Orientation contrast effects in the rod-and-frame test

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Previous research indicates that a tilted visual display is capable of inducing eye torsion and an illusion of self-tilt in objectively upright observers. These effects may contribute to performance errors on the rod-and-frame test by rotating the perceived axes of visual space toward the tilted frame. The kinesthetic-matching method was used in the present study to see whether an effect of the visual orientation contrast between rod and frame sides might also contribute to rod-and-frame test performance. Observers aligned invisible hand-held rods with the visual rod at various tilts under a control condition when the frame was absent, and under experimental conditions with the frame upright or set at 45°. The frame induced matching errors in the direction away from the frame sides which were most nearly parallel to the rod. Since no rotation of apparent visual axes should occur under these conditions, the data suggest that an orientation contrast effect is involved in the rod-and-frame test.

When a line (rod) that is objectively oriented in a vertical (or horizontal) direction is viewed in the presence of a surrounding tilted square (frame), the rod tends to look tilted under certain conditions (e.g., Ebenhøltz, 1977; Lichtenstein & Saucer, 1974; Wenderoth, 1974; Witkin & Asch, 1948). This rod-and-frame illusion is usually studied by asking objectively upright observers to adjust the rod to the apparent gravitational vertical while viewing a retinally large frame. The standard rod-and-frame test (RFT) (e.g., Oltman, 1968) used to measure field-dependent-independent cognitive styles is the most common exemplar of this method. The RFT frame is tilted by 28° and its sides subtend a visual angle of 28°. Under these conditions, an objectively vertical rod looks tilted in a direction opposite to the frame tilt, and rod adjustment settings tend to err in the direction of frame tilt. People are said to be field dependent to the extent that their rod adjustments are affected by the frame (e.g., Witkin, Dyk, Faterson, Goodenough, & Karp, 1962/1974).

The nature of the RFT effect is not fully understood, but the available data warrant several conclusions about the underlying mechanisms. It seems clear that part of the frame effect on rod adjustments is due to an illusory effect of the frame on apparent body position (Ebenhøltz & Benzschawel, 1977; Sigman, Goodenough, & Flannagan, in press). When viewing a large frame that is tilted in a clockwise (CW) direction, for example, objectively upright observers tend to feel themselves tilted in a counter-

clockwise (CCW) direction. It is not surprising, therefore, that rod adjustments to the gravitational vertical are displaced in the direction of the tilted frame to compensate for the illusory experience of self-tilt. Visually induced eye torsion in the direction of frame tilt may also contribute to the RFT effect (Hughes, 1973; Goodenough, Sigman, Oltman, Rosso, & Mertz, in press). The combined effects of eye torsion and illusory self-tilt are too small, however, to fully account for the frame effect on rod adjustments. Some unknown additional mechanism appears to be operating. The present study was designed to examine the possibility that this additional factor may involve an effect of the visual orientation contrast between the rod and the frame sides.

For small displays, there is some evidence of an orientation contrast effect in which the perceived angle between the rod and the sides of the frame that are most nearly parallel with the rod appears larger than the objective angle. Gogel and Newton (1975) used a kinesthetic-matching method for studying the effects of frames subtending 10° of visual angle and tilted by 15° from the vertical. Their observers were provided with an invisible hand-held rod and asked to match the orientation of this kinesthetically sensed rod with the orientation of an objectively vertical visual rod or with the sides of the tilted frame. They found that matches to the rod erred in the direction opposite to the frame, as expected on the basis of the rod-and-frame illusion. When matching the frame sides, however, observers erred slightly, if at all, in the direction of frame tilt (i.e., away from the rod). With a 15° CW frame, for example, this finding suggests that an objectively vertical rod looks tilted in a CCW direction, but the frame sides are

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perceived either veridically or somewhat more CW than their objective positions.

