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# Respective contribution of orientation contrast and illusion of self-tilt to the rod-and-frame effect

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**Abstract.** The visual angle subtended by the frame seems to be an important determinant of the contribution of orientation contrast and illusion of self-tilt (ie vection) to the rod-and-frame effect. Indeed, the visuovestibular factor (which produces vection) seems to be predominant in large displays and the contrast effect in small displays. To determine how these two phenomena are combined to account for the rod-and-frame effect, independent estimates of the magnitude of each component in relation to the angular size subtended by the display were examined. Thirty-five observers were exposed to three sets of experimental situations: body-adjustment test (illusion of self-tilt only), the tilt illusion (contrast only) and the rod-and-frame test, each display subtending 7, 12, 28, and 45 deg of visual angle. Results showed that errors recorded in the three situations increased linearly with the angular size. Whatever the size of the frame, both mechanisms, contrast effect (tilt illusion) and illusory effect on self-orientation (body-adjustment test), are always present. However, rod-and-frame errors became greater at a faster rate than the other two effects as the size of the stimuli became larger. Neither one nor the other independent phenomen, nor the combined effect could fully account for the rod-and-frame effect whatever the angular size of the apparatus.

## 1 Introduction

The rod-and-frame effect (RFE), first investigated by Witkin and Asch (1948), is the influence of a surrounding frame upon the apparent orientation of a rod enclosed within it; adjustment settings deviating from the true vertical toward the tilted frame may reach 6° to 9°. Previous research has shown that the influence of the tilted frame can be modulated by varying the retinal size of the frame (Ebenholtz 1977, 1990; Ebenholtz and Benzschawel 1977; Spinelli et al 1991; Streibel and Ebenholtz 1982). Indeed, the magnitude of this effect is such that an alteration of the RFE down to 1° or 2° can be obtained by reducing the retinal angle to about 10 deg or less. It has been proposed that the effects of retinal size on the RFE are mediated by the shift from parafoveal to peripheral stimulation that typically accompanies any increase in the size of the retinal image of the frame (Ebenholtz 1977). Consequently, different mechanisms would be at work in the case of small (less than 10 deg of visual angle) and large rod-and-frame displays (Coren and Hoy 1986; Ebenholtz and Glaser 1982; Goodenough et al 1979), reflecting the functional differences inherent in the focal and ambient visual systems (Leibowitz and Post 1982). Thus, two general classes of explanation have been offered for the occurrence of the RFE; one, predominant in smaller displays, is based on orientation-contrast phenomena and the other, predominant in large-visual-angle displays, concerns visuovestibular interactions.

There is a considerable body of evidence to support the view that the RFE is due to interaction between the peripheral visual system and the vestibular system that is normally involved in the maintenance of orientation constancy (Dichgans and Brandt 1978; Goodenough et al 1985, 1987). Studies have shown that the influence of the frame extends to the control of body sway (Witkin and Wapner 1950) and that the illusion of body tilt is closely related to rod-and-frame performance (Ebenholtz and Benzshawel 1977; Goodenough et al 1987; Lee and Aronson 1974; Sigman et al 1978). Thus an upright observer, in front of a tilted surrounding frame, feels to be tilting in the opposite direction (Sigman et al 1978). This postural effect in turn influences the positioning of the rod. The idea that visuovestibular interactions are absent in the case of central inducing displays is largely based on moving stimuli (Dichgans and Brandt 1978; Leibowitz and Post 1982), particularly for rotating disc displays which also induce a systematic shift in the perception of the subjective vertical (roll vection). Indeed, stimulation of the central visual field up to a visual angle of 30 deg does not lead to roll vection, as visual stimulation limited to the central retina seems unlikely to be mediated by the vestibular system (Dichgans and Brandt 1978; Ebenholtz 1990). However, authors do not agree on the consistency of individual differences in tilt perception in the presence of a stationary tilted frame or a rotating disc. Indeed, Hughes (1973), using a frame and a rotating disc that subtended about 15 deg of visual angle, reported correlation between the two phenomena whereas Spinelli et al (1991), using displays with much larger visual angle (120 deg), observed that the two conditions were not correlated. It is thus difficult to conclude that the same mechanisms act in the case of static and moving displays. However, other results observed with large frames are consistent with the properties of the ambient visual system since errors in judging rod orientation decrease when the rod and frame are located at different distances in small frames (subtending 10 deg; Gogel and Newton 1975), but this depth-separation effect was not found for peripheral frames (Ebenholtz and Glaser 1982).

