THE EFFECT OF FIN LENGTH CHANGES ON APPARENT SHAFT LENGTH AND DEPTH IN THE MÜLLER-LYER ILLUSION

by

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Abstract

Müller-Lyer figures with outgoing fins were back illuminated and shaft length and depth were both judged. With the angle between the fins constant, progressive increases in fin length produced first an increase in the apparent shaft length and then a decrease. Changes in fin length, however, had no significant effect on apparent depth. These data were interpreted as inconsistent with an account of the Müller-Lyer illusion in terms of perspective theory, since the latter predicts systematic changes in perceived shaft length to be associated with systematic changes in perceived depth.

THE EFFECT OF FIN LENGTH CHANGES ON APPARENT SHAFT LENGTH AND DEPTH IN THE MÜLLER-LYER ILLUSION

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Gregory (1963) has adopted a perspective interpretation of the Müller-Lyer figures (Thiery, 1896) and the use of inappropriate constancy scaling (Tausch, 1954; von Holst, 1957) to propose a theory explaining the Müller-Lyer illusion. According to the theory, the diverging and converging lines in the Müller-Lyer figures provide perspective cues for depth. However, the figures are not normally seen in three dimensions because the perspective cues are countermanded by the two dimensional ground on which the illusion figures usually appear. Nevertheless, Gregory asserts that the perspective cues are capable of activating the visual mechanisms responsible for size constancy scaling. Since size constancy compensates for the decreased retinal image size associated with increased distance, the portions of the Müller-Lyer figure interpreted as more distant are enlarged and those portions interpreted as closer are diminished.

Two important predictions follow from Gregory's inappropriate constancy scaling theory. First, when the Müller-Lyer figures are viewed in the absence of a ground, the figures should appear three dimensional. Gregory (1963) has reported such an effect, but Hotopf (1966) has failed to replicate it. Second, when viewed under these ground-deprived conditions, increases in apparent shaft length should be accompanied by increases in apparent depth. Krueger (1972) has criticized Gregory's account of the Müller-Lyer illusion because increases in fin length of the wings-out figure have been shown to initially increase illusion magnitude and then decrease it. To be consistent with Gregory's position, apparent depth must first increase with increasing fin length and then decrease. Krueger, although providing no empirical support for his position, has argued that apparent depth should become progressively larger as the fins are lengthened. The present experiment was designed to (_a_) evaluate Krueger's argument by measuring apparent depth in wings-out Müller-Lyer figures of varying fin lengths and (_b_) evaluate Gregory's account of the Müller-Lyer illusion by relating changes in apparent depth to changes in apparent shaft length.

Method

Subjects. The Os were twenty undergraduate students from an introductory psychology course at Appalachian State University. The volunteers received academic credit for their participation.

Stimuli and Apparatus. The stimuli were five wings-out Muller-Lyer figures cut out of black posterpaper. The shaft length of each figure was 10 cm. with fin lengths of

2.0 cm., 3.5 cm., 5.0 cm., 6.5 cm., and 8.0 cm., respectively. The width of shaft and fins was .5 cm. and the angle between the fins in all figures was 45°.

The apparatus used by the Os to indicate apparent shaft length consisted of a phosphorescent comparison line painted on 26 X 18 cm. black posterpaper ground. The width of the comparison line matched the width of the shaft in the illusion figures. A narrow strip of black posterpaper was mounted over the comparison line and provided a continuously adjustable mask. The apparatus used to measure apparent depth was similar to that described by Gregory (1966). The Müller-Lyer figures were back illuminated using an enclosed 40 watt incandescent light source. The light was passed through a Fresnell diffusing screen before reaching the stimuli figures to insure even illumination. The Os viewed the figures from a distance of 60 cm. through a pair of mounted polarized glasses, one lens of which was cross polarized with a sheet of polarized glass immediately in front of the Müller-Lyer figures. A half-silvered mirror was located midway between the polarized glasses and the illusion figures. A point of light from a moveable 6 volt Universal light source was reflected from the half-silvered mirror to the O. In this way each O used binocular vision to judge the apparent distance of the point of light while using monocular vision to judge the apparent distance of the shaft in the Müller-Lyer figure.

