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Structural and cognitive components in the Müller-Lyer illusion assessed via Cyclopean presentation

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Several levels of visual information processing contribute to the formation of visual geometric illusions. The present experiment attempted to separate the relative contributions of structural (physiologically based) and strategy (cognitively based) mechanisms in the formation of the Müller-Lyer illusion. A novel experimental procedure that combined Cyclopean stimulus presentation and illusion decrement was employed. The results indicated that approximately 47% of the observed illusion magnitude can be attributed to the involvement of structural factors, a result consistent with other studies that have used different experimental techniques to explore the same issue.

Visual illusions, defined as the systematic distortion of the size, shape, and direction of the figural elements in some simple line drawings, are well known to perceptual researchers. Many global theories have been offered to explain their existence, but unfortunately, no single theory has been completely successful. As a result, some investigators have concluded that these distortions probably arise from complex interactions among many levels of visual processing (Coren & Girgus, 1978b; Coren, Girgus, Ehrlichman, & Hakstian, 1976; Coren & Ward, 1979; Porac & Coren, 1981a). The large number of illusion-producing mechanisms that have been identified can be divided into two general classes. The first class, which may be called *structure mechanisms*, refers to distortions caused by the optical and neural properties of the visual system. The second class, which may be called *strategy mechanisms*, refers to the operation of cognitive-judgmental factors in the formation of illusions.

Over the past 20 years, many of the structural factors that contribute to the formation of visual illusions have been isolated. For instance, because of the limited spatial frequency response of the eye or because of light scattering within the optic globe, optical blurring of the retinal image has been found to contribute to the magnitude of a number of intersecting line illusions, such as the Müller-Lyer and Poggendorf configurations (Coren, 1969; Coren & Porac, 1978; Coren, Ward, Porac, & Fraser, 1978; Ward & Coren, 1976). Neural interactions at the retinal level, in the form of lateral inhibition, and at the cortical level, between orientation-specific cells, also seem to play a role in illusion formation (Békésy, 1967; Blakemore, Carpenter, & Georgeson, 1970; Burns & Pritchard, 1971; Coren, 1970). Other neural mechanisms that might contribute to illusory effects include those that may perform Fourier-like transforms of the retinal intensity patterns (Ginsburg, 1975).

In contrast to the structural factors, each of which seems to be tied to a specific physiological mechanism, are the class of strategic or cognitive contributions to illusory effects. Most of these involve the habitual strategies, methods, and assumptions used by the observer when extracting, or processing, information from the visual array (see Coren & Girgus, 1978a). Examples of these strategies include the tendency to apply three-dimensional processing to two-dimensional arrays (Coren & Girgus, 1977; Gillam, 1980; Gregory, 1968; Ward, Porac, Coren, & Girgus, 1977), confusions between figural elements (Coren, & Girgus, 1972a; Erlebacher & Sekuler, 1969), and the averaging or assimilation of extents within the field or, alternatively, the heightening of differences among figural elements (Girgus & Coren, 1982; Coren & Miller, 1974; Massaro & Anderson, 1971; Pressey, 1974; Restle & Decker, 1977).

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As the survey above indicates, both structure and strategy mechanisms likely play a role in illusion formation. Therefore, the separation and the assessment of the relative contribution of the two levels of processing are important theoretical and experimental issues. One promising experimental procedure depends on the fact that continued viewing of an illusory configuration usually results in a decrease in the magnitude of the illusion. This illusion decrement occurs for many configurations, including the Müller-Lyer, Poggendorf, Zöllner, Wundt-Hering, and Oppel-Kundt illusions (Coren & Girgus, 1972b, 1978; Coren & Hoenig, 1972). The decrease seems to be the result of the elimination or adjustment of the cognitive contribution to the illusory distortion, perhaps as a result of some form of perceptual learning. Such a conclusion is justified by the evidence that decrement responds to traditional learning variables, such as massed versus distributed practice (Dewar, 1968), transfers interocularly (Porac & Coren, 1977), cumulates over days or even weeks of practice (Girgus, Coren, Durant, & Porac, 1975; Judd, 1902), and transfers to other configurations that are rated as subjectively similar (Coren & Girgus, 1974).

