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VISUAL CONSTANCY DURING MOVEMENT: 1. EFFECTS OF *S*'S FORWARD AND BACKWARD MOVEMENT ON SIZE CONSTANCY

R. L. GREGORY AND HELEN E. ROSS[1]

University of Cambridge, England

Summary.—A novel method for estimating constancy is described, which is applied to the estimation of size constancy during motion of observers moved passively on a swing in darkness. *S*s viewed a circle traced on an oscilloscope tube and arranged to shrink as *S* approached it and to expand as he moved away. The variation in size of the display was adjusted by *E* until it appeared of constant size to *S* during his movement. Constancy was greater during forward than backward movement.

This experiment was undertaken in an attempt to discover whether visual size constancy during movement of an observer is the same whether he is moving forward or backward. The problem, as well as the technique we have developed to try to answer it, arose from the observation that after-images viewed in complete darkness may change their size or shape with movements of the observer, much as they change when projected on a visible screen, according to Emmert's Law (Gregory, Wallace, & Campbell, 1959).

The usual method of measuring size constancy—by comparing one shape with another placed at a different distance and matching them for apparent equality (Thouless, 1931, 1932)—cannot be used when there is relative movement between *S* and display. We had to devise a different method for measuring constancy under these conditions. The observer (the experimental *S*) is placed in the dark and is moved harmonically backward and forward while viewing a luminous circle which is made to change in size in a manner related to *S*'s movements. The display expands as the distance between the observer and the display increases, and contracts as the distance decreases, thus reducing the normal change in the retinal image. The amount of variation of the display is adjusted by *E* until *S* reports no change in size during his movements. If no perceptual constancy were operating, the display would have to be doubled in size for each doubling of its distance and halved for each halving of the distance, while perfect constancy would require no change in the size of the display. In practice it has to be changed by some intermediate amount, which gives a measure of constancy during *S*'s movement. This is a null method; like other null methods it is sensitive, is not too dependent on assumptions of linearity, and it has the particular advantage that the necessary observations can be made in the

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short time available. *S*'s task is the simplest possible: he has only to decide whether or not there is an apparent change for a given setting of the display size variation control.

METHOD

Apparatus

There are many ways in which the size of a display may be varied—mechanical, optical, and electronic are all possible—but here we have used an electronic method. This was very satisfactory for this particular experiment, but optical methods have been found better for some other conditions (Anstis, Shopland, & Gregory, 1961).

The apparatus consisted of two parts—a large parallel swinging chair on which *S* sat and an oscilloscope and associated electronic equipment giving a luminous circle of variable size on the tube face. The oscilloscope used was a standard Cossor double beam model, 1049 Mark IV, with short persistence green phosphor. A photograph of the apparatus is shown in Fig. 1.

The display system was connected electrically to the swing by a poten-

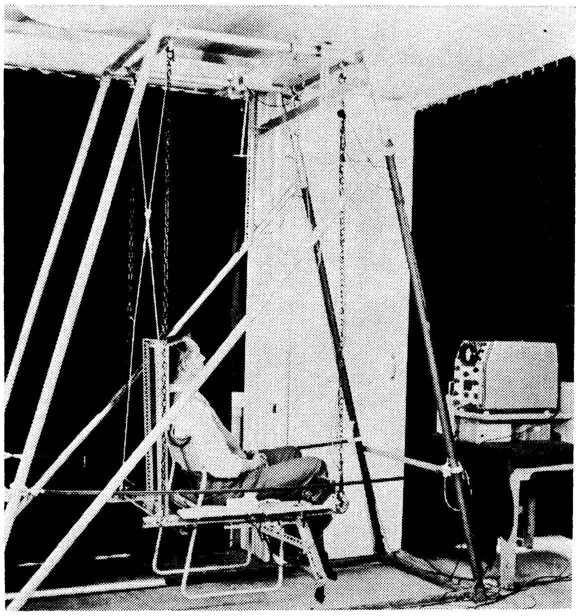

FIG. 1. General view of parallel swing apparatus. The oscilloscope providing the visual display (a circle shrinking as the swing moves forward and expanding as the swing moves back) is shown on the far right. The electrical pick-off from the swing controlling the display size is at the top of the structure on the right of the photograph. The horizontal ropes at hand level were not used in this experiment but were held by *S* to give proprioceptive information of movement in a later experiment.

tiometer which served to decrease the size of the circle when the swinging chair moved toward it, and to increase its size when the chair swung back. The circle was a lissajou figure traced by the oscilloscope beam and given by a single oscillator with a 90° phase shift between the *X* and *Y* plates. The variation in size of the lissajou circle for a given amplitude of swing was determined by two ganged potentiometers controlled by *E*. The setting of the size variation control was given digitally by a geared counter. The counter could be read easily with a flash light shielded to preserve dark-adaptation. This was switched on only when readings were taken and never when *S* was making his judgments.

