The nature of size scaling in the Ponzo and related illusions*

BARBARA GILLAM

College of Optometry, State University of New York, 122 East 25th Street, New York, New York 10010

The failure of previous investigators to obtain a Ponzo illusion when each test line is rotated 90 deg from its conventional placement has been interpreted as a refutation of constancy scaling theory. It was proposed that, instead, these results might be due to a failure of linear perspective to elicit foreshortening scaling, and vice versa, since the two types of perspective have different functions. This hypothesis was tested and confirmed.

Humphrey and Morgan (1965) attempted to refute Gregory's (1963) constancy scaling theory of the Ponzo illusion (Fig. 1A) by means of a version of Fig. 1B. Their argument was that if perceptual expansion of the upper line relative to the lower line of the Ponzo figure results from constancy scaling elicited by the depth cue property of the converging lines, then there should also be expansion of the upper line of Fig. 1B, since that line is also on the "farther" part of the figure. They claim (on the basis of inspection) that this does not occur for Fig. 1B, and therefore that the expansion of the upper line in Fig. 1A cannot be the outcome of constancy scaling.¹ In his reply, Gregory (1965) stated that the failure to obtain an illusion for Fig. 1B might be owing to either the greater distance of the test lines from the illusory background in Fig. 1B or to a "difference between size and shape constancy." Although it is not clear from his statement, Gregory may have had in mind the difference between linear perspective and foreshortening, which are both retinal compressions of contours (or spaces) when a plane is slanted away from the frontal plane but different in principle from each other. The degree of compression in the retinal representation of lines and spaces on the plane and parallel to the axis of slant is a linear function of distance from the eye (linear perspective), whereas for lines on the plane and orthogonal to the axis of slant, retinal compression is a linear fractional function of distance from the eye, asymptoting to a slope of one (foreshortening). Therefore, constancy scaling rules compensating for these compressions of the retinal image must be different for contours on the two dimensions of a receding plane (henceforth referred to as the linear perspective and the foreshortening dimensions, respectively). Bearing this in mind, and assuming Gregory is correct in asserting that constancy scaling in an illusory figure is elicited by depth cues rather than by apparent depth,² it is not at all unreasonable to suppose that a linear perspective inducing figure such as the converging lines of the Ponzo figure would elicit only

linear perspective-type scaling (as in Fig. 1A) and not the foreshortening type of scaling that the expansion of the upper line of Fig. 1B would require.

This analysis suggests the following further question. Does a background figure consisting only of foreshortening perspective induce scaling only for lines on the foreshortening dimension and fail to elicit scaling of lines on the linear perspective dimension? In other words, can Humphrey and Morgan's observation be reversed so that the vertical test lines of Fig. 1B show a greater illusion than the horizontal test lines of Fig. 1A when the linear perspective background is replaced by a foreshortening background? This case is shown in Figs. 2A and 2B. An experiment was carried out to measure the degree of illusion in the four cases shown in Figs. 1 and 2, with the addition of some control figures (3A and 3B).

METHOD

The six figure types used were scaled-up versions of Figs. 1, 2, and 3. The vertical visual angle of the figures was 4 deg at a viewing distance of 284 cm. The foreshortening background of Fig. 2 is equivalent in degree of slant represented to the linear perspective background of Fig. 1. The horizontal test lines were slightly higher than the midpoints of vertical test lines to make them accurate projections of frontal plane and median plane lines with identical midpoints. In Fig. 1A (the classical Ponzo illusion), the background was the linear perspective type and the test lines were on the linear perspective dimension. In Fig. 1B, the background was the linear perspective type but the test lines were on the foreshortening dimension. In Fig. 2A, the background was the foreshortening type and the test lines were

Fig. 1. (A) The Ponzo illusion. (B) Ponzo variant.

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Fig. 2. (A) Foreshortening figure analogous to the Ponzo variant. (B) Foreshortening illusion analogous to the Ponzo illusion.

Fig. 3. Test lines of Figs. 1 and 2 without backgrounds.

on the linear perspective dimension, whereas for Fig. 2B, the background was the foreshortening type and the test lines were on the foreshortening dimension. Control Figs. 3A and 3B contained only the linear perspective and foreshortening test lines, respectively.

A point of subjective equality for each of the two test lines for each of the six figure types was found by means of a double random staircase (Cornsweet, 1962) in which the lower test line was varied in length. To vary the lower line, there were six stimuli made for each figure type with the upper test line always 38 mm long and the lower test lines each 32, 36, 40, 44, 48, and 50 mm long. The six figure types were presented in a different random order to each of the 10 Ss.