Procedure. Os were brought individually into a darkened room and seated directly in front of the mounted polarized glasses. Each O was given instructions on operating the experimental equipment and told to view the illusion figures at all times through the polarized glasses with both eyes open. In estimating shaft length and depth the method of adjustment was followed. To judge shaft length a length of the comparison line was exposed until O perceived it to be equal to the length of the shaft in the Muller-Lyer figure. To judge depth the point light source was moved laterally along a line until the light appeared to O as being as far away as the shaft in the illusion figure. Each O received a total of twenty trials, viewing every stimulus figure four times. Each trial consisted of one judgment of shaft length followed by one judgment of depth. The order of stimulus presentation was determined by a balanced square design.

Results

The mean judgments for perceived length and perceived depth are presented in Table 1. Perceived shaft length reaches a maximum at a fin length of 3.5 cm. and then decreases with further increases in fin length. Perceived depth, however, reaches a maximum at a fin length of 5.0 cm. and then progressively decreases. Across the five stimulus figures, perceived shaft length varies 17.13 cm. whereas perceived depth varies only 5.99 cm. Two treatment by

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Insert Table 1 about here

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subjects analyses of variance indicated that changes in fin length were accompanied by significant, $F(4,76) = 27.91$, $p < .001$, changes in perceived shaft length but the effect of fin length on perceived depth was insignificant, $F(4,76) = .72$, $p > .20$.

Insert Table 2 and 3 about here

Although changes in perceived depth were insignificant, it is still important to consider the relationship between changes in perceived shaft length and perceived depth. Figure 1 presents the means of judged shaft length and judged depth converted to Z scores. Although changes in depth for fin lengths 3.5 cm., 6.5 cm., and 8 cm. are in the direction predicted by an inappropriate constancy scaling theory, the magnitude of the changes is extremely small. In order to

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Insert Figure 1 about here

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evaluate the magnitude of the relationship between perceived shaft length and perceived depth a Pearson correlation coefficient was calculated for each O. Twelve of the _rs_ were positive, ranging from .050 to .825, and eight of the _rs_ were negative, ranging from -.057 to -.865. Interpreting the correlations as a sample from a population consisting of only two classes, _viz._, positive and negative correlations,

the probability of obtaining as many positive correlations is no greater than may be expected by chance (binomial test, $p = .5$).

Discussion

It has been shown that progressive increases in fin length do not produce a monotonic increase in apparent depth, contrary to Krueger's (1972) expectation. Gregory (1972) has suggested that Krueger's expectation was based on a misunderstanding of depth cue scaling. Increasing fin length could be expected to produce a progressively larger depth cue only if the ends of the fins were imagined to be stationery in space. Since in our everyday experiences with three dimensional objects their near ends are seldom fixed, it seems unreasonable that such an assumption would be incorporated into the depth cue scaling mechanism. Furthermore, as Day (1972) has pointed out, it is possible that increases in fin length may diminish the perspective cue since increases in total stimulus size are normally accompanied by decreased perceived distance.

Although the absence of a monotonic increase in apparent depth could be interpreted as evidence supporting Gregory's theory, additional findings point to inadequacies in an explanation of the Müller-Lyer illusion based on inappropriate size constancy scaling. Changes in fin length produce rather large changes in apparent shaft length, but the effect of fin length changes on apparent depth is insignificant. In fact, in one instance a decrease in apparent shaft length is accompanied by an increase in apparent depth. This clearly contradicts the relationship between shaft length and depth as required by a constancy scaling theory. An even more inexplicable finding in terms of constancy scaling is the absence of a consistent positive correlation between judged shaft length and depth. Calculation of the correlation coefficients within Os no doubt artificially inflated the magnitude of the relationship. Nevertheless, the mean Pearson $\underline{r}$ was only .069. Again the indication is that if depth cues exist in the Müller-Lyer figures, they have little influence on the perception of shaft length.