Conversely, in the orientation-contrast explanation the RFE is viewed as a purely visual interaction (Carpenter and Blakemore 1973) similar to many angular illusions. The effect that systematically distorts the perceived angle between the rod and the frame sides (Goodenough et al 1979) is similar to the tilt illusion (rod adjustment in the presence of a tilted inducing line). Moreover, this illusion can also be obtained with an upright frame (Goodenough et al 1979), and this can hardly be explained in terms of constancy mechanisms. However, several studies have shown that purely visual contrast orientation is not specific to central frame conditions. Indeed, there is some evidence of an orientation-contrast effect for a frame visual angle of 28 deg (Goodenough et al 1979) and this may be the reason for error adjustments of 2° to 3° in the direction of the frame (Goodenough et al 1987). According to Goodenough et al (1979), visuovestibular interactions are at work only in the case of large displays, but intravisual effects would be present whatever the frame size. However, some results suggest that the effects of a small tilted frame may not be attributable entirely to visual factors. Indeed, even in the presence of a small rod-and-frame test (RFT) display, errors in rod settings increased dramatically under conditions of body tilt (Spinelli et al 1991) and with horizontal observers (Zoccoloti et al 1992); this effect is usually interpreted as relating to the visuovestibular interaction (Goodenough et al 1985).

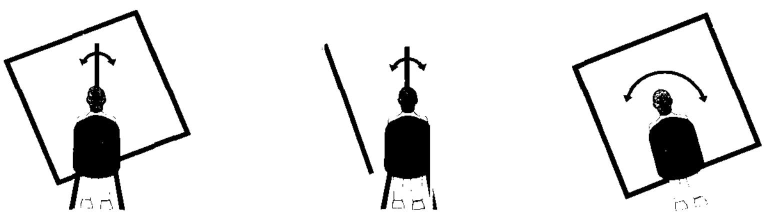
Therefore, whatever the size of the frame, both mechanisms, orientation-contrast effect and illusory effect on self-orientation, always seem to be present. Perhaps the distinction between large and small displays might best be thought of as quantitative rather than qualitative. Since we were interested in examining the mechanisms underlying central and peripheral displays, it seemed important to investigate the relationship between the RFE and independent estimates of the angular effect and the illusion of self-tilt in a variety of display sizes. To determine how these effects combine to account for the RFE, estimates were to be computed within the same group of experimental observers. The specific situation chosen to produce the self-tilt illusion was the body-adjustment test (BAT, body adjustment in the presence of the tilted frame; Witkin et al 1954). The contrast effect was measured by using the tilt illusion (TI) (rod adjustment in the presence of a tilted inducing line). According to the literature, we may assume that body-adjustment errors would be greater wih a visual disturbance of large angular size; the reverse pattern is to be expected from the contrast phenomenon.

Consequently, the contribution of the illusion of self-tilt to the RFT errors should increase with the size of the apparatus while the contribution of the contrast should decrease.

## 2 Method

### 2.1 *RFT apparatus*

Two RFT devices were built. The dimensions of the large device were 154 cm for each side of the frame; the rod was 99 cm long. The sides of the small device were 38 cm and the rod was 24 cm long. The frame and the rod were made of a luminescent tape 2 cm wide and were the only objects visible in a completely dark room. The adjustable line rotated in the subject's frontal plane about an axis in the centre of the frame. The observer viewed the apparatus with the head upright and was seated 189 or 311 cm away from the apparatus; thus the large frame size subtended roughly 45 and 28 deg of visual angle, respectively, whereas the small frame subtended roughly 12 and 7 deg of visual angle, respectively. The subject's task (figure 1a) was to adjust the rod to the apparent gravitational vertical from starting positions at 22° clockwise and counterclockwise of the true vertical. For each frame-size condition, the upright orientation of the rod was measured first under a no-frame condition (two trials) and then within the frame. The frame, when present, was always tilted 22° clockwise or counterclockwise of the true vertical. Four rod-and-frame trials were conducted (ie the four possible combinations of initial rod-and-frame tilts).



(a) (b) (c)

**Figure 1.** Diagram of the main experimental designs for the large visual angle: (a) the rod-and-frame test, (b) the tilt illusion (orientation-contrast effect), and (c) the body-adjustment test (frame effect on self-orientation). The observer was asked to set to the vertical the rod in situations (a) and (b) and the body in situation (c).