Eye movements seem to play an important role in illusion decrement. There is evidence indicating that, when the observer views illusion configurations, eye movements show systematic errors. For instance, when scanning the underestimated component of the Müller-Lyer illusion, the eye tends to undershoot the vertexes, whereas when scanning the overestimated component, it shows a tendency to overshoot them (Coren, 1981; Festinger, White, & Allyn, 1968). Although these erroneous eye movements are corrected, and the observer eventually comes to fixate the vertex, these errors could provide information about the nature and extent of the illusion. This information could then be used to correct the processing errors that led to the illusion originally. This interpretation is supported by data indicating that illusion decrement is greatly reduced when eye movements across the illusion figure are restricted (Coren & Hoenig, 1972; Day, 1962; Festinger et al., 1968). Presumably, in the absence of eye movements, the observer does not learn that an illusion is present, hence there is no pressure to adjust the cognitive portion of the percept toward veridicality.

Because the corrections involved in illusion decrement seem to be cognitive in nature, the decrement has been used as a tool to estimate the relative contribution of cognitive-strategy factors in illusion formation. The rationale is simple. Presumably the initially observed illusion magnitude contains both structural and cognitive components. After prolonged inspection, however, observers have modified their inappropriate cognitive strategies, leaving only the unmodifiable structural contributions to illusion magnitude (Coren & Girgus, 1978a, 1978b; Girgus et al., 1975). Measurements of illusion decrement suggest that approximately 40% to 50% of the magnitude of the Müller-Lyer illusion derives from cognitive factors. However, such estimates assume that the decrement procedure completely eliminates the cognitive contribution to the illusory effect. Any cognitive component that does not disappear as a function of decrement training would be interpreted erroneously as coming from a structural source. Therefore, this prolonged inspection method yields an estimate of the maximum contribution that structural factors could make (or, alternatively, the minimum contribution of cognitive factors).

Fortunately, there is an alternative procedure that can be used to provide independent verification of the estimates of the relative contributions of the structure and strategy mechanisms to illusion formation based upon illusion decrement. This technique involves the Cyclopean stimulus presentation procedures originally designed by Julesz (1971). Figure 1 shows how such a procedure might accomplish this separation. Figure 1B gives the Brentano form of the Müller-Lyer illusion, in which the horizontal extent demarcated by the outwardly turned pair of wings (on the right) is overestimated relative to the horizontal extent demarcated by the inwardly turned wings (the left segment).

We can construct the new "Cyclopean" stimulus in Figure 1A by adding a background to the figure in 1B, consisting of a number of angles in random positions and orientations, each of the same size and shape as the original three angles of the Müller-Lyer illusion (lacking only the dots at the vertexes). The two panels in Figure 1A each show a variant of this new stimulus; however, the two views differ in that the illusion figure is displaced laterally in one panel relative to the other. It requires some effort to find the original stimulus in this new configuration; in fact, it can only be done by looking for the dots at the vertexes of the angles. The background provides an

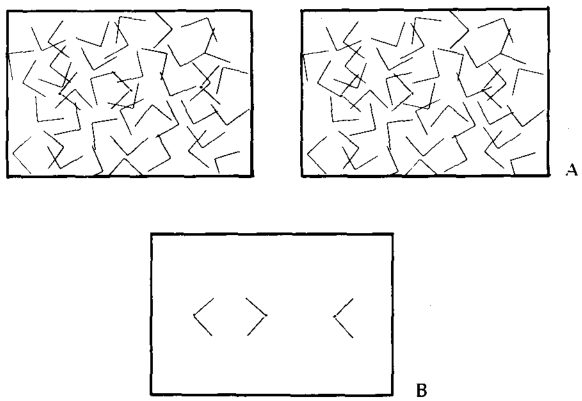

Figure 1. (A) A Cyclopean stimulus containing a Brentano form of the Müller-Lyer illusion. (B) The Brentano form of the Müller-Lyer illusion as normally viewed.