The 36 stimuli were prepared as follows. Multiple transparencies were made of each of the two backgrounds from black ink drawings. Multiple transparencies were also made of each of the six pairs of horizontal test lines and each of the six pairs of vertical test lines (without backgrounds). Except for the controls, which consisted of test lines only, each stimulus was made by superimposing the required test line transparency and the required background transparency and attaching the pair to a cardboard frame. This method eliminated the possibility of differences between stimuli owing to slight drawing errors.

A box with a ¼-in.-thick milk Plexiglas front and containing incandescent lights controlled by a timer was used to present the stimuli. Luminance measured at the surface of the Plexiglas

when the lights were on was 10 fL. The Plexiglas was masked by black flock paper, except for an area the size of the transparency. Below this area was a groove and above the area was an iron bar. The cards containing transparencies could be slid quickly into the groove by E. A magnet was then attached to the iron bar to hold the frame in place at the top. The magnet was painted with fluorescent paint. The S was seated in the dark with his head in a chinrest and his eyes approximately at the level of the center of the transparency. He was asked to look below the self-luminous magnet. After a warning signal, the appropriate transparency was exposed for 1.5 sec after which S was required to say whether the lower line was longer or shorter than the upper line. For all stimuli, one staircase began at 50 mm and the other at 32 mm. The PSE for each figure type for each S was based on 24 staircase trials.

RESULTS

The means in Table 1 show that the predictions were fulfilled. The linear perspective background induced an illusion only for test lines on the linear perspective dimension (Fig. 1A) but not for test lines on the foreshortening dimension (Fig. 1B), which supports Humphrey and Morgan's observation. ("Illusion" refers to greater physical length of the lower test line than the upper test line at PSE.) On the other hand, the foreshortening background induced an illusion only for test lines on the foreshortening dimension (Fig. 2B), and not on the linear perspective dimension (Fig. 2A). The frequencies of Ss' giving various theoretically relevant results are shown in Table 2 and are amply sufficient to establish the significance of the differences between the means shown in Table 1. For every S, the degree of illusion for Fig. 1A was greater than for Fig. 1B, and for every S but one (whose PSEs were equal), the degree of illusion for Fig. 2B was greater than for Fig. 2A. Furthermore, only Figs. 1A and 2B showed more illusion than their respective control figures, 3A and 3B, in a significant number of cases (10/10). The mean PSEs of the lower line for Figs. 1B, 2A, 3A, and 3B were all very close to physical equality, and there were no differences among them.

Another finding of interest shown in Table 2 is that linear perspective has a stronger effect on lines in the linear perspective dimension than foreshortening has on lines in the foreshortening dimension (1A > 2B).

DISCUSSION

The fact that illusory size differences occurred only for test lines on the dimension along which there was perspective compression shows that these illusions are not attributable to distance resolutions, conscious or unconscious. If distance were the mediator between a

Table 1
Mean Point of Subjective Equality of Lower Line With Upper Line as Standard for Each Figure Used in the Experiment*

	1A	1B	2A	2B	3A	3B
Mean PSE (mm)	43.2	38.7	38.7	41.0	38.7	38.7

*Upper line = 38 mm

perspective type of stimulus and size enhancement, such enhancement should have occurred for both dimensions for both backgrounds. On the other hand, the pattern of illusory size differences obtained in the present study supports the view expressed in the introduction that size enhancements arise directly and independently from the two types of perspective compression. In perspective processing of Fig. 1A, the lateral distances between converging lines represent *equal* horizontal distances from the bottom to the top of the figure. The perceived sizes of other horizontal distances are influenced by this scaling and are not based solely on physical equality.³ Only lines converging to the vanishing point are perpendicular to the base and parallel in perspective processing of this figure. Similarly, for Fig. 1B the foreshortened spaces provide a scale of equal *vertical* distances from the bottom to the top of the figure, which cause size judgments to deviate from physical equality in that dimension. The present data imply that on dimensions of a pattern along which there is no scale, no illusion occurs.

A more conservative interpretation would be to ascribe the present results to contrast. However, this cannot easily account for the Ponzo variant shown in Fig. 4 (Gillam, 1971). Both pairs of test lines on this figure are horizontal and collinear, but the right component of each pair appears displaced in a direction away from the vanishing point of the trapezoidal inducing figure. This creates an illusory difference in the separation of left and right pairs equivalent to the Ponzo illusion. The displacement of the two halves of the upper pair occurs without the lower pair, and vice versa (Gillam, 1971), so the illusion is only secondarily one of extent. It is difficult to see what context or background could be used to explain these *displacements* by means of contrast or adaptation level theory. On the other hand, perspective processing theory can account for the illusory displacements in Fig. 4 with no ad hoc assumptions. The converging lines are processed as horizontal parallel lines. The attached test lines appear

Fig. 4. A figure modified from Gillam (1971), showing collinear horizontal lines apparently displaced in a direction away from the vanishing point of the converging parallels. The top right line appears too high for collinearity with the left. The bottom right line appears too low.

displaced because their points of attachment are on different horizontal planes, according to the linear perspective scale although not according to the true or projective scale. Apparently (see Fig. 4), the perspective scaling of horizontal does not extend beyond the boundaries of the inducing figure to actually tilt the test lines, although this has not been measured.