Lewis (1909) has derived a figure from the Müller-Lyer in which the angle between the fins was collapsed to 0° and small vertical marks were inserted to locate the joint of the shaft and the fins. With this collapsed figure it was found that increases in fin length up to approximately one-third of the shaft increased illusion magnitude and further increases in fin length caused a decrease in illusion magnitude. Krueger (1972), using collapsed and normal Müller-Lyer figures of equal shaft length, has shown that the maximal illusion in both figures occurs when the total length of each figure, measured parallel to the shaft, is equal. In addition Krueger has shown that the effect of practice on both figures is similar. If, as this evidence suggests, the same process gives rise to the illusion in these two versions of the Müller-Lyer, an explanation based

on inappropriate constancy scaling would seem even less satisfactory. Perspective cues would not be expected to exist in the collapsed version of the Müller-Lyer; yet, the same illusion persists.

There is little agreement among previous attempts to explain the existence of an optimal fin length in the wings-out Müller-Lyer figure. Obanai (1954) attributes the optimal fin length to induction changes which occur across space. Day (1971) considers the optimal fin length to result from changes in distance cues which are a function of size of adjacent elements, i.e. fins. Krueger (1972) prefers an explanation based on figure ground separation. It should be emphasized that the Müller-Lyer illusion is a problem concerning perception of extent, and therefore, any theory which proports to explain the Müller-Lyer illusion must also explain the effect of changes in fin length on changes in the apparent extent of the shaft. The present experiment has indicated that Gregory's theory is inadequate to account for the changes in the apparent extent of the shaft which accompany changes in fin length.

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Footnotes

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TABLE 1

Fin Length Effects on Perceived Length and Depth

Fin length	2 cm.	3.5 cm.	5 cm.	6.5 cm.	8 cm.
Perceived length	103.46	108.10	104.24	101.36	90.97
Perceived depth	133.32	136.36	139.31	137.29	134.89

TABLE 2

Analysis of Variance: Length

Source	SS	df	MS	F
Subjects	11091.89	19		
Fin Length	3313.27	4	828.27	27.91
Error	2254.92	76	29.67	