These data are difficult to account for as frame effects on subjective body orientation or eye orientation for two reasons. First, it is doubtful that illusory self-tilt or eye torsion occurs with small frames whose sides subtend visual angles of 10° or less. No illusion of self-tilt has been found for retinally small frames by Ebenholtz and Benzschawel (1977), who systematically varied the distance of the frame from the viewer. This conclusion fits well with other evidence. A variety of vestibular responses involving self-movement and orientation have been induced by visual stimuli which impinge on the retinal periphery, but these illusions do not occur with centrally presented visual stimuli (e.g., Dichgans & Brandt, 1974). A retinally large frame is a peripheral stimulus, but a small frame is not. Thus it seems reasonable to conclude that the illusion of self-tilt belongs to a class of illusions in which only peripheral retinal stimuli are capable of inducing responses in the vestibular system (Ebenholtz & Benzschawel, 1977). A similar argument may apply to visually induced eye torsion, but no specific evidence is available as yet on this point. Second, eye torsion and illusory self-tilt belong to a class of frame effects in which the perceived axes of visual space are rotated in the direction of frame tilt. For a CW frame, therefore, one would hypothesize that both the rod and frame look tilted in a CCW direction relative to their objective orientations, and this hypothesis was disconfirmed in Gogel and Newton's data. Thus Gogel and Newton conclude that an orientation contrast effect is responsible for the rod-and-frame effect under their conditions.

These results suggest that at least three distinctly different mechanisms are responsible for rod-and-frame effects: a self-tilt illusion and eye torsion, for large frames, and an orientation contrast illusion, at least for small frames. The question remains as to whether an orientation contrast illusion can account for the as yet unexplained portion of the large-frame effect. The kinesthetic matching method was used in the present study to examine contrast effects with the moderately large frame used in the standard RFT.

METHOD

General Design

All subjects matched the orientation of a kinesthetic rod with the orientation of a visual rod under control conditions with the visual rod alone and under several experimental conditions with the rod and frame both visible. The frame effect was examined in relation to the horizontal rather than to the more commonly used vertical axis, for reasons to be explained below. The settings of the visual rod were horizontal (0°) or tilted 11° , $22\frac{1}{2}^\circ$, or 34° in a CW or CCW direction from the horizontal.

There were four sets of experimental conditions, as follows:

The first set (A) was included to see whether a rod-and-frame illusion could be detected by the kinesthetic matching method. In the trials of this set, the rod was always horizontal, and the conditions of frame tilt were 0° , 11° , $22\frac{1}{2}^\circ$, and 34° CW and CCW. We hypothesized that experimental matches would be displaced from control matches in the direction opposite to the tilted frame, as illustrated in Figure 1A for an 11° CW frame. The hypothesized displacement could occur under these conditions either because of an orientation contrast effect, or because of an induced rotation toward the frame in the apparent axes of visual space, relative to the apparent kinesthetic axes.

Set B was included to examine orientation contrast effects of an upright frame. The visual rod was set at 0° or tilted by 11° , $22\frac{1}{2}^\circ$, or 34° CW or CCW, and the frame was always set at 0° . Each of these conditions can be generated by a rigid rotation of rod and frame from one of the positions in the first experimental set. For example, the Set A condition—rod = 0° , frame = 11° CW—can be rotated 11° CCW to produce the Set B condition—rod = 11° CCW, frame = 0° . The angle between rod and frame remains the same, and an orientation contrast still exists. Since the sides of the frame are aligned with the gravitational vertical and horizontal, no rotation of the apparent visual axes should be induced by the frame under these conditions, however. Consequently, frame effects on kinesthetic matches to the visual rod should reflect an unconfounded contrast illusion.

If the orientation of the visual rod appears to be rotated away from the frame sides which are most nearly parallel to it, then the upright frame should displace the kinesthetic settings away from the horizontal (i.e., measured in terms of tilt from the horizontal, the experimental settings should be larger than the control settings, as illustrated in Figure 1B for the 11° CCW rod).

Set C was the same as Set B, except that the frame was always tilted by 45° . Each of these conditions can also be generated by a rigid rotation of rod and frame from one of the positions in Set A. For example, the Set A condition—rod = 0° , frame = 11° CW—can be rotated 34° CW to produce the Set C condition—rod = 34° CW, frame = 45° —with no change in the contrast angle between rod and frame. The sides of the 45° frame are symmetrically oriented with respect to the gravitational vertical and horizontal, and the frame looks like an upright diamond. We therefore expected only contrast effects to occur, as in the Set B conditions. In this case, however, a contrast effect in which the visual rod appears to be rotated away from the frame sides most nearly parallel to it should displace the kinesthetic settings toward the horizontal (i.e., measured in terms of tilt from the

Figure 1. Hypothesized frame effects.

horizontal, the experimental settings should be smaller than the control settings, as illustrated in Figure 1C). Thus, the same contrast effect should be in opposite directions with respect to the objective horizontal for the Set B and Set C conditions.