The finding that linear perspective has a greater size scaling effect in the one dimension than foreshortening has in the other ties in with data showing that linear perspective produces a greater degree of apparent depth than does foreshortening, and also that linear perspective dominates stereopsis far more in a conflict than foreshortening does (Gillam, 1968). All of these findings may be related to the fact that foreshortening is a nonlinear function of distance, whereas linear perspective is, of course, linear and more economical to process.

It could be argued that the illusion in Fig. 2A is merely the Oppel-Kundt illusion (illusion of filled and unfilled space), since the upper line is cut by eight more lines than is the lower. In fact, Day (1972) attributes the Oppel-Kundt illusion to depth processing on the basis of texture size. However, the present results cannot be related to this illusion in any simple fashion. Using the conditions of the present experiment and $N = 10$, Fig. 2A gave a larger illusion for every S than identical test lines with the upper one cut by eight short, equally spaced, horizontal lines and the lower one unfilled. In fact, there was no illusory difference between the latter under these conditions, which is surprising. Figure 2B does represent a complex situation, since it is the only figure used in which the test lines are cut, giving rise to

Table 2
Frequencies of Ss With a Greater PSE for One Figure Than Another for All Theoretically Relevant Pairs of Figures

Comparison	Frequency	Significance Level
1A > 1B	10/10	.002
1A > 2A	5/9	n.s.
1A > 2B	9/10	.018
1A > 3A	10/10	.002
1B > 3B	6/9	n.s.
2B > 1B	10/10	.002
2B > 2A	9/9	.004
2B > 3B	10/10	.002
3A > 2A	5/8	n.s.

Fig. 5. Other versions of Fig. 2(B).

Mueller-Lyer variants of various kinds, depending on which background lines are considered. Figure 5 shows placements of the test lines on the background figure different from Fig. 2B. The left pair, presented alone and centered on the background, using the procedure of the previous experiment, yielded an illusion greater than that obtained for control lines for eight of nine Ss ($\bar{X} = 5.3$ mm). This shows that the illusion is not specific to one particular arrangement. The right pair was not tested but also seems to exhibit some degree of illusion.

One fact that must be accounted for is that the size scaling effects obtained in this experiment were small compared with those obtained in real scenes (Leibowitz et al, 1969). This could be accounted for in one of the following three ways:

(1) Increasing apparent depth by means of the additional cues in real scenes increases the tendency to respond to converging lines on the retina as parallel (or foreshortened lines as equidistant). In that case, size scaling in a given dimension would require the presence of a gradient of compression along that dimension of the figure no matter what other cues were present which caused apparent depth.

(2) The increased apparent depth within a figure produced by additional cues may *directly* cause size scaling. In that case, size scaling would increase in a given dimension when apparent depth was enhanced, regardless of whether there was a scale for that dimension within the figure.

(3) Cues added to increase "apparent depth" may themselves directly cause size scaling. Gillam (1967) has demonstrated the independence of "stereoscopic shape" and "stereoscopic slant" under certain conditions which can be accounted for by the fact that binocular stimulation specifies the former as well as the latter. The work of Heineman et al (1959) showed that apparent

size varied directly with accommodative convergence, whereas apparent distance did not.

It would be of some theoretical interest in understanding perspective processing to eliminate the third possibility by avoiding disparity and convergence cues and attempt to discriminate between Possibilities 1 and 2. Vickers's (1971) work suggests that apparent depth can be increased by simply adding more contours to a gradient. It may therefore be possible to vary apparent depth by using only linear perspective and to test for apparent size differences of retinally equal lines on the foreshortening dimension. (The difficulty would be in obtaining sufficient depth differences.) If an effect were found, it could be concluded that apparent depth does have a direct effect on size perception and does not merely increase the perspective response to scales already in the figure.

In conclusion, it appears that the illusions measured in the present experiment are the direct outcome of the size enhancements which are necessarily involved in responses to line gradients as perspectives. These are related to, but do not depend upon, distance resolutions on the basis of the same gradients. A scale of "equal" sizes must be present in a given dimension for size enhancements to occur in that dimension.

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NOTES

1. The version shown in Fig. 1B is also given by Tausch (1954), whose Ss did report an illusion for it, in contradiction to Humphrey and Morgan and the present results. However, since no measurements were made, demand characteristics could have been responsible.

2. This view is not unlike the relational theories of size perception discussed by Hochberg (1971).

3. In line drawings, perspective processing and projective processing both weight the final outcome. For a fuller account of the position of the present author on this issue, which is similar but not identical to Gregory's (1963), see Gillam (1971).

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