*$p < .001$

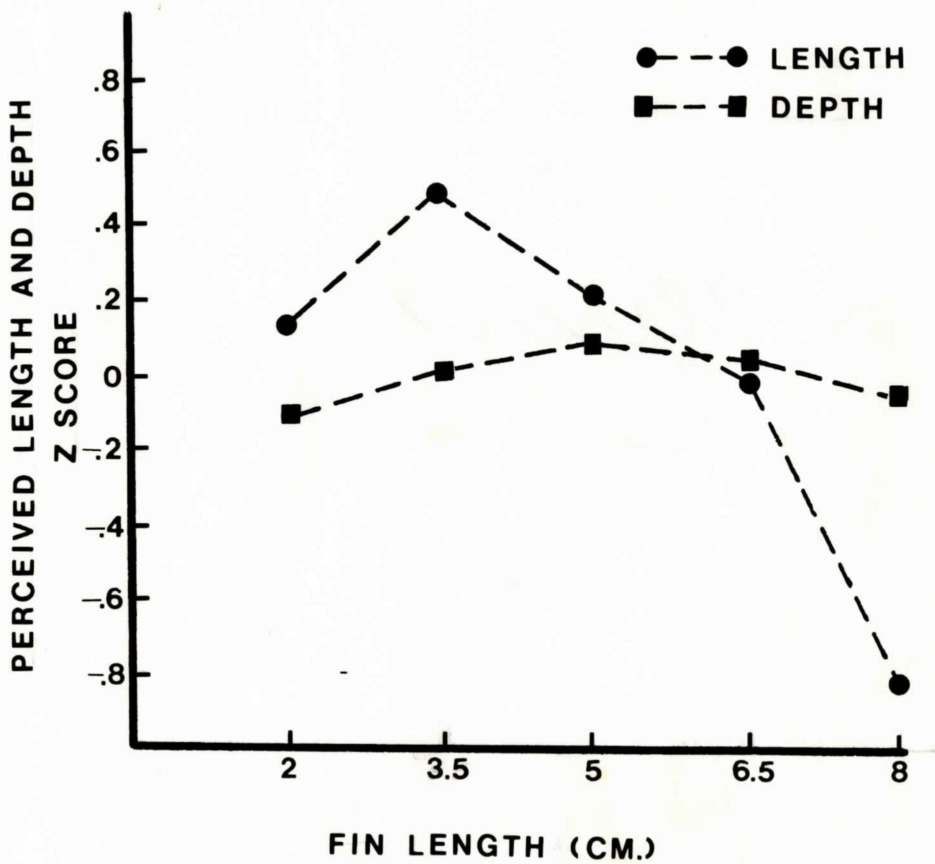
TABLE 3

Analysis of Variance: Depth

Source	SS	df	MS	F
Subjects	67507.19	19		
Fin Length	426.92	4	104.48	.726
Error	10943.24	76	143.99	

Figure Captions

Figure 1: Relationship of judged shaft length and depth as a function of fin length.


LENGTH
DEPTH
PERCEIVED LENGTH AND DEPTH
Z SCORE
.8
.6
.4
.2
0
-.2
-.4
-.6
-.8
2
3.5
5
6.5
8
FIN LENGTH (CM.)

APPENDIX I

TABLE A

Raw Data Scores

		FL1	FL2	FL3	FL4	FL5	r
S_1	length	94.25	97.75	92.75	93.0	84.25	.293
	depth	148.75	126.75	125.0	136.75	125.0	
S_2	length	108.75	99.5	85.75	85.5	78.0	-.553
	depth	102.0	97.75	111.75	100.0	108.0	
S_3	length	96.5	100.5	95.25	84.5	77.5	.636
	depth	89.75	149.0	130.25	118.25	81.25	
S_4	length	108.25	119.75	117.75	108.25	97.0	-.504
	depth	123.75	102.5	131.0	122.5	128.25	
S_5	length	91.25	106.0	102.25	97.25	85.75	.225
	depth	77.75	100.0	115.25	104.5	109.5	
S_6	length	84.25	86.75	83.75	80.75	76.25	-.478
	depth	124.0	125.0	124.0	123.25	126.5	
S_7	length	117.75	126.0	133.5	129.0	112.0	.489
	depth	149.0	139.25	142.5	146.0	128.75	
S_8	length	127.5	120.75	107.75	109.5	89.25	-.865
	depth	110.0	120.5	132.0	131.25	133.5	
S_9	length	90.5	97.0	100.0	110.75	89.5	.458
	depth	101.5	107.0	122.25	125.0	124.5	
S_{10}	length	102.0	103.25	97.25	92.5	84.75	.555
	depth	196.5	213.75	149.0	164.25	173.5	
S_{11}	length	120.5	118.25	117.75	113.5	103.75	-.057
	depth	153.5	158.75	166.0	153.75	159.25	
S_{12}	length	115.5	110.5	102.75	99.25	89.75	.609
	depth	150.25	150.5	155.25	148.5	142.5	
S_{13}	length	92.5	94.25	97.25	93.25	89.75	-.849
	depth	130.0	127.5	123.0	129.75	129.5	
S_{14}	length	103.0	121.0	116.25	114.5	97.5	.317
	depth	97.75	101.5	112.5	86.5	94.75	
S_{15}	length	115.25	113.75	112.0	107.25	106.25	-.237
	depth	131.75	104.75	125.25	120.5	130.5	

