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The role of frame size on vertical and horizontal observers in the rod-and-frame illusion *

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The rod-and-frame illusion was used to examine a proposed distinction between the mechanism responsible for frame effects on rod-adjustment errors with large displays and the mechanism responsible for errors with small displays. It was suggested that visual-vestibular mechanisms are involved only when the rod is surrounded by a large tilted frame. Errors in the perceived vertical with small frame would instead be due to purely visual mechanisms. To examine this dual process model, we compared errors at small and large frame when the body was vertical or horizontal. There is evidence to suggest that tilting the body affects visual-vestibular interactions, but there is no reason to expect that body tilt would affect intravisual interactions. Hence, we hypothesized that body tilt would increase errors for large frame, but not for small frame. Eight subjects were tested in four different conditions, corresponding to the combination of two body orientations (vertical versus horizontal) and two frame sizes (47.5 versus 10.5 deg of visual angle). Fourier analysis of data was performed. Repeated measures ANOVA tested the hypothesis about frame size and body orientation. The hypothesis was not confirmed. More specifically, we found that tilting the body increased errors for the small frame as well as for the large frame. The interaction between frame size and body orientation was not significant. Results are discussed in relation to the proposed dual-process model.

The rod-and-frame illusion (RFI) was developed by Witkin and Asch (1948) to measure visual effects on spatial perception of the vertical direction. The visible RFI stimulus was a tilted square frame, surrounding a rod. Observers were asked to rotate the rod to a setting

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that looks vertical, and errors in setting the rod were used to measure frame effects on the perceived vertical.

Historically, the main interest on RFI was on the problem of individual differences in the degree of field dependence. More recently, research interest has focussed on the neural mechanisms underlying the illusion.

In the last years a two-process model was proposed by various authors (Coren and Hoy 1986; Ebenholtz 1985a; Goodenough et al. 1979a). This distinction has been predominantly based on the size of the visual angle subtended by the frame. This parameter should be distinguished from the size of the frame itself. Ebenholtz has shown that rod-adjustment errors depend on the former, but not the latter (Ebenholtz 1977; Ebenholtz and Callan 1980). For the sake of brevity, in the text we will use frame size referring to the size of visual angle subtended by the frame. In general, it is well known that RFI is considerably larger in conditions of large (20 degrees or more) than small (10 degrees or less) inducing displays (Ebenholtz 1977; Ebenholtz and Callan 1980); it may be noted that with standard presentation large frames impinge on the peripheral retina, while small frames impinge on a more central part of the retina. [1] However, under conditions of large, peripheral inducing displays, orientation effects would also be qualitatively different than under conditions of small, central displays. It has been proposed that large frame effects induced by large frame reflect ambient system functioning (Ebenholtz and Glaser 1982). This system acts automatically, that is without any prior perceptual or cognitive processing (Liebowitz and Post 1982). The RFI induced by large frame would be mediated by a visuo-vestibular reflex. On the other hand, the RFI induced by a small frame would reflect focal system processing of size, shape, depth etc. (Ebenholtz and Glaser 1982); this effect would be mediated by mechanisms other than visuo-vestibular reflex. Intravisual contrast orientations mechanisms were proposed by Goodenough et al. (1979a). Coren and Hoy (1986) posited that RFI induced by displays of intermediate size may involve both mechanisms.

[1] In most, if not all, studies on RFI inducing displays are presented centrally. It must be noted that, with this procedure, the effect of stimulus size is interwoven with that of eccentricity: increasing frame size produces a corresponding increment in eccentricity. To date, there is no experimental evidence which allows to clearly distinguish between the role of these two factors.

There are reasons and experimental data in favour and against this two-process model (for a comprehensive review see Spinelli et al. 1991).

Probably, the more relevant point regards the role of visuo-vestibular reflex in the two cases. The available evidence suggests that the illusion of rod tilt induced by large frames is primarily due to interactions between the visual and the vestibular system (e.g., Bischof 1974; Daunton and Thompsen 1979). In this view, the tilted frame drives the vestibular system in upright observers in the same way as head tilt in the opposite direction in observers with eyes closed. For example, when the otolith organ of the vestibular system is stimulated by tilting the head, in the clockwise (CW) direction for example, the vertical axis of perceived space is rotated in a counterclockwise (CCW) direction from the head to maintain orientation constancy. If a CCW frame drives the otolith system in the same way in upright observers, then the direction of the perceived vertical should also be rotated in a CCW direction from the head, and thus from the objective vertical. This rotation of the perceived spatial axis may account for the illusion of rod tilt in the standard RFI.

