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The role of cognitive factors in the rod-and-frame effect

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Abstract. We compared the contribution and the effectiveness of modulating the orientation perception of two types of visual information: the visual frame and the visual polarity of objects. In experiment 1, we examined the effect of a square frame, a mouse, an elephant, and a map of France on the apparent vertical. In the upright position, despite the presence of tilted individual component features, the visual objects had no illusory visual tilt effects. When tilted, these objects had a substantial effect on the direction that appeared to be vertical. However, rod-setting errors were smaller in the inducing objects than when observed with the frame display. In the second experiment, the results of experiment 1 were replicated with a meaningful circular contour—a porthole and a clock. The presence of the external circular contour did not abolish the illusion on the apparent vertical. Moreover, in experiment 3, a clock whose numbers were displaced and not tilted—to avoid the possible tilt influence of visual cues—was also able to deflect the subjective visual vertical. This finding suggests that through top – down processing shapes can act as a framework which serves as a reference influencing the perceived orientation of the inner objects.

1 Introduction

First investigated by Witkin and Asch (1948a, 1948b), the rod-and-frame effect (RFE) occurs when, in an otherwise dark room, an erect observer views a tilted luminous frame and attempts to set a luminous rod within it to the vertical. Adjustment settings, with a wide range of individual variation, deviate from the true vertical toward the tilted frame. Some investigators sought to reduce the effect of the frame to an interaction between the peripheral visual system and the vestibular system that is normally involved in the maintenance of orientation constancy (Dichgans and Brandt 1978; Ebenholtz 1985a, 1985b, 1990; Ebenholtz and Callan 1980; Goodenough et al 1985, 1987). There is a considerable body of evidence to support the view that the influence of the tilted frame, particularly one of large angular size, is the direct neurophysiological outcome of a stimulation of the peripheral retina (Ebenholtz 1977, 1990; Ebenholtz and Callan 1980). 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), and in addition to its influence on the apparent position of the rod, the frame also has a powerful influence on the apparent position of the observer's body and head (Ebenholtz and Benzschawel 1977; Goodenough et al 1987; Lee and Aronson 1974; Sigman et al 1978, 1979; Witkin and Asch 1948a, 1948b).

In the case of small displays (less than 10 deg), the frame effect is viewed as a purely visual interaction, similar to many angular illusions (orientation contrast effect; Carpenter and Blakemore 1973). This effect, which systematically distorts the perceived angle between the rod and the frame sides (Gogel and Newton 1975; Goodenough et al 1979a; Wenderoth 1974), is similar to the tilt illusion (rod adjustment in the presence of a tilted inducing line). There is some evidence of an orientation contrast effect for a 28 deg frame (Goodenough et al 1979a, 1987). This illusion can also be obtained with a large upright frame (Goodenough et al 1979a), and this can hardly be explained in terms of

constancy mechanisms. Finally, verticality judgment is also affected by orientational properties of the frame through visual mechanisms responsible for global analysis of the figure (ie extraction of the bilateral-symmetry axes; Antonucci et al 1995; Wenderoth and Beh 1977); this global mechanism is observed in the case of small and large displays.

Some results suggest that the effects of a small tilted frame may not be attributable entirely to visual mechanisms. Indeed, even in the presence of a small 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 visual–vestibular interaction. Moreover, whatever the size of the frame, both mechanisms, orientation contrast effect (tilt illusion) and illusory effect on self-orientation (body adjustment test: BAT; Witkin et al 1954), always seem to be present (Cian et al 1995). Thus, the distinction between large and small displays might be thought of as a quantitative (magnitude of the effect) rather than a qualitative effect (absence versus presence of the phenomenon). However, the effect of stimulus size in the BAT was not clear since 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 (Di Lorenzo 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 be to act as a 'world surrogate' that defines the main axes of space. The frame effect as well as the body illusion 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). However, it should be noted that Di Lorenzo 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 visual mechanisms. It would thus be relevant to investigate which visual-context-structuring units will generate a rather physiological effect—as shown for certain geometrical illusions—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).