		FL1	FL2	FL3	FL4	FL5	r
S_{16}	length	101.25	107.75	103.0	103.75	92.5	.597
	depth	124.0	134.25	139.5	132.75	125.75	
S_{17}	length	94.5	96.75	99.5	95.0	85.75	.013
	depth	173.0	185.0	208.75	210.75	200.75	
S_{18}	length	100.75	104.5	101.25	97.75	92.0	.050
	depth	169.0	166.25	166.75	167.75	166.5	
S_{19}	length	92.0	105.25	97.0	98.0	75.75	.825
	depth	170.75	169.25	169.0	172.5	159.75	
S_{20}	length	113.5	132.25	122.0	114.0	112.0	-.157
	depth	143.25	148.0	137.0	150.5	149.0	

APPENDIX II

A THEORETICAL AND EXPERIMENTAL HISTORY

OF THE MÜLLER-LYER ILLUSION

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The Müller-Lyer figures were devised in 1889 by Franz Carl Müller-Lyer. Although known primarily as a German psychologist and sociologist, Müller-Lyer began his career in 1881 as an assistant physician at Strasbourg psychiatric clinic. While at Strasbourg he developed an interest in physiological and experimental psychology and began doing research in the laboratories of Charcot and Dubois-Reymond. In 1888 Muller-Lyer resigned his post at Strasbourg and moved to Munich where he discovered the well-known illusion which bears his name. By 1894 however, his interest in psychology had diminished and he turned to sociology, the area in which he made his most important academic contributions.

The Müller-Lyer figures aroused immediate experimental interest and a rash of early theories were put forth to explain the phenomenon. Müller-Lyer (1889) used the principle of confluxion in offering the first theoretical account of the illusion. A line that is adjacent to an obtuse angle appears longer than a line of equal length which is adjacent to an acute angle. The Müller-Lyer illusion, he believed, is simply a multiplication of this effect. Müller-Lyer's theory implies that the illusion is due to an actual sensory change in the encoding of shaft length rather than a faulty judgment of shaft length which is based on accurate sensory input. Einthoven (1898) proposed that this change in sensation may be due to a dispersion of excitation in the retinal image at the points where the fins and shaft join.

Many of the theories immediately following Müller-Lyer's emphasized the appearance of the figure as a whole. The common suggestion was that the fins produce the illusion not by altering the actual sensation of the shaft, but rather by enlarging the basis for its judgment. For instance, Laska (1890) noted that in one's imagination there is a tendency to close open figures with the shortest possible lines. Therefore he proposed that the more open Muller-Lyer figure, the wings-out figure, would appear longer because it required longer lines for closure. Delboeuf (1893) suggested that the addition of the fins to the shaft draws the attention of the viewer away from the endpoints of the shaft and into the fins themselves, thereby causing the illusion. Brunot (1893) believed that the judgment of shaft length was determined more by the mean distance between the fins than by the distance between the endpoints of the shaft. Similarly Auerbach (1894) and Schumann (1902) emphasized that the Müller-Lyer illusion was dependent on the total impression given by the illusion figures.

In addition to these early wholistic theories there were several dynamic theories which emphasized the role played by the observer in producing the illusion. Lipps (1897) proposed an empathy theory which attributed the Müller-Lyer

illusion to emotional responses made by the viewer while observing the illusion figures. According to the theory the wings-out figure suggests expansion whereas the wings-in figure suggests limitation. These emotional reactions to the figures influence the judgment of shaft length and therefore the wings-out figure is seen as longer.

Other early dynamic theories were proposed by Heymans (1896) and Wundt (1898). Heymans thought that the latent tendency of the observer to make larger eye movements while viewing the wings-out figure than while viewing the wings-in figure was responsible for the illusion. Wundt, who had originally attributed the horizontal-vertical illusion to overt eye movements, reapplied his theory to the Muller-Lyer. He argued that the wings-out figure causes the eyes to move past the endpoints of the shaft during inspection, while the wings-in figure checks the movement of the eyes before they reach the ends of the shaft. This increased and decreased range of eye movements was held to be responsible for the increased and decreased apparent shaft length.

