should allow the elements to be more clearly differentiated and thus result in more veridical perception.

Oyama's feature analyzer theory states that assimilation-contrast distortions are due to the ratio between test and inducing elements and that varying the retinal size of a configuration would have no effect on illusion magnitude as long as the figural ratio were held constant. This formulation is in direct opposition to the predictions of the _pool_ and _store_ model and cannot account for the results of the present studies unless one is willing to attribute those results wholly to the influence of extraneous variables.

Adaptation level theory proposes that the test element of an illusion configuration is judged in relation to the adaptation level, assimilation occurring when the adaptation level is close to the size of the test element and contrast when it is quite distant from the size of the test element. The contribution of contextual elements to the adaptation level should decrease as their distance from the test element increases. Therefore, the illusion magnitude of both the over- and underestimated segments of an illusion should decrease with an increase in retinal size.

Piaget proposes that those portions of a configuration which receive the greatest density of centrations, or acts of attention, tend to be overestimated and that such distortions tend to diminish in magnitude as the observer explores all parts of the figure. Based on this formulation one might expect that increasing the retinal size of a configuration might facilitate perceptual exploration, thus decreasing illusion magnitude. Alternatively, it might be argued that this would bring contextual elements so far into the periphery that exploration of the array might be hampered and the magnitude of size distortions would tend to increase. It might even be argued that, since the context of a contrast illusion is more peripheral than that of an assimilation illusion, increasing the retinal size of these figures might facilitate exploration of the assimilation figure and hinder exploration of the contrast figure. While this would account for the pattern of results in the present experiments, it is apparent that, had other results been obtained, they might be accounted for equally well.

Although a number of theories in addition to the pool and store model are able to account for the decrease in the assimilation effect observed with retinal size, none is able to predict in advance the conditions under which it would occur. It would be desirable for future studies to perform parametric variation of the critical visual angle in order to provide a more precise test of the pool and store hypotheses.

## Implications of the Pool and Store Model

In reviewing the work of previous investigators it was noted that four lines of research seem to support the idea of a processing difference between assimilation and contrast phenomena. These two types of distortion appear to respond differently to the effects of temporal and spatial separation, and they exhibit different practice effects and age trends as well. The theories reviewed address one or more of these phenomena but none is able to account for all four.

The pool and store model, while addressing only the effects of temporal and spatial separation, may have implications also for the decrement and age trend data. Girgus and Coren (Note 1) have suggested that contrast phenomena may decrement with free viewing because test and inducing elements are perceived separately while assimilation phenomena fail to do so because the figural elements are always perceived simultaneously. One assimilation phenomenon which does decrement is the Mueller-Lyer. One might conjecture that this occurs when there is a sufficiently great spatial separation between the wingtips and the shaft. This would be consistent with the results of Hoenig (1972) who found that the overestimated segment manifested decrement only when the visual angle subtended by the shaft was 2° or more. If visual angle is relevant to decrement it should be possible for assimilation figures to decrement when the critical visual angle is sufficiently large. This hypothesis should be tested in future research.

Assimilation effects appear to decline with age while contrast effects appear to increase with age, suggesting that these two phenomena may be mediated by different mechanisms. Pollack (1969) has noted that the age-related decline in the magnitude of the Mueller-Lyer illusion is paralleled by an increase in the visual detection threshold, and he suggest that both these phenomena may be due to an age-related increase in lens pigmentation. Since the increase in lens pigmentation is quite small compared to the age-related decrease in illusion magnitude, Coren and Girgus (1978) have suggested that there may be, in addition, a decrease in the efficiency of neural processes with age. While these factors might account for the age-related decrease in the magnitude of assimilation effects, they fail to account for the apparent increase in the magnitude of contrast effects with age.

It may be that cognitive factors, such as viewing strategies, memory encoding processes, and the ability to make relational judgments are important determinants of contrast phenomena. The tendency to scan all parts of a visual display, to abstract its salient features, and to relate information which is temporally separated all increase with chronological age and may be relevant to the age-related increase in the magnitude of contrast effects. It may be because such cognitive processing strategies are subject to modification that contrast effects are able to decrement with practice.