In this paper, we compare the contribution and the effectiveness in modulating orientation perception of two types of visual information: the visual frame and the visual polarity of objects. The standard visual frame defines the principal vertical and horizontal lines of the environment. When tilted, the visual frame indicates the angle of tilt with respect to the vertical or the horizontal. The visual polarity of objects with a distinct top and bottom may also be used to define a coordinate system with respect to which object properties are estimated. As defined by Howard and Childerson (1994), most objects maintain a constant orientation with respect to gravity and contain an identifiable principal axis with one end distinct from the other. If all polarised objects in view are tilted, observers have a compelling illusion that they are tilted too. The adjustment settings of a rod deviate from the true vertical toward the tilted objects (Howard and Childerson 1994; Witkin and Asch 1948a, 1948b). However, these effects have been shown to exist when observers viewed the interior of a tilted room with tilted furniture. Thus, the effect may be due not only to the visual displacement of the

polarised furniture but also to the angle of tilt with respect to the horizontal or the vertical of the room's floor and walls.

The aim of this experiment is to show whether a larger polarised object surrounding a smaller object tends to be taken as the frame of reference for the smaller object or not. How can we predict the tilt illusion based on the physical properties of the inducing figure other than the axes of symmetry and the horizontal as well as the vertical axes of space? Though some objects have natural polar axes specified by landmarks which distinguish the upright from the inverted position, it may also be necessary to consider cognitive factors when inducing figures contain weaker visual cues to 'up' and 'down'.

2 Experiment 1: Effect of polarised objects

2.1 *Method*

2.1.1 *Subjects.* Twenty-eight adults, all volunteers (sixteen females and twelve males; mean age, 27 years), took part in the experiment. All subjects had normal or corrected-to-normal vision. In conformity with the Helsinki Convention which controls and regulates human experimentation, informed consent was obtained from all subjects.

2.1.2 *Stimuli and apparatus.* Four frames of reference were built (figure 1): a square frame, a mouse, an elephant, and a map of France. The stimuli were upright (ie in a natural orientation) or tilted 20° clockwise (cw) or counterclockwise (ccw) from the standard orientation. The stimuli were picture slides projected in white on the wall of a black room; the dimensions were 50 cm in length (inner side of the frame, north to south of France, animal's belly) and the drawing line 1.5 cm in width. The adjustable rod was 35 cm long and 1.5 cm wide. The figures were displayed with three 3250 ALC Simda Datavision slide projectors. The first projector was used to project the tilted environment, the second a mask, and the third the rod; the latter could rotate about the centre of the slide (centre of the rod). Each projector was fitted with an electromagnetic shutter with a minimum opening and closing time of 13 ms. The experiment was microcomputer-driven. The projectors were positioned so as to superimpose the projected images, and so as to rotate the adjustable line on the subject's frontal plane at about midpoint of the interocular axis.

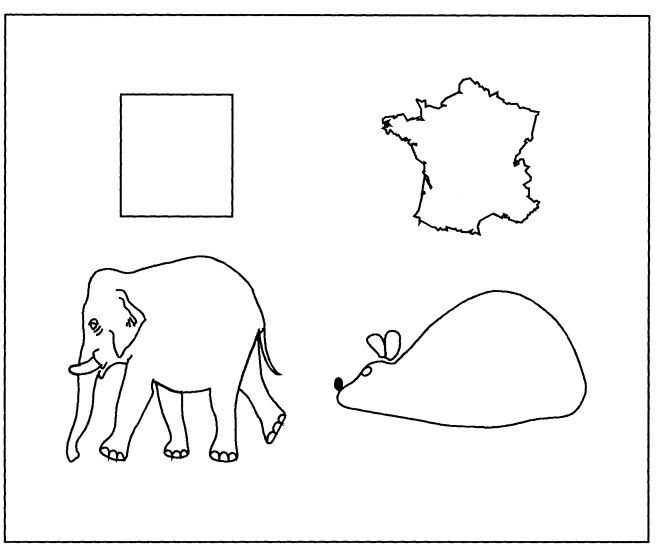

Figure 1. Visual displays presented in the upright position in experiment 1: lines making up the frame, map of France, elephant, and mouse were projected in white on the wall of a black room.

2.1.3 *Procedure.* The observer viewed the figures with his/her head upright and was sitting 100 cm away from the screen; thus the inducing stimuli subtended roughly 28 deg and the adjustable rod 20 deg. When the displays were in the vertical position, the gap between the end of the rod and the inner edge of the top of the shape subtended 4.3 deg. For each trial, 1 s after a starting signal informing the subject that he/she was to gaze at the centre of the visual field, the stimulus (inducing stimulus and adjustable rod) was displayed. The subject's task was to use a joystick to adjust the rod to the apparent gravitational vertical from starting positions at 20° cw or ccw of the true vertical; no time limit was given. The inducing stimulus and the rod were the only objects visible in an otherwise entirely dark room. The projection of the stimulus was followed by a mask (randomly distributed dots) which remained visible for 5 s after the subject's response. For each inducing stimulus, rod adjustment to the vertical was measured first in an upright stimulus condition (2 trials) and then in the tilted stimulus condition (4 trials, ie the four possible combinations of initial rod and stimulus tilts).