Wundt's eye-movement theory, being less subjective than any of the preceding theories, has generated much experimental evaluation. Judd (1905) recorded eye movements with a movie camera and found no evidence of shorter eye movements for the wings-in figure than for the wings-out figure. However, he did find a relationship between the pattern of viewing and the illusion figure. While observing the wings-in figure there were more and longer fixations than while observing the wings-out figure. Judd considered this to be a consequence of the closed shape of the wings-in figure as compared to the open shape of the wings-out figure. Therefore eye movement patterns were attributed to figure appearance rather than attributing figure appearance to eye movement patterns. Lewis (1908) provided further evidence against the eye movement theory by showing that tachistoscopic exposures of the Muller-Lyer figures in durations too short to allow for detailed eye movement did not reduce the magnitude of the illusion. More recently Pritchard (1958) has shown that the Muller-Lyer illusion persists when the illusion figures are viewed as stabilized retinal images. Taken together this evidence has been sufficient to indicate that eye movements are not the causal factor in producing the Müller-Lyer illusion.

Apart from the early holistic and dynamic explanations of the Müller-Lyer two other theories emerged which were of importance. Bretano (1892) contended that the Muller-Lyer illusion was a special case of the general principle that acute angles are overestimated and obtuse angles are underestimated. He presented the Muller-Lyer figures in what has come to be known as the Bretano form, the fins without the shaft, and found that the space between the fins was still overestimated when viewing the wings-out figure and underestimated when viewing the wings-in figure. Thiery (1896) believed that perspective features of the Muller-Lyer figures were important in producing the illusion. He saw both illusion figures in three dimensions, the wings-out figure as a sawhorse with the legs protruding towards the viewer and the

wings-in figure as a sawhorse with the legs extending away from the observer. Thiery suggested that the utilization of these different depth cues by the visual system was in some way responsible for creating the illusion.

Following the early surge in theoretical accounts of the Müller-Lyer attention was turned to determining factors which influence illusion magnitude. Benussi (1904) first showed that observers who had been instructed to adopt a whole-perceiving attitude saw a larger illusion than observers who had been instructed to adopt a part-isolating attitude. In addition Benussi found that when figures with fins and shaft of different colors were presented the magnitude of the illusion was further reduced. Presumably the different colors caused the observers to perceive the shaft as even more isolated from the fins. Recent experiments (Gardener & Long, 1961; Day, 1962; Mountjoy, 1965) have confirmed the influence of instruction on illusion magnitude. Such results suggest the importance of cognitive factors in the Muller-Lyer and tend to support the earlier holistic interpretations of the illusions.

Another factor which was found to influence illusion magnitude was practice. Judd (1902) had observers adjust the shaft of a wings-out Müller-Lyer figure to match the length of the shaft in a wings-in figure and found that after four days of repetition with 125 to 250 trials per day the illusion was eliminated. Also Judd found that the effect of practice transferred to figures of different shaft lengths and different fin angles. Elimination of the illusion in one figure either eliminated or greatly reduced the number of practice trials needed to eliminate the illusion in a new figure. Judd suggested that the decrement in illusion magnitude was the result of a change in the pattern of eye movements used to observe the figures. Lewis (1908) offered an alternative explanation, claiming that the decrement resulted from a change in central attentional processes. The observers learned to abstract the shaft from the fins while making their judgments. Both explanations are essentially learning explanations and attribute the decrement in illusion magnitude to a gradual change in the perceptual processes which occurs over the course of the experiment. Kohler and Fishback (1950a, 1950b) have provided another explanation based on asymmetrical cortical satiation. They argue that the decrement in illusion magnitude cannot be attributed to any form of perceptual learning because improvements occur without the observer being given any knowledge of the results, continuous trials produce a negative illusion, the illusion cannot be destroyed in all observers, and when the illusion is destroyed in one orientation it often reappears when the figure is presented in another orientation. Kohler and Fishback (1950a) have provided data from an extremely small subject pool to support their theory but other tests have produced negative results (Mountjoy, 1958, 1960; Moed, 1959). Finally Day (1962) has shown that the decrement in illusion magnitude occurs as a function of the extent to which comparison of the two figures is possible. Decrement occurs for any size figure when free eye movement is allowed but with large figures

and a fixation point there is no reduction of illusion magnitude.