In discussing the problem of categorizing distortions as assimilation or contrast phenomena, it was noted that the difficulty seemed to reside in an inability to specify the relevant context. For example, the Ebbinghaus illusion is usually categorized as a contrast phenomenon because the size of the flanking circles seems to be relevant to the obtained distortion. However, since apparent size also varies with the distance between the central and flanking circles, one might argue that the entire figural extent is the relevant context. In this case the Ebbinghaus would be categorized as an assimilation-contrast effect. With this in mind, it is interesting to reconsider the data of Girgus et al. (1972). In Figure 12a illusion magnitude is plotted as a function of the distance between the edge of the center circle and the proximal edge of the surrounding circles. In Figure 12b the same data have been regraphed to show illusion magnitude as a function of the visual angle between the edge of the center circle and the distal edge of the surrounding circles. Since the size of the central circle was kept

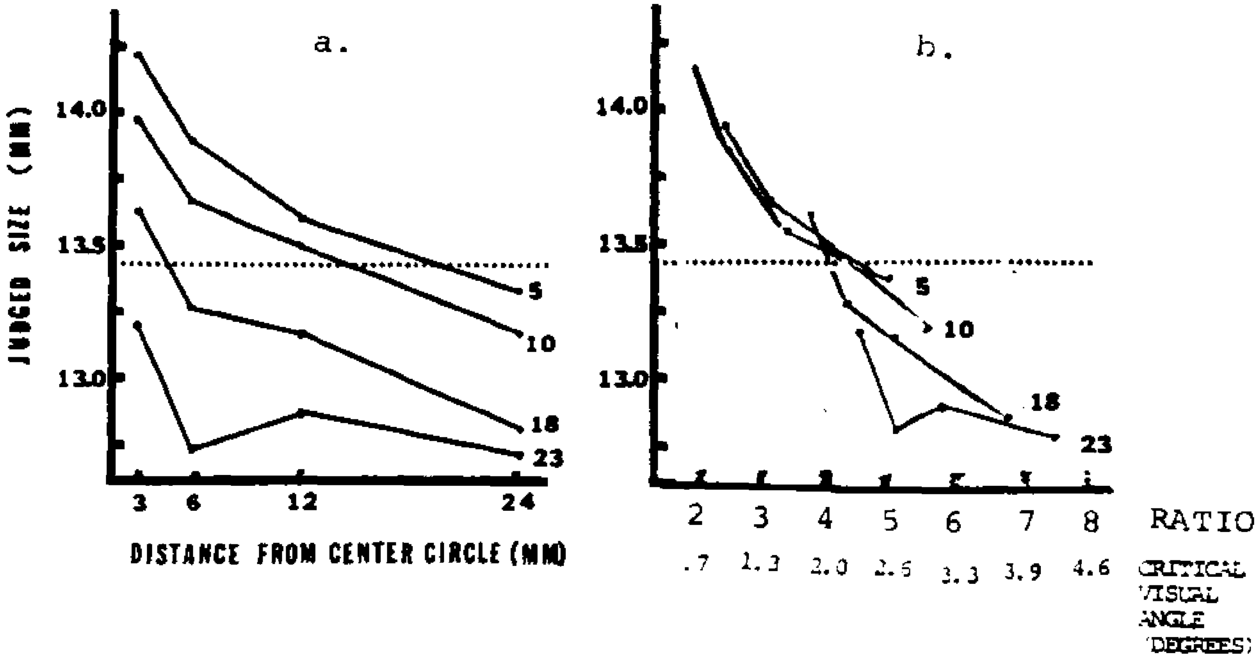


Figure 12. Illusion magnitude of the Ebbinghaus graphed two ways. a) Data of Girgus et al. (1972) with judged size of center circle displayed as a function of the distance between the proximal edges of center circle and context circles. b) Same data graphed as a function of critical visual angle (separation between edge of center circle and distal edge of context circles) and size ratio (diameter of total figure/diameter of center circle). Size of context circle in mm is shown at right of each curve. Dotted line represents judged size of control circle.

constant, the critical visual angle is perfectly correlated with the size ratio between the diameter of the entire figure and the diameter of the central circle. Therefore the abscissa in Figure 12b shows both variables. It is apparent in Figure 12b that when the critical visual angle is within foveal width the size of the context circles is irrelevant and illusion magnitude varies as a function of critical visual angle and/or figural ratio. When the critical visual angle is greater than 2°, underestimation increases with the size of the context circles as well as with ratio and/or critical visual angle. This could be due to the involvement of a visual scanning mechanism when the display exceeds foveal width. It may be that the size of the context circles becomes relevant at this point because when they are small the distance between them is large and the observer is less likely to encounter a contextual element when scanning the display. In addition, contour interaction processes may be strengthened by the greater proportion of contour provided by the larger context circles.