On the other hand, it has been proposed that visuo-vestibular interactions are minimal or absent in the small, central RFI (Ebenholtz and Benzschawel 1977). This hypothesis is based on the current knowledge of the characteristics of the ambient visual system. In general, experimental evidence is consistent with this view: the ability of visual stimuli to induce responses of the vestibular system generally depends on their retinal eccentricity. To be effective, the stimuli must impinge on the retinal periphery (Dichgans and Brandt 1974; Liebowitz and Post 1982).

Consistent with the idea that a large frame affects visuo-vestibular interactions, a number of responses, mediated by vestibular system, typically present in the case of head tilt, have also been recorded in upright observers of a large tilted frame. They include visually induced eye torsion in the direction of frame tilt (Crone 1975; Goodenough et al. 1979b; Hughes 1973), and an illusion of self-tilt in the opposite direction (Ebenholtz and Benzschawel 1977; Sigman et al. 1978, 1979). Critical for the hypothesis of a dual processing governing RFI effects is the observation that this cluster of vestibular responses is not present with small frame: Ebenholtz and Benzschawel (1977) found a head-tilt illusion in response to a tilted peripheral frame subtending

56.2 or 26.8 degrees, but no evidence of this illusion for centrally-fixated displays subtending 12.2 degrees. In a similar vein, it has been found that eye torsion was present in response to a peripheral frame subtending 40 degrees, but not to a central frame subtending 10 degrees (Goodenough et al. 1979c).

In evaluating these findings, there is reason to suspect that the absence of eye torsion under small frame condition may perhaps be a result of the lack of sensitivity of the measure. It should be remembered that RFI errors are considerably larger in conditions of large versus small displays (Ebenholtz 1977; Ebenholtz and Callan 1980). However, even in the case of large visual displays eye torsion is a small size phenomenon (ca. 0.2 degrees, Goodenough et al. 1979b). Assuming that the eye torsion effect is proportional to the dimension of the rod adjustment error, the expected effects would be very small in the case of small frames, and may be therefore difficult to detect. Similar considerations might apply to head tilt illusion measurements.

Other information relevant for the evaluation of the dual-process model come from the moderating role of depth cues. In the case of central displays subtending 10 degrees, Gogel and Newton (1975) found a 'depth adjacency' effect in which frame effects on rod settings were larger when the rod and frame were located in the same frontal plane than when they were located in planes that differed in distance from the observer. Ebenholtz and Glaser (1982) replicated this finding for central frames. For peripheral frames, rod settings were about the same whether the rod and frame were located at the same or different distances from the subject. For peripheral displays, Ebenholtz and Glaser conclude that RFI effects enter unusually early in the sequence of processing steps, before information about distance of the stimuli from the observer.

Consistent with this idea, Ebenholtz and his colleagues have found that the changes in figural organization of the visual inducing display have minimal effect on the RFI, when the stimulus subtended about 30 degrees (e.g., Streibel et al. 1980).

Another difference between central and peripheral RFI displays involves how tilted the frame looks. Peripheral displays affect perceived frame tilt as well as perceived rod tilt (Di Lorenzo and Rock 1982).

In the case of peripheral vision, if visual-vestibular interactions cause a rotation of the subjective vertical from the objective vertical toward the frame, then changes should occur in perceived orientation of the frame as well as the rod. But no changes are implied in perceived angles between the rod and frame sides. With respect to the orientation of the subjective vertical, the visual-vestibular interaction should cause an objectively vertical rod to be tilted in the opposite direction from the frame. Moreover, the frame should be less tilted with respect to the subjective vertical than it is with respect to the objective vertical. So when an observer experiences the RFI illusion of rod tilt in the opposite direction from the frame, the frame should look less tilted than it actually is.

However, central displays do not have similar effects on perceived frame tilt (Gogel and Newton 1975). In the case of central vision, these authors found that the illusion of rod tilt was not accompanied by a similar change in perceived frame tilt. Instead, they found a change in perceived angles between the rod and frame sides. These findings cannot be attributed simply to a change in the axis of perceived space. So Gogel and Newton rejected the view that their illusion of rod tilt is caused by rotating the subjective vertical toward the frame.

