Necker cube reversibility and perspective dominance as a function of rotation and retinal disparity

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Reversal rate and dominance of one phenomenal orientation of the shadow of a von Hornbostel (skeletal) cube were measured for 15 Ss under four conditions: stationary without retinal disparity (conventional Necker cube), stationary with retinal disparity, rotating about the vertical axis without disparity (conventional kinetic-depth display), and rotation with retinal disparity. Rotation decreased reversal rate but did not produce dominance of either phenomenal orientation. Retinal disparity led to dominance of the phenomenal orientation compatible with the disparity depth cue and a decrease in reversal rate. The effect of disparity on the dominance of one phenomenal orientation was enhanced by rotation.

Necker cube reversals are attenuated but not eliminated by stereopsis. Furthermore, when steady fixation is maintained, the view consonant with the retinal disparity is seen about 60% of the time and, if free viewing is allowed, this figure rises to about 75% (Cormack & Arger, 1968). One possible explanation for the greater potency of stereopsis under free viewing conditions is that the image motion accompanying eye movements serves as a more effective stimulus for binocular receptive fields including those sensitive to disparate contours found by Barlow, Blakemore, & Pettigrew (1967). If this is so, then a dynamic ambiguous figure, such as that produced by a kinetic-depth display, might be more sensitive to stereopsis than a stationary Necker cube. Howard (1961) has observed that the phenomenal orientation of a rotating skeletal cube, viewed directly, is sensitive to stereoscopic depth cues but gives no data comparing stationary and rotating objects. The present study explores this possibility by investigating reversal rates and phenomenal orientation of an outline cube under four conditions: stationary without disparity (conventional Necker cube), stationary with retinal disparity, rotating without disparity (conventional kinetic-depth effect), and rotating with disparity.

For this study, a kinetic-depth device which could present a stereo-display was developed. The basic design is shown in Fig. 1. Concentrated light sources L1, L2, and L3 (hi-intensity lamps) cast sharp shadows of a von Hornbostel (skeletal) cube (C) on a rear-projection screen (PS) made of white bond paper. With L2 only, a single shadow of an outline cube was formed. Using L1 and L3 together, two disparate shadows were formed at PS. The amount of disparity between the two shadows and their separation on the screen could be adjusted by moving L1 and L3 and/or by moving C. A reduction screen (RS) prevented light leakage from reducing target contrast. Disparate shadows produced by L1 and L3 were viewed at optical infinity through a split-lens stereoscope. The single image cast by L2 was viewed binocularly at optical infinity through lenses whose focal lengths were equal to those of the split lenses in the stereoscope.

Fig. 1. Arrangement and dimensions of stereo-kinetic display apparatus.

The von Hornbostel cube was made of black rods 1.5 mm in diam and was mounted on a 10-rpm motor which could turn it clockwise (looking down from above) about the vertical axis. The shadow as it appears at one orientation is shown in Fig. 2 with dimensions given in degrees of visual angle. The line width of the shadows was approximately 36 min visual angle (va). The maximum disparity (that between the front and back corners) between the two shadows produced by L1 and L3 was 4.1 deg va. The retinal disparity which would be produced by a real cube of the dimensions shown in Fig. 2 at the actual viewing distance of 17.8 cm is 3.3 deg va. Except for the front of the projection screen, the whole apparatus was shielded by a lightproof enclosure.

Room illumination, and thus screen brightness and target contrast, varied somewhat during the course of the experiment. The screen was shielded by a viewing hood which minimized these effects of room illumination. A chin rest controlled head movement. Various timers, switches, and counters were used to control trial length and to record responses.

For the main experiment, six female and nine male Ss, ranging in age from 17 to 33 years, were drawn on a volunteer basis from a college student population. All were naive as to the purpose of the study. The only visual screening used was to insure that Ss could fuse the figures presented in the split-lens viewer. A separate group of 17 naive Ss were drawn from the same population for use in a pilot study to check the apparatus for bias.

Since the concentrated light source produced diverging beams of light, the shadows cast by the side of the von Hornbostel cube nearer the lights were larger than those cast by the side nearer the projection screen. Although no distortion was apparent under casual observation, it might still produce response bias. Such distortion would simulate a linear perspective depth cue, and Ogle (1962) reports that the perceived orientation of a Necker cube is influenced by linear perspective. Similarly, Hershberger (1967) has shown that under some conditions such distortion influences Ss' reports of the phenomenal direction of rotation in a kinetic-depth display. Consequently, 17 Ss were given four 1-min trials with the shadow as in Fig. 2. For two trials, the side of the von Hornbostel cube casting the shadow of the upper face (upper large diamond in Fig. 2) was nearer the light, L2. This would yield linear perspective which would tend to place the upper face forward (UFF). For the other two trials, the position of the von Hornbostel cube was rotated 180 deg so that the linear perspective would place the lower face forward (LFF). A line

Fig. 2. Representative stimulus figure.

drawing was used during the instructions to S to demonstrate reversals. S viewed the projection screen directly, i.e., without a viewer. S was instructed to adopt a passive attitude and to report the phenomenal orientation of the figure by holding down a pushbutton whenever, and for as long as, the lower face appeared nearer and to release it when the upper face appeared nearer. The order of UFF and LFF conditions was randomized across Ss. Intertrial intervals varied from 30 to 60 sec. The time (seconds) that the lower face appeared nearer was recorded.