embedding context that disrupts a unified view of the original figure composed of three angles. However, when the stimulus pair in Figure 1A is viewed stereoscopically, one will see the original configuration (1B) floating above the patterned background because of the binocular disparity difference between the two views. The Müller-Lyer illusion exists in Cyclopean viewing even when the configuration is not visible in the individual monocular views (Julesz, 1971). Under these viewing conditions, we would expect both structural and cognitive components to be evoked. There are converging lines in close proximity on the same retinal surface promoting the involvement of the standard structural contributions to the illusory effect. In addition, the global figural organization will evoke the erroneous cognitive strategies. On the other hand, consider an observer who views one of the stimuli in the 1A pair *monocularly*. The same structural factors present in the Cyclopean situation are present here, since the presence or absence of binocular disparity should not affect lateral inhibitory effects or optical blur; hence, we would expect some illusory distortion to exist. However, the global relationship between the elements, namely that of a grouping consisting of a pair of inward and a pair of outward pointing angles, is not perceptually apparent. The relevant components, which normally induce this percept, are too entangled and embedded in the background which contains a myriad of similar components in different orientations. Therefore, one would expect that the erroneous cognitive strategies usually evoked by global aspects of the standard configuration should not be activated under these viewing conditions, with a resulting reduced illusory effect. The degree of reduction in the magnitude of the illusion ought to be virtually the same in this procedure as is that obtained via illusion decrement, if our presumptions are correct that both techniques are eliminating the cognitive strategy mechanisms from the illusory effect. Cyclopean presentation and illusion decrement may be considered converging operations to assess the relative contributions of structural and cognitive mechanisms in illusion formation. To test this hypothesis, the following experiment was conducted.

METHOD

Stimuli and Apparatus

The usual procedure for producing Cyclopean stimuli involves computer generation of the stimulus material, which is then photographed and presented in a stereoscope for viewing. Unfortunately, this static form of presentation has certain limitations when it comes to the measurement of illusion magnitude. The principal problem resides in the fact that the display is fixed and does not permit the illusory effect to be measured via the relatively speedy method of adjustment, which minimizes time spent viewing the figure and, hence, also minimizes unwanted illusion decrement. To circumvent this problem, an actual three-dimensional apparatus, which produces a Cyclopean Müller-Lyer illusion and

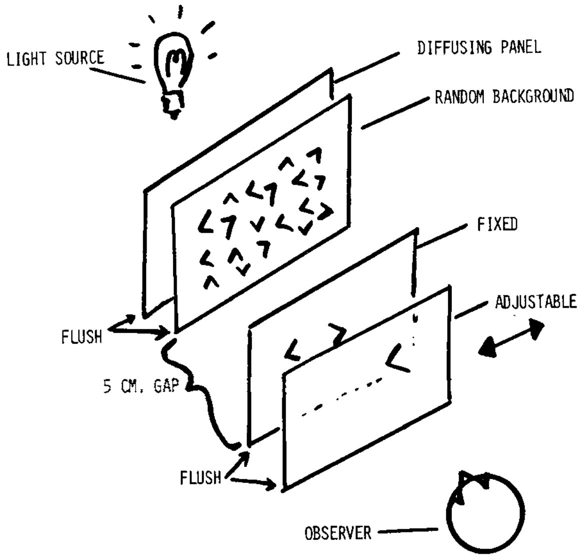

Figure 2. The apparatus used to produce a Cyclopean version of the Brentano form of the Müller-Lyer illusion in which the horizontal extents are adjustable by the subject for measurement purposes.

yet still has the capability of allowing the illusion to be measured via direct adjustment on the part of the observer, was constructed. This apparatus is shown in Figure 2. Light was supplied by fluorescent lamps diffused through a flashed opal panel in the apparatus, providing a uniform illumination of 67.5 cd/m². Two panes of clear Plexiglas were flush-mounted in a track to create the adjustable figure. One pane contained the apparently shorter segment of the Müller-Lyer illusion (with the wings pointed inward, as in the left segment of Figure 1B) and was fixed in position. The second contained a single angle with outward pointed wings, whose lateral position was adjusted with a knob resting near the observer's right hand. A scale mounted above the apparatus allowed illusion measurements to be taken to the nearest 0.5 mm. The angles were drawn in an opaque black ink. All lines were 2 mm wide, and all met at an angle of 90 deg. The vertexes of the three angles were indicated by a 3-mm-diam red (Munsell equivalent 7.5 R 5/12) dot, created with translucent ink. The wings of each angle subtended 2 deg of arc, and the distance between the vertexes in the fixed portion of the figure had a visual angle of 8 deg.