The differences outlined above have suggested the idea that central RFIs have an intravisual effect depending on relationships between the frame and the rod, instead of a vestibular effect which is present in peripheral vision, depending on relationships between the frame and the vertical axis (Coren and Hoy 1986; Ebenholtz 1985a; Goodenough et al. 1979a).

The present study addresses the question of the validity of the two-process model for central and peripheral RFI.

If central RFI effects are distinguishable from vestibular effects that occur only with large frame, then a distinction between central and peripheral displays should also be expected in the way RFI rod-adjustement errors are determined by body position. It is known that peripheral visual effects vary significantly as a function of body position (e.g., Bischof 1974; Goodenough et al. 1985). When subjects lie in a horizontal position on their sides, for example, peripheral RFI effects are much larger than when subjects are in an upright position. When subjects lie on their sides the otolith organ is also relatively insensitive to body tilt. The RFI difference between vertical and horizontal subjects has therefore been attributed to the role of otolith sensitivity in moderating visual-vestibular interactions (e.g., Bischof

1974). In this view, peripheral visual effects should increase with head tilt because they vary inversely with otolith sensitivity. If central RFI effects are not mediated by visuo-vestibular mechanisms, then it seemed reasonable to hypothesize that they would be independent of body position. Therefore, this hypothesis predicts a significant interaction between frame size and body orientation.

Two methodological problems arise when comparing RFI effects across display sizes and different body orientations. To deal with these problems we used Fourier analyses that measure the size of frame effects in terms of the amplitudes of sine waves that best fit the data. These analyses have several advantages for our purpose over traditional methods (for a more detailed discussion see Goodenough et al. 1985).

Comparing frame effects across display sizes regards the shape of the function between frame tilts and rod settings which is different for large and for small frames. In fact, in the case of peripheral displays, most studies show that rod settings tend to err in the direction of the frame when the frame is tilted between an upright position (0 degrees) and 45 degrees. For central displays subtending 6–7 degrees, however, Wenderoth (e.g., 1974, 1977) has found reversals in error direction for frame tilts between 22.5 and 45 degrees. In this range of display tilts, rod settings evidently err from the vertical in the opposite direction to the frame. [2]

The problem of comparing effects that vary in shape can be handled effectively with Fourier analysis: differences between shapes are reflected in the relative size of the various sine waves used to describe the data. In the present study, we chose to use a primary sine wave of 90 degree cycle length plus a secondary (first harmonic) sine wave of 45 degree cycle length.

We chose the 90 degree sine wave because of a basic property of the frame itself. Since the four sides of a square are identical, a rotation of the frame through a full (360 degrees) circle must result in a periodic function that repeats itself four times, or every 90 degrees. So the data should show primary waves that are 90 degrees in length.

[2] Similar reversals in error direction, called indirect effects, were also observed by Wenderoth and collegues with drifting and non-drifting 'plaids' (i.e., two super-imposed gratings of different orientations) acting as inducing figures (Johnstone and Wenderoth 1989a, 1989b; Wenderoth et al. 1989).

A 45 degree sine wave should also be useful in describing the data, particularly if there is a tendency in central displays toward reversals in error direction between 22.5 and 45 degrees of frame tilt. It should be considered that, in this range of frame tilts, the frame is an ambiguous figure that can be perceived as a square tilted in one direction or a diamond tilted in the opposite direction (e.g., Goodenough 1981; Wenderoth 1982; Wenderoth and Beh 1977; Witkin and Asch 1948). When the frame is tilted 35 degrees CW, for example it may be described as a square tilted 35 degrees CW or a diamond tilted 10 degrees CCW. In this example (and whenever the frame is tilted between 22.5 and 45 degrees) the diagonal of the frame is closer to the vertical than the sides of the frame and may be used as a reference for the verticality judgement. If so, then the data on rod settings should show significant waves that are only half as long as the primary waves (i.e., 45 degrees in cycle length). In view of the previous findings on reversals in error direction in central displays, it might be expected that 45 degree waves are more prominent with central than with peripheral frames.

Another problem arises when comparing RFI effects across different body orientations because the direction of the perceived vertical is affected by tilting the body. When observers lie horizontally in a dark room, the perceived vertical shifts in the direction of body tilt (Howard 1982). This shift has been called the '*A*' effect in recognition of its discovery by Aubert (1861). The *A* effect can be measured by asking subjects to adjust the rod to the vertical in the absence of any frame. It varies considerably from subject to subject, but averages about 15 degrees for adults who are lying on their sides (Bauermeister 1964; Goodenough et al. 1985; Wapner 1968).