Set D was included to see whether the tilted frame had any effect on apparent rod position when rod and frame were aligned with each other. The frame was tilted by 11° , $22\frac{1}{2}^\circ$, and 34° CW and CCW, and the rod had the same orientation as the frame. No contrast effect should occur under these conditions. However, if there is an illusory rotation toward the tilted frame in the apparent axes of visual space, relative to the kinesthetic axes, then the frame should displace the kinesthetic settings toward the horizontal (i.e., measured in terms of tilt from the horizontal, the experimental settings should be smaller than the control settings). This hypothesis is illustrated in Figure 1D for the 11° CCW rod and frame.

For each subject, one trial was conducted with a 60° CW and one trial with a 60° CCW starting position of the kinesthetic rod under each condition. Thus there were 14 control trials and 52 experimental trials, with one trial for each combination of starting positions and visual rod-and-frame conditions. The trials were divided into two successive blocks, such that all rod-and-frame conditions occurred once within each block. A different, randomly selected sequence of trials was chosen for each block and for each subject.

Subjects

The subjects were 25 young adult male volunteers who were paid for their participation in the study.

Apparatus

The equipment included the visual rod and frame, the kinesthetic matching apparatus, and a chair.

The visual rod and frame were constructed of electroluminescent strips and were the only visible objects when the lights were turned out in the darkroom housing the equipment. Both rod and frame were located 112 cm in front of the subjects, and pivoted around a horizontal axis running through their centers and the subjects' mid eye position. The rod was 1 cm wide and 52 cm long, and the square frame sides were 1 cm wide and 56 cm long. Thus, the frame sides subtended about 28° of visual angle.

The kinesthetic matching technique was adapted from Templeton (1972). The subjects viewed the visual rod and frame through the hollow center of a disk, with an inside diameter of 45 cm, which rotated around the same axis as the visual rod and frame and was located 26 cm in front of the subject. Handles were attached to opposite sides of the disk such that an imaginary line could be drawn through the long axis of each handle and the center of disk rotation. The subject held one rod handle with each hand, palm down, and could rotate the disk to a point where the invisible handles lay on the same line as the visual rod (i.e., where it seemed, to the subjects, that their hands would be holding the ends of the visible rod if it were extended in both directions).¹

The orientation of the visual rod and frame and of the kinesthetic disk could be read by the experimenter to the nearest $\frac{1}{2}^\circ$ on protractors which were mounted on the support structure. The zero points on the protractors were set at the horizontal, with deviations from the horizontal in a CW direction given positive signs and in a CCW direction given negative signs.

Adjustable head supports for clamping the subject's head in a fixed position were mounted on the back of the chair.

Procedure

The subjects were instructed and given a set of practice trials during a 5-min dark-adaptation period. At the beginning of each trial, the subject's hands were in his lap, the rod-and-frame display was turned off, and the kinesthetic rod was located in the starting position. The subject was first told which handle was "up," in the trial starting position, and was asked to grasp the

Figure 2. Kinesthetic settings to the rod alone as a function of rod orientation.

handles and inform the experimenter when ready. The visual display was then turned on, and the subject adjusted the kinesthetic disk to match the visual rod, a task that required only a few seconds. He informed the experimenter when finished, and after the display was turned off closed his eyes and returned his hands to his lap.

There was approximately 30 sec between trials, during which the experimenter recorded the adjustment and reset the equipment for the next trial. A 1-min rest period was given between blocks.

RESULTS

Rod Varied - Frame Absent

Kinesthetic matches to the orientation of the visual rod in the absence of the frame were generally fairly accurate. While some subjects tended to overestimate and other subjects tended to underestimate rod tilts, the mean settings over all subjects were not much different from rod orientations, as shown in Figure 2. Small but significant systematic errors were found, however. An analysis of variance showed a significant starting position effect ($F = 9.78$; $df = 1,24$; $p < .01$) in the undershoot direction, a significant effect of visual rod orientation ($F = 5.94$; $df = 6, 144$; $p < .001$), but no significant interaction between orientation and starting position. The effect of rod orientation was due to a slight tendency ($.7^\circ$) to overestimate 11° rod tilts ($F = 5.02$; $df = 1,24$; $p < .05$) and to underestimate (1.9°) 34° rod tilts ($F = 14.62$; $df = 1,24$; $p < .001$).