Each subject took part in a single 30 min session. The sequence of presentations was counterbalanced over participants. Errors in rod adjustment to the vertical were used to measure performance. For the upright condition, the subjective vertical was calculated from the algebraic mean settings. For the tilted condition, errors were considered as positive if they were in the direction of the stimulus tilt, and negative if they were in the opposite direction; the measure of the effect was calculated as the algebraic mean settings of trials.

2.2 *Results*

Preliminary data analyses were applied to the mean rod settings with upright shapes to detect possible bias of the stimulus used. Mean adjustment errors not only failed to differ from each other ($F_{3,81} = 1.18$, $p > 0.3$), but they also failed to differ significantly from zero ($p > 0.10$). An ANOVA of adjustment errors was performed with stimulus type and tilt orientation (right versus left) as repeated measures. Results showed a significant stimulus-type effect ($F_{3,81} = 11.26$, $p < 0.001$) but no effect of tilt orientation ($F_{1,27} = 0.17$, $p > 0.5$). A posteriori analysis (Tukey) showed that the errors produced with the frame (mean rod settings $\pm$SEM: $2.69° \pm 0.42°$) were greater than the errors produced with the other shapes ($p < 0.001$), but there were no differences between the elephant ($1.74° \pm 0.28°$), mouse ($1.56° \pm 0.23°$), and map ($1.69° \pm 0.25°$) conditions ($p > 0.5$; figure 2). However, there were more errors while viewing a tilted shape than while viewing the standard upright shape as the rod settings for the tilt orientation were significantly different from zero (elephant: $t_{27} = 6.11$, $p < 0.0001$; mouse: $t_{27} = 6.72$, $p < 0.0001$; map: $t_{27} = 6.61$, $p < 0.001$) and always in the same

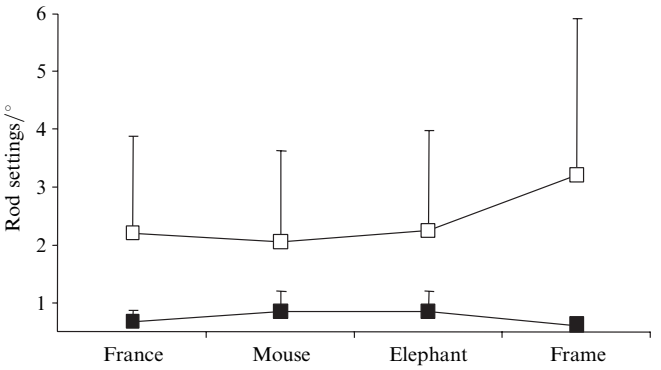

Figure 2. Mean rod settings in the upright condition (■) and tilted condition (□) in experiment 1. Error bars indicate standard deviation.

direction as the inducing tilt. Moreover, there was homogeneity in the same participant's performance under the different tilt conditions (Kendall coefficient of concordance, $W_s = 0.21$, $X_2 = 17.95$, $p < 0.0001$).

2.3 *Discussion*

In the upright position, despite the presence of tilted individual component features (eg elephant's legs), the visual objects and the upright frame had no illusory visual tilt effects. When tilted, these objects had a substantial effect on the direction that appeared to be vertical. Thus, verticality judgment seems to be affected by the orientational properties of the objects through mechanisms responsible for shape perception which assign top, bottom, and sides to objects (static visual-polarity cues). However, even if people tend to be consistent from condition to condition (high correlation), they vary widely in the way they respond to their surrounding. Indeed, rod-setting errors are considerably smaller in the inducing objects than when observed with the frame display. Wenderoth (1977) and Wenderoth and Beh (1977) suggested that the illusion magnitude is determined by which kind of axis falls closest to the judged orientation. Large illusions are obtained if the axis closest to the judged orientation corresponds to an orientation which is physically present. The failure of the tilted-object condition to be as effective as the frame condition may be due to the fact that polar axes were defined by the directions of the main lines (side) of the frame, whereas they were virtual in the inducing object conditions.