Shifts in the perceived vertical due to the *A* effect are clearly accompanied by similar shifts in the effect of the frame (Bischof 1974; Goodenough et al. 1985). For subjects with an average 15 degree *A* effect who are lying CCW on their left sides, for example, a frame has no effect if it is turned on at 15 degrees CCW tilt from the objective vertical, it has a CW effect if it is objectively vertical (tilted by 15 degrees CW from the perceived vertical), and it has an equivalent CCW effect if it is turned on at a 30 degree CCW tilt from the objective vertical (15 degrees CCW from the perceived vertical). Thus, the magnitude and direction of RFI effects are a function of the angle between the frame and the subjective (perceived) spatial axis, rather than between the frame and the objective axis.

In summary, when subjects are lying on their sides, it is expected that the function describing the relationship between rod settings and frame tilt is shifted in phase by an amount that is equivalent to the shift in perceived vertical with their A effect. Frame effects are confounded with A effects when the RFI is scored by traditional methods because of these dramatic shifts with changes in body position.

The problem arising by changing body position can be handled effectively by Fourier analyses because they measure the size of frame effects independently of phase shifts in these effects. In terms of the dual-process model we might expect that the amplitudes of the Fourier components would increase in the body tilt condition for the large frame while they would not significantly change in the case of a central frame.

Method

Subjects

Eight 20- to 30-year-old volunteers (6 males and 2 females) participated in the study.

Apparatus and stimuli

An RFI device was built which could be used with either of two different frames. One had 100 cm long sides (peripheral frame) and one had 25 cm long sides (central frame). A single 21 cm long rod was used. Both the frames and the rod were made of a 1.2 cm wide luminescent tape and were the only visible elements in an otherwise darkened room.

The frames and the rod were coplanar.

In the central frame conditions the observer was located 135 cm away from the stimulus. Thus, the frame sides subtended a visual angle of 10.5 degrees. In the peripheral frame conditions the observer was located 120 cm away from the apparatus. Thus, the frame sides subtended a visual angle of 47.5 degrees. The small difference in line thickness due to the different distances used in the two conditions was considered as not relevant.

In the vertical body conditions the subject was seated on a chair with his/her head supported in a vertical position by a head-rest. In the horizontal body conditions the subject was lying on his/her right side (CW tilt) on a flat bed covered with a light mattress, with the head on a head-rest. Care was taken in the body-tilted conditions to keep the subject's perpendicular to the objective vertical by adjusting eye alignment to the plane of the bed. In both vertical and horizontal body conditions, the subject's eyes were at approximately the same height as the center of the display.

Procedure

Each subject took part in 4 one-hour sessions. In two sessions the subject was presented with the central frame conditions with both body-vertical and body-horizontal blocks of trials given in the same session; in the other two, with the two peripheral frame conditions. The order of central–peripheral frame conditions was counterbalanced across subjects.

Eight frame tilts were used (45, 33 CCW, 22.5 CCW, 11 CCW, 0, 11 CW, 22.5 CW, and 33 CW). In each case the rod could initially appear with either a 15 CCW or a 15 CW tilt. This produced a total of 16 different visual displays. Each display was presented twice in each of the two body-vertical conditions (central–peripheral frame) and three times for each of the two body-horizontal conditions. This produced a total of 310 trials.

Stimuli were presented in blocks of either 16 (body upright) or 24 (body tilted) trials. The order of presentation of the stimuli was randomized separately for each subject. In each session, two blocks of body-vertical trials were given first followed by two blocks of body-horizontal trials. Immediately before and after each block of trials four rod-alone trials were given, half with a 15 CW and half with a 15 CCW rod starting position. A brief rest period was allowed between blocks.

The method of adjustment was used. The subjects were instructed to direct the experimenter in aligning the rod with the gravitational vertical. The largest rod movements were 3 degree steps, however bracketting was permitted. No time limit was given. Errors in rod-adjustment to the vertical to the best half of a degree were used to measure performance. These errors were signed positively if tilted CW from the objective vertical and negatively if tilted CCW.

In the plan of the data analyses, amplitude measures were computed separately for each frame size in each body position for each subject. Amplitudes were then pooled across subjects to test for the significance of each Fourier component. In these analyses, for each subject, total degrees of freedom were the number of data points used (eight frame tilts) minus one. Of the remaining seven degrees of freedom, two were used to estimate phase and amplitude parameters for each Fourier component (90 and 45 degrees); the remaining three were used to estimate the residual variance. Degrees of freedom were pooled across subjects to perform separate ANOVAs for each body orientation by frame size condition.