No general tendency to overestimate tilts from the nearest vertical or horizontal was found, as has been reported by Templeton (1972). Our data are very similar, however, to data reported by Gogel and Newton (1975) on kinesthetic matching errors as a function of rod tilts from the vertical.

Figure 3. Kinesthetic settings to a horizontal rod as a function of frame tilt.

Rod Horizontal - Frame Varied

The data on kinesthetic matches to the horizontal rod as a function of frame tilt are summarized in Figure 3. In these data, the settings for the frame-absent condition were subtracted from the settings with the frame present to eliminate response biases. Over all frame conditions, matching errors varied significantly with frame orientation ($F = 19.76$; $df = 7, 168$; $p < .001$). The data on frame tilts of 11° , $22\frac{1}{2}^\circ$, and 34° were further analyzed by assigning positive and negative values to errors away from the frame and toward the frame, respectively. Since no significant differences were found as a function of the direction of frame tilt, the CW and CCW frame conditions were collapsed. In these data, a significant tendency was found to err in the direction opposite to the frame tilt ($F = 38.78$; $df = 1, 24$; $p < .001$), and this tendency varied significantly with frame tilt ($F = 24.13$; $df = 2, 48$; $p < .001$), showing a significant effect at 11° ($t = 7.04$; $df = 24$; $p < .001$) and at $22\frac{1}{2}^\circ$ ($t = 5.14$; $df = 24$; $p < .001$), but not at 34° . These results are consistent with the findings of Gogel and Newton (1975), and suggest that an objectively horizontal visual rod looks tilted away from the frame, as expected. The effect appears to decrease with increasing frame tilts over the range of frame orientations examined.

Rod Varied - Frame 0° or 45°

Under these conditions, we expected to find pure orientation contrast effects, if any existed—i.e., kinesthetic settings should err in the direction opposite to the frame sides which are most nearly parallel relative to control settings. The 0° frame should, therefore, *increase* apparent rod tilt, while the 45° frame should *decrease* apparent rod tilt. To test these hypotheses, analyses were conducted on the algebraic differences between experimental and control settings with a plus value assigned when experimental settings deviated more from the horizontal than the control settings in the direction of visual rod tilt. Means of these differences are shown in Figure 4. Overall analyses of variance showed significant effects of rod tilt for both the 0° frame ($F = 3.48$; $df = 2, 48$; $p < .05$) and the 45° frame ($F = 13.53$; $df = 2, 48$;

$p < .001$). The 0° frame significantly *increased* kinesthetic settings to the 11° rod ($t = 3.06$; $df = 24$; $p < .01$), but no significant difference between control and experimental conditions was found with rod tilts of $22\frac{1}{2}^\circ$ or 34° . The 45° frame significantly *decreased* kinesthetic settings with rod tilts of 11° ($t = 19.95$; $df = 24$; $p < .001$), $22\frac{1}{2}^\circ$ ($t = 26.13$; $df = 24$; $p < .001$), and 34° ($t = 36.32$; $df = 24$; $p < .001$), with larger effects as rod tilts increased. These data suggest that both the 0° and 45° frames displace apparent rod position away from the frame sides that are most nearly parallel to it, to a decreasing extent as the difference between the orientations of these display elements increases. Moreover, the 45° frame has a larger effect than the 0° frame. This difference in frame effectiveness is suggested most unambiguously at the $22\frac{1}{2}^\circ$ rod position, at which the orientation difference between rod and frame is $22\frac{1}{2}^\circ$ for both 0° and 45° frames and the rod position to be matched is the same as well. Under these conditions, the 45° frame shows a significantly greater effect (3.0°) than the 0° frame ($.1^\circ$) ($t = 5.24$; $df = 24$; $p < .001$).

Rod and Frame Aligned and Varied

Introducing the frame at the same orientation as the rod reduced estimated rod tilts. Pooling over the 11° , $22\frac{1}{2}^\circ$, and 34° rod orientations, the mean kinesthetic setting was displaced from the horizontal by significantly less with the frame present than in the frame's absence ($F = 18.64$; $df = 1, 24$; $p < .001$). This effect tended to decrease slightly with increasing tilts of the rod and frame, varying from 1.1° for the 11° tilt condition to $.4^\circ$ for the 34° condition, but

Figure 4. Orientation contrast effects.

these differences among tilt conditions were not significant.

