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Test of Gregory's Constancy Scaling Explanation of the Müller–Lyer Illusion

Much of the recent interest in geometrical illusions has centred on a size constancy explanation by Gregory[1–3]. Size constancy occurs when the apparent size of an object remains constant, independent of the distance of the object from the observer, even though the size of the retinal image varies with the distance. The mechanism which produces size constancy has been called constancy scaling[2].

In Gregory's theory—a modification of perspective theory[4]—geometrical illusion figures are considered to be similar to two-dimensional projections of three-dimensional figures. As in three dimensions, constancy scaling operates to increase the apparent size of apparently more distant parts of a figure, and to decrease the apparent size of apparently nearer parts. In a two-dimensional figure, perspective features provide the observer with cues for judging the apparent distance of parts of the figure. These perspective features trigger constancy scaling, which affects the apparent size of parts of the figure and produces an illusion, even though the figure need not be seen as having depth.

Gregory's theory cannot account for all illusions because, as Day[5] has pointed out, illusions can be generated by figures without perspective features, such as the dumbbell version of the Müller–Lyer figures. It is still, however, of interest whether illusions in figures containing perspective features can be explained by the operation of constancy scaling. The Müller–Lyer figures seem to have perspective features: the wings and their directions. If Gregory's theory is correct, constancy scaling should thus influence the perception of the Müller–Lyer figures.

Gregory[2] assumes that Müller–Lyer figures are similar to projections of typical three-dimensional objects. For example, Fig. 1*a*—with the wings directed outwards—is similar to a projection of the corner of a room, where the central axis corresponds to the corner and the outside wings correspond to the intersections of the walls with the ceiling and with the floor. Because of the effect of the wings as perspective cues, the central axis is judged as though it were farther away than the wings, that is, as though the figure were a three-dimensional object. Accordingly, constancy scaling operates, and increases the apparent length of the central axis. On the other hand, Fig. 1*b*—with the wings directed inwards—has the perspective cues of a projection of an outside corner of a building. The central axis is thus judged as though closer than the wings and therefore appears too small because of constancy scaling.

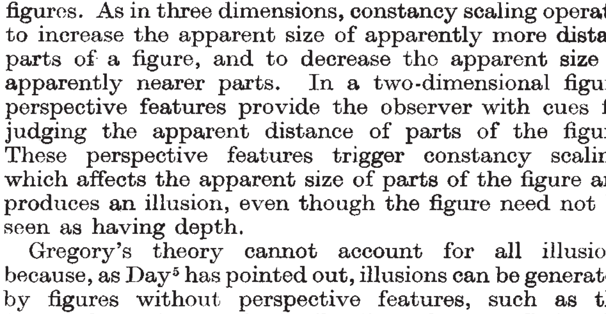

Fig. 1. *a* and *b*, Müller–Lyer figures. *c* and *d*, The same figures with enlarged width of central axis.

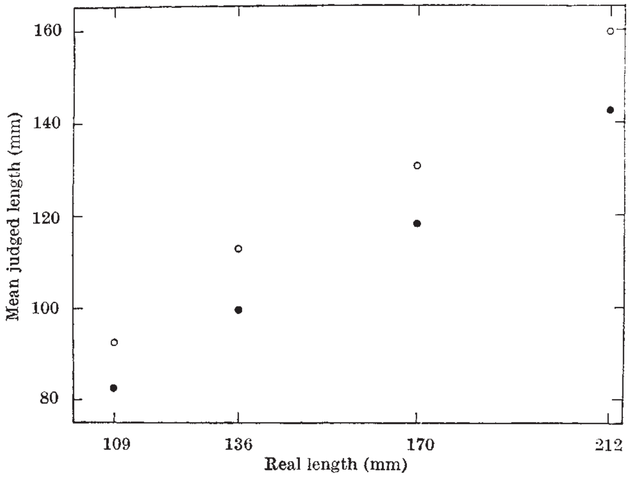

Fig. 2. Mean judged length of the central axes of Müller–Lyer figures as a function of the absolute length and the direction of the wings (●, inward; ○, outward).

If Gregory's theory is correct and internally consistent, constancy scaling not only augments the apparent length of the central axis of Fig. 1*a* but also should augment its apparent width. That is, if constancy scaling is involved, both the apparent length and the apparent width of the central axis should be affected and should be distorted in the same direction.

The present study provides a direct test of the assumption of constancy scaling by determining whether subjects' length and width judgments of Müller–Lyer figures are distorted in the same direction. Because the Müller–Lyer figures usually consist of relatively fine lines, as shown in Figs. 1*a* and 1*b*, any illusion in the perception of the width of the central axis might not be noticed on casual observation. With thicker central axes, however, as shown in Figs. 1*c* and 1*d*, any illusion in the judged widths should be readily discernible. Note that these figures provide the same perspective depth cues as do the standard Müller–Lyer figures: the wings and their directions.

In the figures used here, the inward and outward wings met the central axis at 30 and 150 degrees, respectively. Four sizes of the central axis were used: 40 × 109, 27 × 136, 64 × 170 and 43 × 212 mm. Figures were presented one at a time, vertically as in Fig. 1, at a distance of 105 cm from the subjects and about 12 cm above eye level. The figures were projected on to a green blackboard with a slide projector.

Subjects were told to judge the apparent length and width of the central axis of each figure. The response sheet contained a horizontal and a vertical line which met and ended at a point near the upper left corner of the sheet. The subject responded by making a mark on each line to indicate the length and width of the central axis. The figure remained present while the subject made his response. No more than two subjects were tested at a time. Fourteen subjects judged each of the eight figures six times in randomized blocks of trials. Responses were measured to the nearest millimetre.