### 2.2 *The TI device*

Two inducing lines were constructed of the same size as the frame side (38 cm and 154 cm long, 2 cm wide), and shown from the same two distances, thus subtending 7, 12, 28, and 45 deg of visual angle. They were presented on the left of the adjusting rod (figure 1b). The same distance ratio between rod and inducing line as in the RFT was retained. The same procedure as that for the rod-and-frame session was used: four trials for each inducing line size were also preceded by the two control trials without the inducing line.

### 2.3 *The BAT*

The subject was seated in a tiltable chair (figure 1c) with the head aligned with the body by means of a headrest. The task was to set the chair to the gravitational vertical from starting positions at 22° clockwise and counterclockwise of the true vertical. The adjustable chair rotated about the midpoint of the interocular axis to allow the eyes to remain focused on the centre of the frame during the adjustment. The body-adjustment method was used in a completely dark room (control) or while the subject viewed a tilted inducing line (as in the TI device) or a tilted frame. The frames and inducing lines subtending 7, 12, 28, or 45 deg of visual angle were the same as those used in the RFT and TI device, but the central adjusting rod was not present. For each visual-angle condition, the test consisted first of two body adjustments in the dark, four adjustments while viewing the frame, and four adjustments while viewing the inducing line. The last two conditions were counterbalanced over participants.

2.4 *Design*
Thirty-five adults, (seventeen women and eighteen men) all volunteers, took part in four half-hour sesions. Each session involved a specific visual-angle condition and included the RFT, the TI, and the BAT. The order of the tests and of the four sessions was counterbalanced over participants. Errors in rod adjustment or body adjustment to the vertical were used to measure performance. For the control conditions, the subjective vertical was calculated by using the algebraic mean settings. For the experimental conditions, errors were considered as positive if they were in the direction of the frame tilt or rod tilt, and negative if they were in the opposite direction; the measure of the effect was calculated as the algebraic mean settings.

## 3 Results
3.1 *Perception of the vertical in the absence of visual disturbance*
The ANOVA carried out on the various adjustments in the absence of other visual information showed that the angular size of the rod had no effect on the perception of upright ($F_{7,238} = 0.32$, $p > 0.9$). The mean error was 0.34°, with a standard deviation of 1.35°. Concerning the body-adjustment control, there was no significant difference between measures ($F_{3,102} = 0.84$, $p > 0.4$). This result highlights the consistency of the measure. The mean error was −0.05° and the standard deviation 2.1°. Thus, the observers had little difficulty in adjusting a rod or their body to the vertical; the two situations did not differ (Wilcoxon, $z = -1.69$, $p = 0.092$).

3.2 *The effect of angular size on the RFE*
The mean deviations from the upright in the RFT are given in table 1. An overall examination of the subjects' performance showed a range of errors, varying with the visual-angle conditions ($F_{3,102} = 7.15$, $p < 0.00001$). Thus, the frame effect was a linear function of the visual angle (multiple $R = 0.47$, $Y = 0.09X + 0.045$). However, when the visual angle of the frame was equal to 7 deg, the RFE failed to differ significantly from zero ($z = -1.3$, $p > 0.2$), consistent with the finding of Ebenholtz and Glaser (1982) when using a small frame. Moreover, the ranking of participants was statistically highly consistent, whatever the frame size (Kendall coefficient of concordance, $W = 0.83$, $\chi^2 = 87.18$, $p < 0.00001$). Thus, there was homogeneity in the same participant's performance under the different RFT conditions.

**Table 1.** Mean adjustment error in ° from gravitational vertical (with SD in parentheses; $n = 35$) in the four upright estimation conditions as a function of visual angle.

| | 7° | 12° | 28° | 45° |
|---|---|---|---|---|
| RFT | 0.47 (1.76) | 1.22 (2.13) | 3.05 (3.11) | 4.01 (3.36) |
| TI | −0.16 (0.73) | −0.03 (0.91) | 0.63 (0.43) | 0.95 (1.45) |
| BAT rod | −0.07 (1.76) | 0.08 (1.84) | −0.10 (1.76) | −0.73 (2.20) |
| BAT frame | 0.35 (0.61) | 0.51 (0.81) | 0.79 (1.08) | 0.82 (1.01) |

3.3 *The effect of angular size on the TI*
The ANOVA carried out on mean errors in the different TI displays showed a significant visual-angle effect ($F_{3,102} = 14.26$, $p < 0.00001$). The magnitude of the TI was shown to be dependent upon the visual angle (table 1). Indeed, as for the RFE, the TI

was a linear increasing function of the display size (multiple $R = 0.4$, $Y = 0.03X - 0.35$). However, some participants showed a negative effect in response to the small displays, whereas none of them did so in response to the large frame. Thus, the orientation of the test line was numerically in the direction opposite to the tilt of the inducing line for 7 and 12 deg of visual angle. However, there was no statistically reliable repulsive effect for the display of 12 deg since the values did not actually differ from zero ($z = -0.9$, $p > 0.3$). A relationship between the adjustments on the various apparatus sizes was also observed (Kendall coefficient of concordance, $W = 0.35$, $\chi^2 = 36.7$, $p < 0.00001$).