Another possible explanation would be that errors may be determined by the deviation of the polar axis from the vertical but also by the kind or the number of axes which can be drawn. It is therefore possible for an axis more salient than the object's polarity to modulate orientation perception when tilted and for any near-to-vertical element emerging from the visual display to be taken into account in orientation judgment (Antonucci et al 1995). The different axes reinforce each other or have opposite effects (Wenderoth and van der Zwan 1991; Wenderoth et al 1993). Therefore at 20° of tilt cw, all inducing objects have natural polar axes tilted 20° cw. In the frame condition, all elements close to vertical were oriented 20° cw, thus all axes reinforced each other; whereas in the tilted-object conditions, depending on the objects and tilt, there were upright cues and some elements tilted ccw which could have opposite effects (eg elephant's legs, virtual line connecting some elements on the map).

Lastly, the animal's belly may constitute a circle which limits the illusory effect produced by the virtual axis of the inducing figure. However, the critical role of the circle reference is supported by results obtained when a circular contour is presented outside the tilted frame display (Ebenholtz and Utrie 1982, 1983). If the magnitude of errors were influenced by the enclosing circle thus we can suggested that figures were not considered as global shapes but rather in terms of individual component features.

The results obtained do not allow us to discard the geometrical properties of the inducing figure as a factor. Moreover, if subjected to Fourier analysis, the tilted objects could contain similar orientation components as the frame; then it is difficult to disambiguate cognitive from noncognitive factors. To minimise the relative contributions of such variables to the magnitude of the effect, circular shapes can be used as they do not carry orientational information. If these shapes contain cues that determine a meaningful object to have a natural upright position, they may have a substantial influence on the perception of orientation of the objects seen within it (framework).

3 Experiment 2: Effect of meaningful circular contours

3.1 *Method*

3.1.1 *Subjects.* Twenty-seven adults (thirteen females and fourteen males; mean age, 24 years), all volunteers (informed consent) took part in the experiment. None had participated in experiment 1. All subjects had normal or corrected-to-normal vision.

3.1.2 *Stimuli.* Four frames of reference were built (figure 3): a square frame, a circle, a clock, and a porthole. The stimuli were tilted 20° cw or ccw . The dimensions were 50 cm in length (inner side frame, diameter of circle, diameter of inner part of the porthole, and distance between opposite numbers on the clock—eg from 12 to 6). The adjustable rod was 35 cm long and 1.5 cm wide.

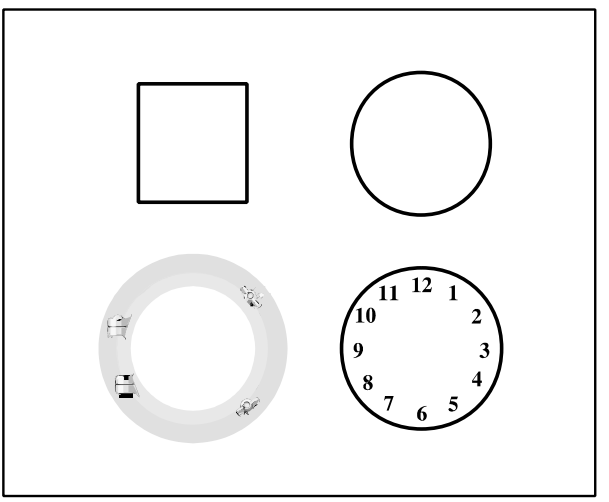

Figure 3. Visual displays in experiment 2: frame, circle, porthole, and clock presented in the upright position. Lines making up the frame, the circle, and the clock, were projected in white and the porthole in yellow (here shown grey) and black on the wall of a black room.

3.1.3 *Apparatus and procedure.* The apparatus used was the same as for experiment 1. The observer viewed the figures with his/her head upright and was sitting 100 cm away from the screen; thus the inner part of inducing stimuli subtended roughly 28 deg, the adjustable rod 20 deg, and the gap between the end of the rod and the inner edge of the top (or bottom) of the shape was 4.3 deg. The subject's task was to adjust the rod to the apparent gravitational vertical from starting positions at 20° cw and ccw of the true vertical. Four trials were required for each inducing-stimulus situation. The sequence of situations was counterbalanced over participants. Errors in rod adjustment to the vertical were used to measure performance. Errors were considered as positive if they were in the direction of the stimulus tilt, and negative if they were in the opposite direction; the measure of the effect was calculated as the algebraic mean settings of the four trials.