These data are consistent with the view that one component of the Ebbinghaus illusion is an assimilation-contrast factor, supporting the notion of a parallel between this illusion and the Delboeuf, as suggested by Girgus et al. (1972). Further research might explore the relationship between these two configurations to see whether the illusion magnitude function of each is similar in shape and whether the ratio producing maximal overestimation is similar under conditions of foveal separation of test and inducing elements.

In proposing that assimilation-contrast distortions arise from a general process by which pattern information is extracted from the visual field and coded for later usage, the pool and store model may have implications for phenomena other than visual illusions. Future research might investigate the effect of the critical visual angle on size constancy. Consider, for example, a house flanked by trees. When the observer is quite distant from this scene the visual angle between the trees and the house would be quite small, while it would be quite large if the observer were close. The model implies that the house would appear larger when it is distant than when it is close, acting against both size constancy and the usual breakdown in size constancy that occurs at large distances.

## Implications of the Framing Effect

The framing effect may have both methodological and theoretical relevance to the study of illusions. The present results suggest that the widespread assumption that the use of a control figure nullifies the effect of such extraneous distortion is probably erroneous. Before it is possible to specify methodological controls to eliminate framing effects, a number of questions must be explored. One is whether the frame might influence the apparent size of an illusion figure directly or whether it does so only indirectly, by distorting comparison figures. Another is whether framing effects would be operative when test and comparison figures are in different size frames. Still another is whether the two halves of a configuration would be equally influenced by the frame.

It seems possible that framing effects, and perhaps also other types of extraneous distortion, might be induced by measurement methods other than choice from a series of comparison figures. It seems likely that any measurement technique that employs a visual display is potentially capable of inducing extraneous distortion. Methodological considerations have received little attention in the literature, perhaps in part due to the prevalent notion that the use of a control figure neutralizes such measurement errors. The present findings suggest that measurement techniques may, themselves, be worthy of systematic investigation.

Another implication of the present findings is that the usual practice of keeping frame size constant across experimental conditions may, in certain cases, induce a framing effect. This might occur if the frame-figure relationship is inadvertently varied in the course of manipulating figure size, whether it is manipulated directly or indirectly by varying the size of context elements. For example, since the overall extent of each segment of the Mueller-Lyer is different, the frame-figure relationships are also nonidentical and this may, in part, be responsible for the findings that each segment responds differently to variations in figure size (Bayer & Pressey, 1972) and fin length (Sekuler & Erlebacher, 1971). In support, Bross, Blair and Longtin (1978) found that each segment of the Mueller-Lyer responded differently when figure size was held constant and the size of the circular frame enclosing the figures was varied. Interestingly, the authors performed this manipulation in order to vary the size of the hypothetical attentive field as a test of Pressey's assimilation theory, and they explicitly reject the notion that their results may be due to the effect of the circular contour, arguing that the use of a control figure would negate such extraneous distortion. Framing effects may also interact with stimulus duration under conditions of tachistoscopic presentation, becoming effective only when the duration is sufficiently long to permit eye movements.

In addition to having methodological implications, framing effects may also have theoretical implications. One important question, relevant to the nature of size distortions in general, is whether framing effects are due to an assimilation-contrast process or whether they are a manifestation of an entirely different process. Fellows (1968) identifies framing effects with a process he calls "enclosure" which he sees as distinct from assimilation-contrast effects. This view is based on his observation that overestimation of a line enclosed in a rectangular frame varied with their spatial separation but, no matter how great the gap between the line and its enclosure, underestimation or contrast was never observed. It may be that the rectangular contoúr of the card on which comparison lines were presented induced their underestimation, obscuring any contrast effect that may have been present. If this were true it would imply that the framing effect is, in principle, an assimilation-contrast effect. The framing effect observed by Fellows has been identified by Robinson (1972) with an assimilation-contrast process. He suggests that the contextual elements of an illusion configuration act as a frame, marking off extents beyond the test figure which then exert an effect on its apparent size. If assimilation-contrast effects and framing effects are similar, both should vary with critical visual angle and/or size ratio. Hopefully, further research will be able to specify the effect of each of these variables more clearly.

In summary, while the present studies provide only tentative support for the _pool_ and _store_ model, they suggest a number of methodological changes which might allow more definitive results to be obtained in subsequent studies. Furthermore, the finding that the frame affects illusion magnitude has not been demonstrated previously and may have both methodological and theoretical relevance to the study of illusions.

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