The next major theoretical account of the Müller-Lyer illusion was offered by Motokawa (1950). The theory is similar to Einthoven,s (1898) in that both claim the illusion results from some deformation in the retinal image of the illusion figure. Motokawa briefly exposed a Müller-Lyer figure and then measured the phosphene threshold at particular points in the visual field. Next the field of excitability was mapped by comparing the thresholds following exposure of the illusion figure to the thresholds preceding exposure of the illusion figure. Induction fields were found to exist for both Müller-Lyer figures and discontinuity in the field existed at the juncture of the fins and shaft. If edges are seen at each point of discontinuity and the judgment of shaft length is based on the distance between these edges then the wings-out figure would produce an overestimation of shaft length and the wings-in figure would produce an underestimation of shaft length. Nakagawa (1958) has confirmed and extended Motokawa's findings concerning the Müller-Lyer.

Motokawa's suggestion that the Müller-Lyer illusion may be retinal in origin has generated further testing. Ohwaki (1960) has reported that the magnitude of the Müller-Lyer illusion was greatly reduced by presenting the test and inducing portions of the figures separately to each eye. Springbett (1961) has confirmed these results with other illusion figures. Both authors argued that if the illusions were due to central processes they should have remained in tact. Day (1961) has replicated

Ohwaki's findings concerning the Muller-Lyer but attributed the reduced illusion to depth effects and/or retinal rivalry produced by tachistoscopic viewing. Furthermore Day has argued that in the case of the Müller-Lyer reduction in illusion magnitude could not be attributed to the separation of test and inducing elements because the illusion is equally as strong in the Bretano form. Schiller and Weiner (1962), using illusion figures other than the Müller-Lyer, have shown that when retinal rivalry is eliminated by brief exposure of the figures the magnitude of the illusions is not reduced. On final analysis then, the locus of the Müller-Lyer illusion remains largely undetermined. The results of Schiller and Weiner's experiment would be expected if retinal processes were not involved in producing the illusion but they would also be expected if the inducing portions of the illusion figures were sufficient to create the deformation in the retinal field of excitation.

Piaget (1961) has proposed a theory based on relative centrations to account for many of the geometrical illusions, including the Müller-Lyer. According to the theory, those portions of the stimulus figures which receive the greatest density of centrations, or acts of attention, during inspection are overestimated in size. Errors become maximal with more highly localized attention and diminish as attention becomes more widespread. It should be immediately pointed out that centrations are not necessarily held to be synonymous with eye fixations, although the two are often confounded. Therefore

objections that have previously been raised to the eye-movement theory are not applicable. Piaget considers attention to be a central rather than peripheral process.

The evidence Piaget has offered supporting his interpretation of the Müller-Lyer has been derived from experiments showing age differences in illusion magnitude. Since adults adopt a more active search pattern than children while inspecting illusion figures (Piaget and Bang, 1961a, 1961b) it would be expected that the magnitude of the Muller-Lyer illusion would decrease with increases in chronological age. Piaget (1961) has shown this to be the case. Furthermore, Noelting (1960) has shown that practice is ineffective in reducing the magnitude of the Müller-Lyer illusion for younger children but it is maximally effective for adults.

Although the decrease in illusion magnitude with increasing chronological age appears to support Piaget's centration theory, Pollack (1963) has suggested an alternative explanation for this decrement. Since the magnitude of many geometrical illusions decrease with decreasing contrast (Oyama, 1960) and several studies (Brody, 1955; Weale, 1961a, 1961b, Hinchcliffe, 1962) have shown that there is a decreasing sensitivity to light in the retina and occipital lobe with increasing chronological age, it appears that this decrement in illusion magnitude may be the result of a corresponding decrement in contour thresholds. Also there is evidence to indicate that chronological age is a more important determiner of illusion magnitude than mental age (Spitz and Blackman, 1958; Pollack, 1964). This suggests the importance of physiological factors over cognitive factors in determining illusion magnitude. Finally, Pollack (1970) has shown that although Müller-Lyer figures produced by lightness contrast (white on black) show a decrement in illusion magnitude with increasing age, Muller-Lyer figures produced by hue contrast (red, yellow, green, or blue on gray) do not show such a decrement.