The results of the experiment contradict Gregory's theory. Fig. 2 shows that the Müller–Lyer illusion occurred;

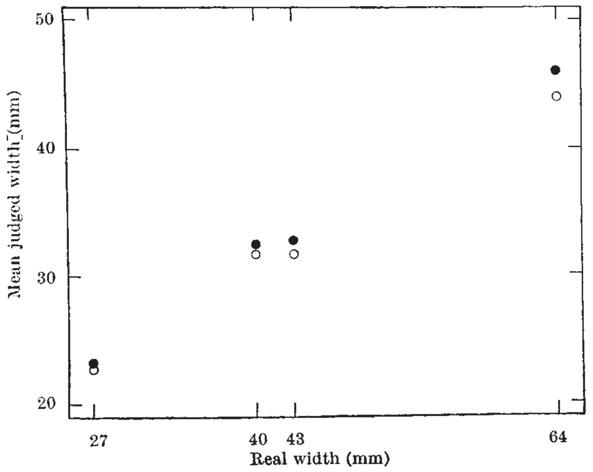

Fig. 3. Mean judged width of the central axes of Müller–Lyer figures as a function of the absolute width and the direction of the wings (●, inward; ○, outward).

the lengths of the central axes with outward-directed wings were judged longer than the corresponding axes with inward-directed wings. As explained above, it follows from the theory that the width judgments should have been distorted in the same direction; but they were not. Fig. 3 shows that the width judgments were, rather, distorted in the opposite direction: the widths of the central axes with outward-directed wings were judged smaller than the corresponding axes with inward-directed wings. A repeated-measures analysis of variance revealed that this average difference (1·13 mm) was significant ($P < 0{\cdot}01$).

One of the most popular explanations of the perceptual distortion of the lengths of these figures has been Gregory's perspective theory. But this theory does not predict the judgments of width obtained here. This study was a critical test, for the figures used have substantial cues for depth and should, according to the theory, have triggered constancy scaling. Given its inability to account for the perceived width of the figures, Gregory's theory cannot provide a consistent account of the Müller–Lyer illusion.

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Facets of Control in Human Walking

USING eight normal barefoot male subjects, we have studied, for both feet simultaneously, the timing characteristics of the various phases of heel and toe contact with the ground. Two types of experiment were performed for walking on the level, one with speed fixed at 4·5 feet/s while pace frequencies were varied between 1·25 and 4·00 per s; another with speeds of natural walking ranging from 2·0 to 6·7 feet/s. We chose to experiment with barefoot subjects to eliminate the possible influence of different footwear, recognizing that walking characteristics, with and without footwear, would not necessarily be identical. For both natural and forced pace walking we found that averages of the various footswitch phases, when normalized with respect to the average periodic time, remained fairly constant. Also, for natural walking, both pace frequency and step size seem to depend on the square root of the speed.

The barefoot subjects had shaped, fine mesh stainless steel electrodes taped over the heel and toe regions of both feet on top of an insulating layer of adhesive tape. The toe electrode covered the area under the big toe as well as the pad of the foot directly behind the toes, and the heel electrode covered the load bearing parts as indicated by the thick-skinned regions. They kept pace with a motorized cart whose speed could be controlled, and after traversing some 20 feet over which a steady-state walk could be reached the subjects walked on a roughened sheet of 1/16 inch aluminium 30 feet long and 18 inches wide.

A small junction box on a belt around the subject's waist held four resistors with values in the proportions 8 : 4 : 2 : 1 and commoned at one end. The other ends of each resistor were connected to their respective footswitch electrodes and the common junction was connected to a 6 V battery and a resistor in series mounted on the cart. The aluminium walkway was connected to the latter resistor by way of the shield of a signal cable running from the cart. The footswitch states determined the voltage appearing across the resistor. This voltage was led through the signal cable directly to our digital computer which was programmed to sample it at the rate of 200 Hz while the subject was over the aluminium surface. Then the programme translated the signal into graphic responses associated with each footswitch and effected analyses of the data acquired for the number of steps taken over the 30 foot length. Average values of the various phases of walking were computed, together with their mean deviations, variances and standard deviations. With the onset of the right-heel-down phase as the starting condition, two average down phases of each footswitch performance were plotted. Results were derived from the averages of three to twelve sampled steps depending upon speed of walking or frequency of pacing. The maximum mean deviation recorded was 0·078 and the maximum standard deviation 0·084 for a time period of around 0·5 s. In general, values for these deviations were considerably less. Various plots were made from the computed data.

Fig. 1 is typical and shows average periodic time as measured for the onset of the right heel down state plotted on the abscissa, with ordinates each expressed as a fraction of the average periodic time as follows: RHD, the time for which the right heel is down; RTD, the time

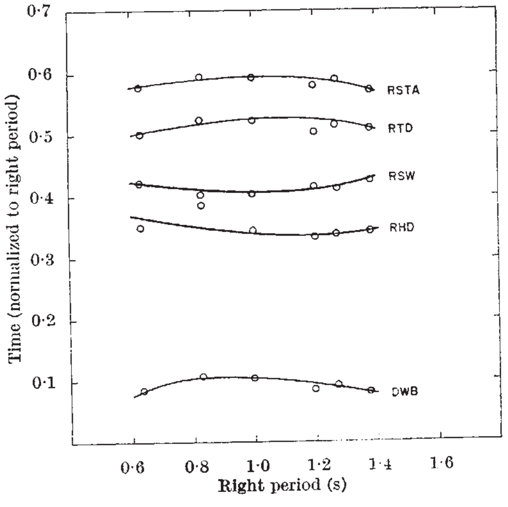

Fig. 1. Timing normalized to right period of footswitch phases against right period.