DISCUSSION

Orientation Contrast Effects

The finding that the 0° and 45° frames displace apparent rod orientation away from the frame sides that are most nearly parallel to it supports the view that an orientation contrast illusion occurs with the rod-and-frame display. Thus, part of the RFT effect appears to belong to a class of visual angle illusions which include the Zöllner illusion and many others. It is not surprising, therefore, that susceptibility to the rod-and-frame illusion and susceptibility to the Zöllner illusion are highly related (e.g., Immergluck, 1966; Shinar, 1977).

One promising physiological model that is capable of accounting for the contrast effects observed in this study has been proposed by Carpenter and Blakemore (1973). A variety of angle illusions are explained by this model in terms of inhibitory interactions between orientation selective units in the visual cortex. The finding in the present study that the frame effects decrease as the differences in orientation between rod and frame sides increase from 11° to 34° is consistent with the physiological model and with a variety of evidence on other types of angle illusions (e.g., Carpenter & Blakemore, 1973).

It is not surprising to find that the inducing effect of the 45° frame and the 0° frame are different. Many visual phenomena are known to vary with the obliqueness of the display (e.g., Appelle, 1972). Additional research is needed to understand more specifically why the 45° frame is more effective than the 0° frame, however.

If the RFT is partly due to an orientation contrast illusion, then individual differences in RFT performance may also be due in part to differences in the magnitude of contrast effects, perhaps reflecting differences in the properties of orientation selective units. This view is consistent with Buchsbaum and Silverman's (1970) finding that subjects who are field dependent on the RFT show more similar cortical evoked responses to line stimuli at different orientations than is true for field-independent subjects, raising the possibility that orientation detectors may be more broadly tuned for field-dependent people. The finding that rod adjustments to alignment with the frame are more accurate for field-independent than for field-dependent subjects (Rudin, 1968; Sullivan, Note 1) can also be understood in these terms.

Rotation of Visual Axes

The reduction in the tilt of kinesthetic settings when the rod and frame are aligned suggests that the

rod (and the frame) look less tilted than they are with respect to the kinesthetic axes. If so, then the apparent axes of visual space may be rotated in the direction of frame tilt relative to the axes of the trunk. One mechanism that could have such an effect involves eye torsion that is uncompensated perceptually. There is evidence that a frame or grating is capable of producing a torsional rotation of the eyes in the direction of tilt of the visual display (Crone, 1975; Hughes, 1973; Goodenough et al., in press), but no torsional response has been found to a rod alone (Howard & Templeton, 1964). Using the standard RFT display at 28° of tilt, we found a mean of $.3^\circ$ of torsion, and working with a somewhat smaller frame, Hughes has reported similar torsional values which are significantly correlated with the magnitude of the RFT illusion. Crone varied the orientation of a striped grating and found maximum torsion of about 1.0° between 10° and 20° of display tilt from the vertical with torsional responses decreasing to zero as display tilts increased to 45° . These torsional responses are on the same order of magnitude as the effects in the present study when rod and frame are aligned. Thus, it seems reasonable to suppose that the tilted rod and frame are literally less tilted from the vertical and horizontal retinal axes than they are from the vertical and horizontal kinesthetic axes, and that eye torsion may account for the overestimation of rod tilt when the frame is aligned with the rod.

The Rod-and-Frame Illusion

The evidence suggests that a tilted frame has at least three effects which contribute to RFT performance; an orientation contrast effect, an eye torsion effect, and an illusory effect on self-orientation. To determine whether the combined effects of these three components fully account for the RFT illusion, it would be useful to have independent estimates of the magnitude of each component on the same subjects. Such data are not yet available. Moreover, it is difficult to precisely estimate the magnitude of the contrast effect with a horizontal rod and tilted frame by the technique used in the present study, particularly since the 45° frame is more effective than the 0° frame. More research is obviously needed to answer this question. It also remains to be determined which one(s) of these components may be responsible for the many correlates of RFT performance that have been reported.

REFERENCE NOTE

1. Sullivan, C. T. *Perceptual "field dependence": Experimental comparison of negative and positive measures*. Paper presented at the meeting of the American Psychological Association, Chicago September 1975.

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NOTE

1. The rod handles could be held comfortably with palms down through the range from 60° CW to 60° CCW from the horizontal. However, no satisfactory grip positions could be found for a comparable range of settings around the vertical. The horizontal axis was chosen in preference to the vertical axis for this reason.

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