3.2 *Results and discussion*

The mean adjustment errors are presented in figure 4. An overall examination of the subjects' performance showed a range of errors varying with the inducing-stimulus condition ($F_{3,78} = 46.84$, $p < 0.0001$). The error in the circle condition ($0.02° \pm 0.15°$) was smaller than in the porthole ($1.3° \pm 0.18°$) or clock ($1.1° \pm 0.14°$) conditions (Tukey, $p < 0.001$) which did not differ (Tukey, $p > 0.7$); both were smaller than the frame effect ($2.56° \pm 0.3°$; Tukey, $p < 0.001$). To test for the presence of illusory effects, means were tested against zero by Student's t-statistics. In the circle condition,

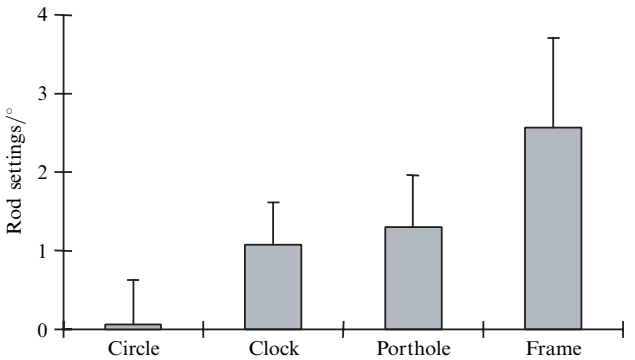

Figure 4. Mean rod settings and standard deviations (error bars) in experiment 2.

rod-setting errors were very weak and the values failed to differ significantly from zero ($t_{26} = 0.14$, $p > 0.8$). In the other circular-shape conditions, observers showed a clear illusory effect in the direction of the suggested tilt, with positive errors which differed from zero (clock: $t_{26} = 7.83$, $p < 0.0001$; porthole: $t_{26} = 7.42$, $p < 0.0001$). Moreover, the porthole and clock effects were related to the frame effect (Kendall coefficient of concordance, $W_s = 0.51$, $X_2 = 27.55$, $p < 0.0001$). Thus, there was some homogeneity in the same subject's performance.

Our results, consistent with the data published in the literature, show that a circle has no effect on the orientation perception. Indeed, such a geometrical shape does not have polar axes. However, if landmarks are added to the circle so that it becomes an object with an orientation, judgment errors occur and they are of the same nature as those observed in the previous experiment. These errors are less extensive than the errors induced by a frame. Two criticisms may be made, suggesting that there were angular relations between the rod and inducing elements. The first criticism is porthole related. Indeed, it may be suggested that the four elements that allow the viewer to consider the circle as a porthole could represent a corner display without sides. The demonstration has been made that a partial frame consisting of corners only or of four elements present on the vertex of each corner could produce errors (Ebenholtz 1985b; Nyborg 1977; Streibel et al 1980), and that these errors were significantly lower than those produced by a comparable full-frame configuration. The second criticism is linked to the presence of tilted numbers on the clock. Indeed, there is evidence that if all objects in view are tilted, the adjustment settings of a rod deviate from the true vertical toward the tilted objects (Howard and Childerson 1994; Witkin and Asch 1948a, 1948b).

4 Experiment 3: Effect of cognitive orientation

4.1 *Method*

4.1.1 *Subjects.* Twenty-two adults (eleven females and eleven males; mean age, 28 years), all volunteers (informed consent) took part in the experiment. None had participated in experiments 1 or 2. All subjects had normal or corrected-to-normal vision.

4.1.2 *Stimuli.* The inducing stimuli were the frame and the clock with the same dimensions as those described in experiment 2. The stimuli were tilted 15° cw or ccw so that the upright was equidistant from axes 12 – 6 and 11 – 5 in the case of a right tilt of the clock (figure 5) and from axes 12 – 6 and 1 – 7 in the case of a left tilt. Moreover, numbers on the clock were displaced and not tilted to avoid the possible tilt influence of the numbers.