The display (the circular trace on the oscilloscope) was automatically switched off for each half-cycle of the swing, so that it was visible either when *S* was moving forward or backward, but never both. The display was switched on and off by means of a specially made silent friction switch actuated by the swing. This switch was arranged to bias off the electron beam for one direction of movement, the direction being determined by a reversing switch under *E*'s control. No after-glow was visible on the tube face after switching or changing the size of the display. The display brightness was controlled by the normal brightness control of the oscilloscope and was set to be clearly visible but not so bright that the surrounding screen was illuminated. It was sometimes necessary to reduce the brightness during the experiment when *S* became dark-adapted.

The diameter of the display circle with the swing in the central position was intended to remain constant for any setting of the size variation control but, owing to the change of impedance, the oscillator output varied slightly giving a variation in display size of about 0.1 cm. over the range, the average size being 1.6 cm. This error is not reflected in the calculated results, however, since the true values of the display size were used in calculating the ratios.

The swing structure was built from heavy tubing. The swinging chair was provided with a foot and head rest, and was suspended from three chains and one metal rod. To this metal rod were mechanically connected the potentiometer and the switch which blacked out the display for one direction of swing. The chair was thus mounted in a parallelogram and remained horizontal throughout its swing. This arrangement was used in order to give horizontal acceleration forces to *S*, and more particularly, to the balance mechanisms of the inner ear. A normal swing is somewhat ambiguous in this respect, for all the forces merely increase *S*'s effective weight, except for small horizontal forces occurring off the centre of gravity which are somewhat difficult to determine. The parallel arrangement gave acceleration forces similar to those encountered in driving and flying, except for a vertical displacement amounting to 5.5 cm. The period of swing was 1.5 sec. per half-cycle, and the half time of the amplitude of swing was 22 sec. The display was placed 161 cm. from the eye at mid-swing, and the maximum amplitude of swing was 76 cm.

Procedure

*S*s were 19 research students and undergraduates, 13 male and 6 female, with an age range of 18 to 30 yr.

S was seated in the parallel swing in a completely darkened room. He started the swing by pressing his feet against the floor; he then placed his feet on the rest. While making his judgments, he sat passively on the swing with his head against the back of the chair and his feet on the rest. The size variation control was set initially in the expected range. Half the *S*s were given first the condition in which the display was visible only when they moved forward, the other half when they moved backward. The conditions were reversed half way through the experiment, so that all *S*s were tested under both conditions.

S reported verbally to *E* whether the luminous circle appeared to expand or contract. He also reported whether the display appeared to be stationary or to move toward or away from him. The situation was to some extent perceptually ambiguous. The display was not always seen as fixed in space, but would sometimes appear to advance and retreat as well as to expand and shrink (cf. Ittelson, 1952, p. 56). Occasionally only change in distance was reported. "Coming nearer" was then treated as equivalent to "expanding," and *vice versa.* Four *S*s reported only distance changes.

A special difficulty was encountered: *S*s tended to suffer nausea with repeated swinging. This made it undesirable to carry out a lengthy psychophysical procedure for determining *S*'s constancy index. (Our *S*s were volunteers!) The procedure used was as follows. An approximate constancy index for each *S* was first of all found, using trial settings of the size-variation control (SVC). Five SVC settings were then selected, 2 above and 2 below that value, covering the range over which *S* was uncertain. It was not possible to use the same SVC settings for all *S*s, as they differed considerably both in constancy index and in variability of judgment. A typical example is the *S* whose index was estimated at 0.15, and was then tested with SVC settings of 0.03, 0.09, 0.15, 0.22, 0.28. These 5 settings were given in random order until each had been given 4 times. Some *S*s showed high variability; for these, extra SVC settings were used, but only three judgments were made at each setting so as not to increase the length of the experiment. The use of extra settings made it impossible to use a predetermined random order. Extra settings were used for 5 *S*s; the number of extra settings is shown in Table 1 by asterisks.