The general procedure for the main experiment was similar to that presented above. Ss were given four 60-sec trials, one each of four different conditions. Condition St (stationary figure with no disparity) was similar to Condition UFF in the pilot study. Light L2 was used and S viewed the figure through the appropriate viewer. Condition StD (stationary with disparity) employed Lights L1 and L3, and S viewed the disparate figures through the split-lens viewer. Condition R (rotating without disparity) and Condition RD (rotating with disparity) duplicated Conditions St and StD, respectively, except that the von Hornbostel cube was rotated clockwise about the vertical axis (looking down from above) at 10 rpm. Instructions were the same as in the pilot experiment, except that for Conditions R and RD S was told to hold the switch down for as long as the figure appeared to rotate clockwise as seen from above. Order of conditions was randomized across Ss. Number of reversals and time (seconds) that the switch was held down were recorded for each trial.

Table 1
Per Cent Time and Mean Number of Reversals for Two Disparity Conditions With and Without Rotation

Rotation	Per Cent Time		Reversals	
	No Disparity	Disparity	No Disparity	Disparity
Stationary	48.3	74.0	14.3	8.6
Moving	49.5	94.3	9.8	.9

RESULTS

In the pilot study designed to measure the effects of the perspective produced by the point source illumination, the means for the upper face forward (UFF) and the lower face forward (LFF) conditions were 27.0 sec and 27.7 sec, respectively. The difference between them of .7 is not significant ($t = .23$, $df = 16$, $p > .2$) and neither differs significantly from $30.00 - t = 1.25$, $df = 16$, $p > .1$ and $t = .87$, $df = 16$, $p > .1$, respectively.

The percents of time that the cube was seen in the orientation consonant with the disparity are presented in Table 1. Under the no-disparity condition, the figures refer to the same phenomenal orientation. Analysis of variance for repeated measures indicated that the effects of disparity are significant ($F = 24.7$, $df = 1/14$, $p < .001$). The effects of rotation are not significant ($F = 2.7$, $df = 1/14$, $p > .1$), and the interaction of disparity with rotation is significant ($F = 4.7$, $df = 1/14$, $p < .05$).

All 15 Ss reported reversals for the stationary figure without disparity, and all Ss also reported reversals for the stationary figure with disparity. For the moving display, 10 Ss reported reversals for the no-disparity condition, but only two Ss reported reversals for the disparity condition. By the sign test, the effect of rotation on reversals ($p < .001$) and the effect of disparity ($p < .001$) are both significant.

DISCUSSION

The results of the pilot study indicate that the linear perspective cue resulting from the use of point sources of light at 100 cm was too small to produce a measurable bias in the reported phenomenal orientation of the cube. Furthermore, Ss showed no preference for either phenomenal orientation independent of perspective. This would appear somewhat at variance with the results of Orbach, Ehrlich, & Heath (1963), but their data are not really comparable because their Necker cubes were drawn from a completely different viewpoint with one set of edges of the cube being horizontal.

In the main experiment, the mean times for the stationary figures replicate Cormack & Arger's (1968) data. Their means were 30.4, 42.8, and 43.5 sec for no disparity and two different amounts of disparity, respectively. This is very close to the 29.0 sec for no disparity and 44.4 sec for disparity in the present study.

The reduction in reversal rate associated with rotation may be related to the data of

Orbach & Zucker (1964) who found that various kinds of motion of a Necker cube reduced reversal rate. They reported almost complete cessation of reversals under some conditions and discussed this in terms of cortical satiation. Their rotation and other motions were about different axes and at different contour velocities than those employed in this study.

The reduction in reversal rate accompanying retinal disparity may be an artifact produced by the dominance of one phenomenal orientation. Five of the 15 Ss reported no reversals for the stationary condition with disparity, and 13 of 15 reported no reversals for the rotating condition with disparity, and in each of the above cases, the reported orientation was in agreement with the disparity cue.