Finally, significant components were examined by repeated-measure ANOVA to test the hypotheses about frame size and body position.

Results

Figs. 1 and 2 show how rod settings vary with frame tilt for each experimental condition.

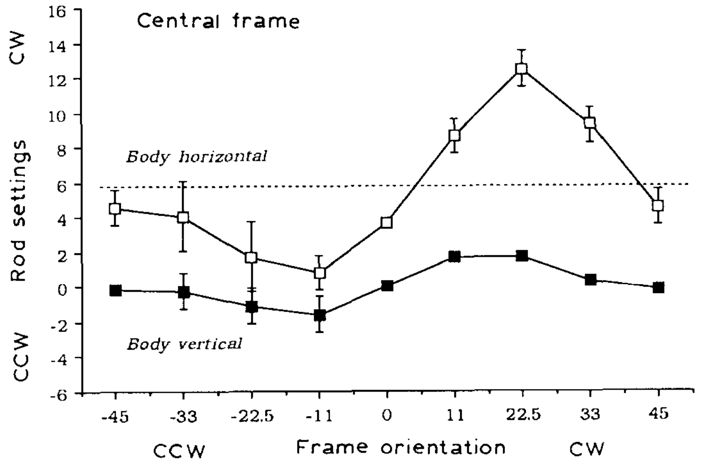

Fig. 1. Rod settings as a function of frame orientation for the central frame (10.5 degrees of visual angle). Positive and negative values indicate clockwise and counterclockwise tilt of rod settings (ordinate) and of frame orientation (abscissa), respectively. Data obtained were averaged over 8 subjects. Filled squares refer to body vertical condition, open squares to body horizontal condition. The dashed line indicates the mean rod setting in the absence of the frame (*A* effect).

The data summarized in the figures confirm a number of previous findings. First, they show the expected *A* effect, although it is somewhat smaller in our data than has generally been reported (Bauermeister 1964). The dashed line in the figures indicates

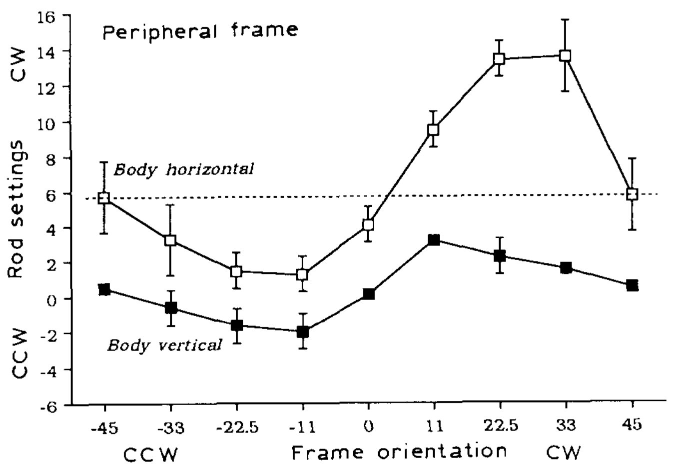

Fig. 2. Rod settings as a function of frame orientation for the peripheral frame (47.5 degrees of visual angle). See fig. 1.

Table 1
ANOVA on Fourier components.

Experimental condition	Fourier component	*df*	Variance estimate	*F*	*p*
Body vertical					
Frame 47.5 deg	90 deg	16	16.38	28.24	< 0.001
	45 deg	16	2.03	3.50	< 0.01
	Residual	24	0.58		
Body horizontal					
Frame 47.5 deg	90 deg	16	99.48	43.63	< 0.001
	45 deg	16	7.50	3.29	< 0.01
	Residual	24	2.28		
Body vertical					
Frame 10.5 deg	90 deg	16	8.56	47.55	< 0.001
	45 deg	16	2.21	12.27	< 0.001
	Residual	24	0.18		
Body horizontal					
Frame 10.5 deg	90 deg	16	61.87	46.87	< 0.001
	45 deg	16	10.38	7.86	< 0.001
	Residual	24	1.32		

the *A* effect estimated by the mean rod setting in the absence of the frame (5.7 degrees in the direction of body tilt). Second, rod settings in the condition of body tilt are displaced upward of an amount that is comparable to size of the *A* effect, as expected (Bischof 1974; Goodenough et al. 1985). Third, for the vertical body position, the figures also show that frame effects are larger for the large peripheral display than for the small central display, as has been found before (Ebenholtz 1977; Ebenholtz and Callan 1980). Finally, most importantly for our purposes, the data shown in fig. 2 clearly confirm previous findings for peripheral displays that the RFI effect is larger when the body is tilted than when it is upright (Bischof 1974; Goodenough et al. 1985).