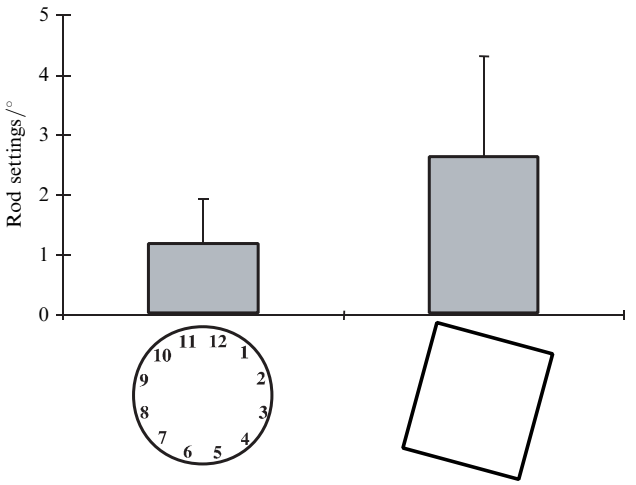

Figure 5. Mean rod settings and standard deviations (error bars) for the tilted clock and frame in experiment 3.

4.1.3 *Apparatus and procedure.* The apparatus used was the same as for experiment 1. The observer viewed the figures with his/her head upright and was sitting 100 cm away from the screen; thus the inner part of inducing stimuli subtended roughly 28° and the adjustable rod 20 deg. The subject's task was to adjust the rod to the apparent gravitational vertical from starting positions at 15° cw and ccw of the true vertical. Four trials were required for each inducing-stimulus situation. The sequence of situations was counterbalanced over subjects. Errors in rod adjustment to the vertical were considered as positive if they were in the direction of the stimulus tilt (12–6 axis for the clock), and negative if they were in the opposite direction. The measure of the effect was calculated as the algebraic mean settings of the four trials.

4.2 *Results and discussion*

Results showed that rod-setting errors in the clock situation were significantly different from zero ($t_{21} = 6.04$, $p < 0.0001$; figure 5) and always in the same direction as the inducing axis 12–6, but errors produced with the frame were greater than errors produced with the clock ($t_{21} = 5.11$, $p < 0.0001$; $2.65° \pm 0.42°$ and $1.21° \pm 0.2°$, respectively). Both situations were highly correlated (Spearman $r = 0.82$, $p < 0.0001$).

4.3 *Corollary experiment*

To test for the absence of any positive bias of the peripheral circular contour in the clock effect, a new set of ten adults (three females and seven males) were tested. The inducing stimuli were the frame and the clock with the same dimensions and tilt as those described in section 4.2.1. Two new conditions were added, the clock without the circumscribing circle and the tilted frame surrounded by a circle. Four trials were required for each inducing-stimulus situation. The sequence of situations was counterbalanced over subjects. Errors in rod adjustment to the vertical were considered as positive if they were in the direction of the stimulus tilt (12–6 axis for the clock), and negative if they were in the opposite direction.

Mean rod settings were submitted to an ANOVA with tilted shape (clock and frame) and surrounding circle (present versus absent) as repeated measures. Results showed a significant stimulus-shape effect ($F_{1,9} = 6.14$, $p < 0.04$) but no effect of the surrounding circle ($F_{1,9} = 0.086$, $p > 0.7$). The errors produced with the frame (circle present $2.11° \pm 0.52°$; absent $2.37° \pm 0.67°$) were greater than the errors produced with the clock (circle present $1.45° \pm 0.29°$; absent $1.29° \pm 0.34°$; Tukey, $p < 0.04$). Why the circular contour failed to reduce the frame effect in this experiment remains to be determined.

However, we can suggest that the presence of the circumscribing circle could not explain the reduction of the orientation effect of the displaced clock numbers.

5 General discussion

The frame of reference according to the definition of Rock (1990, page 245) is "a unit or organization of units that collectively serves to define a coordinate system with respect to which certain properties of all objects, including the phenomenal self, are gauged". A larger structure that is nearby or surrounds a smaller object tends to be taken as the frame of reference for the smaller object. However, the framework effect has been studied mainly by measuring judgments of the vertical when it is surrounded by a tilted square frame or geometrical shapes with linear segments. Owing to the presence of angles between the rod and the frame and bilateral-symmetry axes, these effects may also be construed in terms of visual mechanisms. In this paper, we compare the contribution of different cognitive shapes and their effectiveness on modulating orientation perception. In each object, the visual units did not indicate the same angle of tilt with respect to the vertical or the horizontal but produced a significant structure which had a natural (ie animals) or exclusively cultural orientation (ie map, porthole, or clock).