The background that changed the illusion figure to a Cyclopean stimulus consisted of an array of angles identical to those forming the illusion configuration, lacking only the red dots to mark the angle vertexes. These angles were distributed randomly across the field. To provide binocular disparity, the background was set back 5 cm from the illusion array. This viewing mode is truly Cyclopean, since each monocular view is virtually identical to that shown in Figure 1A. One sees the illusion array floating above the background only under binocular viewing conditions.

The subject's head was restrained in a head- and chinrest with elastic binders that served to further immobilize the head. An eyepatch placed over one eye was used to achieve monocular viewing in the conditions that required it. In monocular viewing conditions, the observer's sighting, dominant eye was always employed (Porac & Coren, 1981b).

Subjects

Forty undergraduate volunteers from the University of Victoria served as observers. All had a minimum of 20/20 acuity and normal stereopsis, as measured with a battery of visual tests administered with a Keystone Telebinocular. Each participant was naive as to the purpose of the experiment.

Procedure

The experimental design consisted of four groups of 10 observers each. In the Cyclopean condition, the observer binocularly viewed the illusion configuration in front of the background. In the Cyclopean monocular condition, the perception of the global illusion array was eliminated, since the observer viewed the Cyclopean stimulus monocularly; the observer's view of the array was thus equivalent to that of one of the panels in Figure 1A. The red dots at the angle vertexes enabled the observers to discern the extents to be judged. Two control configurations were also used. In these, the background was removed so that the stimulus appeared as in Figure 1B, and the observer viewed either binocularly or monocularly.

Each observer adjusted the apparatus so that the apparent distance between the right and center red dots (at the vertexes of the angles) was equal to that between the left and center dot. Starting positions for the measurements of illusion magnitude were set randomly so that ascending adjustments had to be made on some trials and descending ones had to be made on others. After an initial pair of measurements, decrement training commenced. During this period, the observers scanned the illusion figure, moving their eyes from vertex to vertex (red dot to red dot) in a systematic fashion. The inspection period was 5 min long, and two measurements of illusion magnitude were obtained after each 1-min interval.

RESULTS AND DISCUSSION

The results are summarized in Figure 3, which plots the illusion magnitude, as a function of inspection time, in millimeters for each of the four groups.

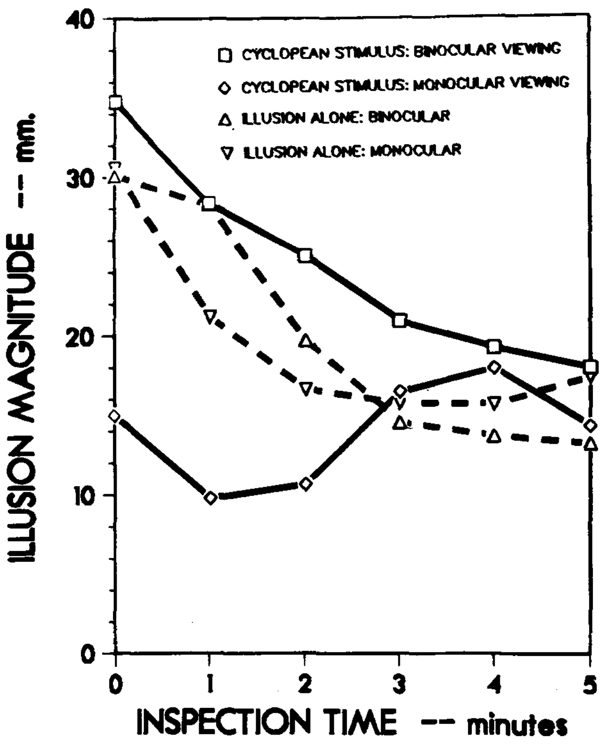

Figure 3. The magnitude of the Müller-Lyer illusion as a function of time for the four viewing configurations. (Conversion to percent illusion is obtained by dividing each value by 0.8.)