The strong enhancement of the effects of disparity by rotation are in agreement with inferences drawn from Barlow, Blakemore, & Pettigrew's (1968) data on binocular receptive fields sensitive to disparate contours. Not only may moving contours serve as especially effective stimuli for cells with binocular receptive fields, but the set of cortical cells stimulated by the stationary figure may be much more restricted than the set stimulated by the rotating figure which is constantly changing form. These changes bring contours at different orientations and with different directions of motion to given retinal points, thereby stimulating fresh cortical cells. Conversely, maintaining fixation on a single point with a stationary figure should reduce the number of cortical cells stimulated below that involved with free scanning of the figure. This would lead to the decrease in the effects of disparity with fixation already noted (Cormack & Arger, 1968). This interpretation should not be construed as bearing directly on a theory of ambiguous figure reversals. Whatever the mechanism underlying reversals, it appears to be sensitive to depth cues. The data presented here simply suggest that the potency of retinal disparity as a depth cue is enhanced by image motion, and a mechanism for this enhancement is offered.

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Whitmarsh (1957). Four categories of words were chosen: countries, musical instruments, birds, and cloths. A triad of words drawn from the musical instrument category was designated as the critical triad (trumpet, harp, cello).

CONDITIONS

The experimental problem was to assess the effects of particular STM histories upon the recall of a common triad. Three histories were constructed: Condition 1—A heterogeneous history provided by a triad of countries, a triad of cloths, and a triad of birds. Condition 2—A homogeneous history consisting of three triads of words drawn from the same category as the words of the critical triad, i.e., musical instruments (this condition was the control condition for PI release). Condition 3—A homogeneous history consisting of three triads of words drawn from a different category, i.e., countries, than that from which the critical words had been drawn.

Two retention intervals of 5 sec and 15 sec were used. There were, therefore, six groups designated as: Condition 1, 5 sec; Condition 1, 15 sec; Condition 2, 5 sec; Condition 2, 15 sec; Condition 3, 5 sec; Condition 3, 15 sec.

PROCEDURE

Each S in each group received four trials, the three trials of the experimental history and the critical trial. A trial was composed of the following events presented as a sequence of slides by means of a Kodak Carousel projector and controlled by means of a tape-timer; first, a ready signal of 2-sec duration; second, a word triad of 2-sec duration that S read aloud once; third, a three-digit number present throughout the retention interval of either 5 or 15 sec from which S counted backwards aloud by three's to the beat of a metronome set at 60 beats

Taxonomic categories and proactive interference in short-term memory¹

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The Ss were given four successive short-term memory trials with word triads. The retention interval was either 5 sec for all four trials or 15 sec for all four trials. When the word triads on each trial were drawn from different taxonomic classes, proactive interference was not found to develop across trials for either the 5-sec or 15-sec retention intervals. Furthermore, when the word triads on Trials 1-3 were from the same taxonomic class and the word triad on Trial 4 was from another taxonomic class, a release from proactive interference was obtained in both the 5-sec and 15-sec retention interval conditions. The results suggest that proactive interference in short-term memory is relatively class-specific and that release from proactive interference is best explained by an interference interpretation rather than a novelty interpretation.

Recently Loess (1967) has shown that proactive interference (PI) does not develop across taxonomic categories in short-term memory (STM). Also, Loess (1967) demonstrated the release from PI effect (Wickens, Born, & Allen, 1963) by presenting words from a second category after PI had been built up through successive presentations of words from a single taxonomic category. Loess's results indicate, therefore, that PI is relatively class-specific and that the phenomenon of PI release is due to the new items being free from the interference generated by the preceding items.

The present experiment was conducted to further assess these relationships, between taxonomic category change and PI, in STM.

In regard to the lack of PI development across taxonomic classes observed by Loess (1967), two methodological points may be raised. First, Loess used a 9-sec retention interval. Given the observation (Keppel & Underwood, 1962) that PI is greater the longer the retention interval, it is possible that the interval used by Loess was too short to allow for the effective development of PI across taxonomic classes. Second, in the Loess study a 6-sec intertrial interval was used. Since PI has been shown to weaken over the intertrial interval (Peterson & Gentile, 1965), this 6-sec rest period may have allowed for the dissipation of PI. The intertrial interval used by Loess was considerably less than those examined by Peterson and Gentile (1965), but it may have been of sufficient duration to eliminate PI effects in this particular instance, when words from specific taxonomic classes were used as the stimulus items.

The present experiment was, therefore, designed to take into account these considerations. Furthermore, it was designed to allow for a direct comparison between the "no PI build-up" condition and the "release from PI" condition. A prediction, on the basis of Loess's data, is that a word triad from a particular taxonomic class should be recalled equally as well after a taxonomically different homogeneous history as after a taxonomically different heterogeneous history.

SUBJECTS

The Ss were 180 undergraduates from the introductory psychology program at the University of Connecticut. Each S was allocated, in order of appearance at the laboratory, to one of six groups, with 30 Ss per group.

MATERIALS

Word triads were prepared from the list generated by Cohen, Bousfield, &

Fig. 1. Per cent recall over trials for the 5-sec conditions.