This general procedure allows us to investigate the effect of any perceptual cues of movement on size constancy. Visual cues as well as proprioceptive information of the observer's movement may be controlled at will, their effect being given as a setting of the size variation control. In this first experiment the room was entirely dark—reducing visual cues to the minimum. *S* was passive, and no proprioception was available from the limbs. He viewed the display with only one eye; the effect of using two eyes will be discussed, together with the effect of adding proprioceptive information of movement, in a later paper.

Calibration and Treatment of Data

Constancy measures normally fall between zero and one. Zero constancy means that the perceived size follows the retinal size while perfect constancy (one) means the perceived size remains the same although the retinal image changes with viewing position. In this experiment perfect constancy is given by a ratio of one between the diameters of the display circle at the forward and backward positions of the swing. Zero constancy is given by the ratio at which the retinal image of the object remains of constant size as *S* swings. The constancy value of this ratio is a function of the distance of the swing from the display, and for zero constancy the ratio must be the same as the ratio of the distances of *S*'s eye from the display at the forward and backward positions.

In this case the ratio was $123/199 = 0.618$. Since the ratios indicating zero and perfect constancy are known, any intermediate ratio gives a value of constancy by linear interpolation. The data were treated by a graphical method described by Woodworth and Schlosberg (1955, pp. 202-205). The SVC values for each *S* were plotted on the x-axis, and on the y-axis the percentage of "expanding" judgments. A freehand curve (ogive) was drawn through these points. The SVC value on the x-axis at which the curve crossed the 50% point was taken as *S*'s constancy index for that condition. The value at the 84% point was also taken, the difference giving the range of SVC values lying within one standard deviation. This can be taken as a measure of *S*'s variability.

Results and Discussion

The results for this experiment are given in Table 1. It will be seen from Table 1 that constancy was greater for forward than backward movement. The

TABLE 1
MEAN CONSTANCY SCORES AND *SD*s USING ONE EYE ONLY

S	Sex	Forward	Backward	*S*	Sex	Forward	Backward
1	M	0.45±0.01	0.24±0.27**	11	M	0.41±0.17	0.0 Off scale
2	M	0.26±0.17	0.14±0.20	12	M	0.05±0.08	0.18±0.07
3	M	0.28±0.17	0.15±0.11	13	F	0.13±0.15	0.00±0.35***
4	F	0.24±0.23	0.25±0.16	14	M	0.13±0.10	0.00±0.25
5	F	0.14±0.15	0.0 Off scale	15	M	0.18±0.10	0.03±0.20
6	M	0.14±0.13	0.14±0.13	16	M	0.18±0.20	0.03±0.15
7	F	0.11±0.28*	0.17±0.31	17	M	0.08±0.25*	0.00±0.25
8	F	0.18±0.13	0.20±0.15	18	M	0.10±0.11	0.10±0.12
9	F	0.41±0.11	0.23±0.15	19	M	0.34±0.11	0.20±0.08
10	M	0.18±0.17	0.24±0.31*	*M*		0.18±0.15	0.14±0.16

Note.—The difference between *SD*s is not significant, but the difference between the constancy scores for forward and backward conditions is significant by Wilcoxon test ($p < 0.01$, 2 tails). Asterisks indicate the number of extra SVC settings used.

median values were 0.18 and 0.14, respectively, the difference being significant at the 1% level by the Wilcoxon test, in which normality is not assumed.

Too few females were used to detect any difference between male and female *S*s.

It seems that systematically changing the display size can provide a satisfactory technique for estimating size constancy during movement. There seems to be no reason why this technique should not be extended to measure constancy for shape.

We found considerable differences among *S*s in their perceptual interpretation. Although all *S*s knew that the display was in fact fixed in space, only a few *S*s always saw it as stationary. Some *S*s usually saw the display as moving in the opposite direction to themselves, while others were more affected by the size variation of the display, seeing it retreat while shrinking and advance while expanding. As mentioned earlier, there were four *S*s who saw only movement and never any size change. A similar variety in perceptual interpretation was found by Ittelson (1952) with *S* stationary and the display changing in size and position.

This perceptual ambiguity makes it very difficult to find a single setting of size variation which *S* will accept as giving no change in his visual world. On the other hand, systematic perceptual changes do occur with changes in size variation, and so it is possible to get an estimate for each *S*'s constancy index.

In this present experiment this perceptual ambiguity no doubt produced considerable variance in the estimates, but there is no reason to believe that it produced systematic differences between the two conditions, namely, moving toward or away from the display in total darkness. We may thus assert with some confidence that size constancy is somewhat greater when the observer is carried forward than backward. This could be due to greater experience of forward movement, either individual or ancestral.

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