In all experiments, the rod was systematically set in the same direction as the tilt of the outer shape. This perceptual outcome may be consistent with the frame-of-reference hypothesis. The observers accept a large shape presented in the dark as a reference for determining the visual coordinates of space. All measures were highly correlated. However, the inducing frame produced the greatest influence, while the effects of the meaningful shapes did not differ from each other. This significant reduction of the effect indicated that the reliance on the shapes was not complete. The overall superiority of the frame condition may be interpreted by the possibility that the frame is a salient configuration (Antonucci et al 1995). The visual frame only indicates the angle of tilt with respect to the vertical or the horizontal while for the other shapes what is 'up' and what is 'down' is suggested. It has also been demonstrated that large illusions are obtained if the overall direction which influences rod adjustment is physically present (side of the frame), whereas smaller illusions result when these directions are virtual (ie inducing object conditions).

Other factors may account for the difference in magnitude. If the characteristics of the various mechanisms acting in the rod-and-frame effect are taken into account, we may propose that different perceptual outcomes result from the action of the frame and the other shapes. First, orientational contrast interactions have been shown to occur between inducing and test elements in the frame condition. The local mechanism acts by modifying the perceived angle between the square sides and the rod (Gogel and Newton 1975; Goodenough et al 1979a; Wenderoth 1974). However, this local mechanism would be less active for gaps of about 4° such as those used in the present experiment (Coren and Hoy 1986; Zoccolotti et al 1993). Moreover, despite the presence of tilted individual component features, the upright visual objects had no illusory visual tilt effects. This suggests that errors depend upon the relative orientation of the figure which is considered as a global shape rather than upon the relative orientation of individual component features.

Second, verticality judgment is affected by the orientational properties of the frame through visual mechanisms responsible for the global analysis of the figure. This process is mostly based on the extraction of the bilateral-symmetry axes (Antonucci et al 1995; Wenderoth and Beh 1977). For a majority of the shapes used in this experiment there is no vertical plane of bilateral symmetry or near symmetry. Moreover, in the clock condition, illusions occur in the direction of an imaginary axis which distinguishes the upright from the inverted position of the object (12 – 6 axis), regardless of

whether or not it represents an axis of symmetry. However, these arguments would be strengthened by a complete angular function of the observed effect.

Lastly, visual–vestibular mechanisms are active in the case of large peripheral displays presented in the dark (Ebenholtz and Benzschawel 1977; Goodenough et al 1979b, 1985). In the presence of a tilted square, the upright observer feels subjectively tilted and the coordinates of the entire visual scene are rotated accordingly. However, if the peripheral visual stimulus does not carry orientational information conflicting with that provided by the gravitational input—such as in the case of the experimental conditions with a circle—the vestibular system provides sufficient information to evaluate the vertical (Zoccolotti et al 1997). However, the frame and the clock situations produced the expected illusory effect on the rod, despite the presence of a circular contour. Moreover, the illusory effect was not reduced when the visual elements did not conflict with the output of the vestibular system—clock condition in which the numbers were displaced avoiding the possible tilt influence of visual cues. However, a study of body adjustment in the presence of the tilted shapes would help to arrive at conclusions about the impact of cognitive orientation on the activation of visuo-vestibular mechanisms.

In conclusion, the aim of this study was to test predictions concerning the direction of rod settings as a function of frame shape, but no attempt has been made to isolate the determinants of the magnitude of the error. Thus, further experiments are needed to more fully determine the relative contributions of the different mechanisms to the magnitude of the effects. At all events, results have shown that the perception of a square-like configuration is not necessary for the occurrence of the RFE. They also suggested that the effects of the different surrounding objects do relate to the same phenomena to a certain extent. However, the critical factor affecting rod adjustment in the shape conditions may be related to cognitive processes. The cognitive polarity of objects modulated the rod adjustment. Subjects have a mental representation of these objects with known direction indicating what is generally up and down, right and left. This suggestion does not invalidate the interpretation of the shape effects in terms of a frame-of-reference hypothesis. The observer accepts a large object presented in the dark as a reference for determining the visual coordinates of space (Rock 1990). We may suggest that the mechanisms underlying the subjective visual vertical are also susceptible to top–down influences. In this way, Mast et al (1999) have shown that visual mental imagery can exert the same directional influence on the subjective visual vertical as the perception of the corresponding stimulus where angular relations between the rod and inducing elements were present. Thus, it may be necessary to consider cognitive factors before a complete account is given of the RFE.

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