### 3.4 *The effect of angular size on body adjustments*

A summary of the body-adjustment errors for each of the experimental situations is given in table 1. The ANOVA carried out on the different display conditions showed a significant effect of visual-stimulus factor ($F_{1,34} = 14.7$, $p < 0.001$), there were more errors for body adjustment while viewing the frame than while viewing the inducing line, a nonsignificant effect of visual-angle factor ($F_{3,102} = 0.73$, $p = 0.53$), and a significant interaction between these two factors ($F_{3,102} = 3.1$, $p < 0.03$). In fact, for the inducing-line situation, errors observed for each visual angle failed to differ significantly from zero ($z < -1$, $p > 0.05$). The tilted-rod stimulus was not sufficient to produce the self-tilt illusion. However for the frame condition, there was a significant visual-angle effect ($F_{3,102} = 3.2$, $p < 0.03$). Moreover, there was a linear relationship between adjustment errors and the size of the display (multiple $R = 0.2$, $Y = 0.012X + 0.3$). Thus the errors produced with the peripheral frame were greater than the errors produced with the central frame. Also, there was a relative homogeneity in the performance under the various visual-angle conditions for the BAT in the presence of the tilted frame (Kendall coefficient of concordance, $W = 0.095$, $X_2 = 9.9$, $p < 0.02$).

### 3.5 *Comparison between the effects of angular size on the three upright perception conditions*

The ANOVA showed a significant situation effect ($F_{2,68} = 22.67$, $p < 0.00001$), a significant effect of visual-angle factor ($F_{3,102} = 52.58$, $p < 0.00001$), and interaction between the two ($F_{6,204} = 26.54$, $p < 0.00001$). Therefore, though the linearity assumption for all three phenomena as a function of the angular size of the apparatus is acceptable (linearity deviation: $F_{6,408} = 0.58$, $p > 0.05$), the three straight lines cannot be considered parallel (deviation from parallelism, $F_{2,408} = 11.65$, $p < 0.0001$). Consequently, the angular-size effect on errors is different on each of the three tests ($F_{2,408} = 29.33$, $p < 0.0001$); the RFE increases faster than the contrast effect or the frame effect on self-orientation (figure 2). A two-by-two comparison of the phenomena showed that the TI and BAT regression lines were not only parallel ($F_{1,272} = 1.37$, $p > 0.05$) but also that they ran together; there was no difference in the angular-size effect ($F_{1,272} = 1.46$, $p > 0.05$).

### 3.6 *Relationship between adjustment errors according to test condition and angular size*

The correlational analysis showed that the RFE was related to both the contrast effect and the body illusion whatever the angular size (table 2). Therefore, the participants with the higher frame effect were more sensitive to the TI and to the illusion of self-tilt, as the two phenomena are independent. It should also be noted that the correlation coefficient between the RFE and the TI increased with the angular size of the apparatus, whereas the correlation coefficient between the RFE and the illusion of self-tilt did not vary.

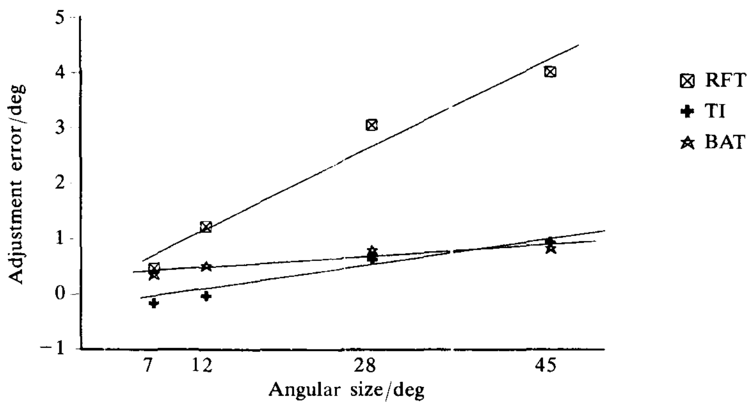



**Figure 2.** Mean adjustment errors as a function of angular size (regression) according to the upright estimate conditions. The linearity assumption for all three phenomena as a function of the angular size of the apparatus is acceptable. However, the RFE increased faster than the contrast or the vection effects, which are parallel and ran together.