We had hypothesized that, before the inspection period, both the structural and the cognitive strategy components of the illusion would be evoked in the three conditions in which the configuration could be seen as a global pattern, but that in the condition in which observers viewed the Cyclopean stimulus monocularly (equivalent to viewing one panel of Figure 1A), any cognitive strategy contribution to illusion magnitude evoked by the holistic relationships among the elements would be lost, or at least greatly reduced. As Figure 3 shows, the monocular Cyclopean condition does produce lower initial illusion. An overall analysis of variance shows a significant difference among the means [$F(3,36)=4.55$, $p < .01$]. Paired contrasts show that there is no difference among the means of the three conditions in which the illusion can be seen holistically (with an average of 40% illusion, given the 80-mm test extent); however, all are significantly greater than the condition that activates only the structural mechanisms (which produces only a 19% illusion).

Our second hypothesis was that only the cognitive strategy component of the illusion would be subject to decrement during free inspection of the figure, leading us to predict a decrease in illusion in three conditions but none in the monocular Cyclopean condition. We performed an overall analysis to evaluate this prediction. It showed a significant effect of viewing time on illusion magnitude [$F(5,180)=18.32$, $p < .001$]; however, there was also a significant interaction between time and viewing condition [$F(15,180)=4.36$, $p < .001$]. This interaction is clear in Figure 3 in the apparent decrease in illusion magnitude for all but the monocular Cyclopean condition, in which it remained relatively constant over the viewing period. A series of one-way analyses of variance were used to assess the effect of inspection time on illusion magnitude for the individual groups. The results confirm the visual impression conveyed by the figure. There is a significant reduction in illusion magnitude as a function of viewing time for three of the groups [$F(5,45=7.03$, 15.90, and 9.97, $p < .001$] but not for the monocular Cyclopean group [$F(5,45)=1.57$].

According to our original analyses, illusion decrement should eliminate all, or almost all, of the illusion magnitude attributable to cognitive strategy components. Indeed, after the 5-min inspection period, the initial significant difference in illusion magnitude between the monocular Cyclopean condition and the other three had vanished [$F(3,36)=0.43$], indicating that all groups were, at that point, equivalent. The remaining illusory effect is still significantly greater than zero for all groups, however, and what remains should now consist of only the structural component.

Do Cyclopean presentation and illusion decrement agree in the estimates they yield of structural and cognitive contributions to illusion magnitude? In this study, the agreement is striking. From the differences in initial illusion magnitude between the monocular Cyclopean condition and the other three, we estimate that structural factors contribute 47% of the illusory effect. From the illusion decrement, we also estimate the structural contribution to be 47%. In both instances, the remaining contribution of 53% presumably arises from cognitive strategy mechanisms. In addition to the congruence shown by the two estimates of structural involvement in the present study, the obtained values also fall within the general estimates of between 40% and 50% for structural contributions to the illusion found in other studies (Coren & Girgus, 1978a, 1978b; Coren & Porac, 1983).

Cyclopean presentation, with its appropriate monocular control, and illusion decrement with continued active viewing of the stimulus provide converging operations that allow the estimation of the relative contribution of structure and strategy contributions to illusion magnitude. The advantage of the Cyclopean presentation procedure over the illusion decrement procedure used alone is that it does not require a protracted viewing period in order to obtain the relevant measurements (since initial illusion magnitude in a Cyclopean stimulus reflects the same degree of structural involvement as demonstrated after 5 minutes of inspection of a non-Cyclopean stimulus). Its relative disadvantages are that it requires some extensive modification of the stimulus and also a fairly elaborate stimulus presentation and illusion measurement apparatus. In any event, it does seem to provide an alternative method for exploring the relative contribution of the many mechanisms and levels of visual information processing that contribute to the formation of the classical visual-geometric illusions.

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