Pollack and Chaplain (1964) have proposed a theory to account for the Müller-Lyer illusion which is based on the interaction of contour processes across space. The theory suggests that there is a continuous function of contour interaction such that there is no interaction when the contours are aligned, maximal repulsion when the contours form an angle of 90°, and maximal attraction when the contours are parallel. Since the fins of the wings-in Müller-Lyer figure always form an angle of less than 90° with the shaft there is always some degree of attraction. The attraction causes a fusion of the shaft and the fins near their juncture and therefore shaft length is underestimated. In the case of the wings-out Muller-Lyer figure the angle between the fins and the shaft is always greater than 90° and therefore some measure of repulsion occurs, leading to an overestimation of shaft length. In addition, the repulsion of the shaft and the fins is reinforced by the opposition of the fins themselves. This is said to account for the larger magnitude of illusion in the wings-out form. Pollack's theory receives some support from the physiological analysis of figural after-effects offered

by Osgood and Heyer (1952).

Gregory (1963) has proposed an inappropriate constany scaling theory to account for the Muller-Lyer illusion. According to the theory, the Muller-Lyer figures contain perspective cues indicating depth (Thiery, 1896) and these cues function to inappropriately arouse the visual mechanisms responsible for size constancy (Tausch, 1954; von Holst, 1957). Since the Müller-Lyer figures are normally seen as flat and therefore would not be capable of activating size constancy. Gregory (1968) has argued that there must be a visual mechanism capable of encoding distance information on an unconscious level. This mechanism, referred to as a depth cue scaling mechanism, operates on the basis of perspective features which are normally associated with distance (converging and diverging lines, overlay, elevation, etc.). When these features are at variance with actual distance size constancy is inappropriately aroused and illusions result. Since perspective cues indicate that the shaft of the wings-out Muller-Lyer figure is more distant than the shaft of the wings-in figure and since size constancy compensates for the decreased retinal image size associated with increased distance it follows that the shaft of the wings-out figure will appear enlarged while the shaft of the wings-in figure will appear diminished.

Gregory's theory has generated much experimental evaluation and results have not offered uniform support. For instance, Massaro and Anderson (1970) have found that when using three dimensional wings-out Muller-Lyer figures there is no difference in the magnitude of the illusion whether depth cues provided by the diverging fins are in opposition to or complement the real depth cues. In addition, Dengler (1972) has shown that when the shafts of a wings-in and wings-out Müller-Lyer figure are replaced by a rectangle the rectangle in the wings-out figure is judged both longer and narrower than the rectangle in the wings-in figure. Furthermore it is difficult to understand in terms of inappropriate constancy scaling how practice effects from haptic judgments can transfer to the visual modality (Rudel and Teuber, 1963).

Recently two new interpretations of the Müller-Lyer illusion have emerged which deserve mention. Day (1971) has proposed that the two forms of the Müller-Lyer are separate illusions. In the case of the wings-out figure it is argued that the size of the attached elements, i.e. fins, determines the illusion. An increase in fin length alters the distance stimuli of the figures such that illusion figures with longer fins appear nearer. By means of size constancy scaling the shaft length of the apparently nearer figures is diminished. In the case of the wings-in figure the size of the space between the fins determines the illusion. The smaller this inner space the greater is the magnitude of the illusion. This account of the illusion in the wings-in figure is based on the findings of Erlebacher and Sekuler (1969). Finally, Krueger (1972) has suggested that an explanation of the illusion in the wings-out Müller-Lyer figure based on figure-ground separation is possible. When the outgoing fins are short they are not perceptually distinct from the shaft and therefore

the shaft appears longer. However, as the outgoing fins are lengthened they appear progressively more distinct from the shaft and have a progressively smaller influence on the judgment of shaft length.

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