**Table 2.** Spearman correlations between the three upright estimation conditions for the four display sizes.

| Display size/deg | RFT/BAT | RFT/TI | BAT/TI |
|---|---|---|---|
| 7 | 0.55, $p = 0.001$ | 0.54, $p = 0.001$ | 0.22, $p = 0.20$ |
| 12 | 0.32, $p = 0.059$ | 0.52, $p = 0.001$ | 0.16, $p = 0.36$ |
| 28 | 0.40, $p = 0.016$ | 0.64, $p < 0.0001$ | 0.17, $p = 0.32$ |
| 45 | 0.47, $p = 0.005$ | 0.75, $p < 0.0001$ | 0.29, $p = 0.09$ |

## 4 Discussion and conclusion

It is consistent with the results of early RFT research (Ebenholtz 1977, 1990; Ebenholtz and Callan 1980) that errors produced with the peripheral frame were larger than errors produced with the central frame. Indeed, the RFE increased linearly with the angular frame size. The relationship between frame size and adjustment errors was also evident on the BAT; however, the increase in errors was much smaller than on the RFT. The most unexpected result was that errors resulting from the contrast effect were also greater on a larger apparatus than on a smaller one. It was also established that there is a linear relationship between the magnitude of the TI and the angular size of the inducing line. Though errors recorded in the three situations increased linearly with the angular size, the regression lines were not parallel. The observed interaction was the result of rod-and-frame errors becoming greater at a faster rate than the other two effects as the size of the stimuli became larger.

However, the RFE was related to independent estimates of the orientation-contrast effect and of the illusory effect on self-orientation. Whatever the size of the frame, both mechanisms always seem to be present. Thus, small and large frames are not different fundamentally in nature, but do relate to the same phenomena to a certain extent. The distinction between large and small displays might be thought of as a quantitative (effect magnitude) rather than a qualitative effect (absence vs presence of the phenomenon). Furthermore, though neither of the phenomena can fully account for the rod-and-frame performance individually, the RFE cannot be described as the sum or combination of the two elementary illusions either (multiple $R = 0.79$, RFE = 1.14 body illusion + 1.57 TI + 0.93). Indeed, multiple regression showed a similar weak contribution to the RFE of both components and a relatively high constant value. This may imply either that the two phenomena—when present—interact by strengthening the effects of each other, or that the problem remains of identifying the other mechanisms that are necessary to produce the RFE.

The effect of stimulus size in the BAT, however, was not clear, as the errors recorded for small frames could hardly be attributed to visual-vestibular interactions. One may be tempted to put forward a proposition according to Rock (1990): the structure of the frame can act as a framework, which tends to define or at least to influence the definition of the main axes of space and thus to be perceived as either upright or as far less tilted than it actually is (DiLorenzo and Rock 1982). Thus, the outermost, visible, surrounding structure ought to define the stationary framework to which all objects in the field, including the self, would be referred. Consequently, there would be an effect even with a circumscribed small reference frame. One may therefore understand why adjustment errors occur on the BAT even for a small angular size. Moreover, the effect of angular size on adjustment errors could be explained in terms of the larger the frame size, the more likely it would serve as a 'world surrogate' that defines the main axes of space. Thus, the frame effect as well as the body illusion described here can be regarded as a measure of the potency of a framework to dominate perception in spite of the potential conflict between visual and gravitational information (Rock 1990).

In conclusion, given the extent of rod-and-frame errors as compared with TI or BAT errors, the framework concept may seem more appropriate to account for the RFE. However, it should be noted that DiLorenzo and Rock (1982) and Rock (1990) used specific shapes, such as squares or rectangles, as a framework. Owing to the presence of angles between the rod and the frame, their effects may also be construed in terms of orientation contrast. It would thus be relevant to investigate which visual-context-structuring units will generate a rather physiological effect—as shown for certain geometrical illusions (orientation contrast)—or a rather cognitive effect, ie the effect of an organised structure whose implicit or explicit main axes will have a substantial influence on the perception of orientation of the objects seen within it (framework).

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