The data of fig. 1 also show some unexpected results. Contrary to the hypothesis, the frame effect increases in the horizontal body condition for the small central display, as well as for the large peripheral display. Moreover, we found no evidence for the central display of a reversal in error direction between 22.5 and 45 degrees of frame tilt.

The data shown in figs. 1 and 2 are described in more detail by the Fourier analysis summarized in tables 1, 2, and 3.

Table 1 shows ANOVA, testing for significance of the two Fourier components of 90 and 45 degree cycle lengths.

For the peripheral frame subtending 47.5 degrees of visual angle, the table shows that the 90 degree primary wave and the 45 degree harmonic are significant in both vertical and horizontal body positions. These results confirm previous findings (Goodenough et al. 1985).

Table 2
Mean amplitudes (in deg) in the 2×2×2 design (Fourier component by frame size by body orientation).

Fourier component (deg)	Frame size (deg)	Body orientation	
		Vertical	Horizontal
90	47.5	2.3	6.9
	10.5	1.4	5.1
45	47.5	0.9	1.8
	10.5	0.8	2.2

Fourier analyses have not previously been reported for a central frame. In the data from the present study, however, the same pattern of results was found for the central frame as for the peripheral frame.

Table 2 lists the mean amplitudes for the significant 90 and 45 degree sine waves under each experimental condition, and table 3 summarizes the ANOVA designed to compare amplitude differences among conditions.

The significant main effects of body position and frame size indicate larger errors in rod settings in conditions of body tilt and large frame, respectively.

Overall, 90 degree sine wave amplitudes are considerably larger than 45 degree sine wave amplitudes. However, amplitudes vary significantly as a function of frame size. The 90 degree sine wave amplitude increased from small to large frame ($p < .05$, Duncan test); no difference between the two frame size conditions was present for the 45 degree sine wave (see fig. 3).

Table 3
ANOVA on body orientation, frame size and Fourier component.

Source	*df*	Estimate	*F*	*p*
Subjects (S)	7	5.47		
Body orientation (B)	1	110.43	47.47	< 0.001
Frame size (F)	1	5.27	5.48	0.051
Fourier component (C)	1	100.98	27.87	< 0.005
B×F	1	0.13	0.17	n.s.
B×C	1	35.74	33.16	< 0.001
F×C	1	8.39	6.76	< 0.05
B×F×C	1	1.95	1.68	n.s.
S×F	7	0.96		
S×B	7	2.33		
S×C	7	3.62		
S×F×B	7	0.75		
S×B×C	7	1.08		
S×F×C	7	1.24		
S×B×F×C	7	1.16		

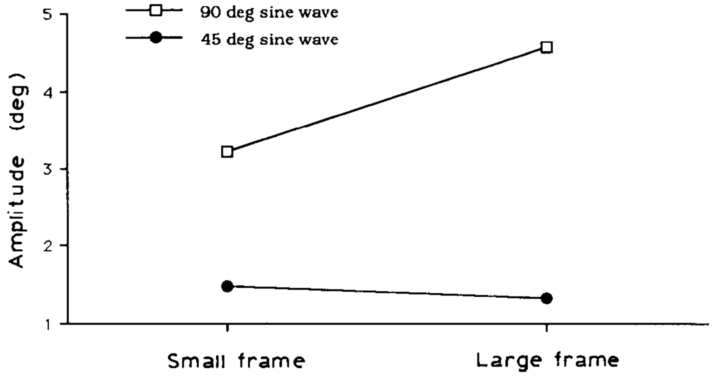

Fig. 3. Amplitudes of the 90 and 45 degree sine wave components as a function of frame size.

A significant body position by amplitude interaction was observed: 90 degree sine wave amplitudes increase with body tilt considerably more than 45 degree sine wave components.

The more important question for our purpose, however, concerns the hypothesized interaction between frame size and body orientation, which was not significant. Contrary to the hypothesis, body position is about as important in determining frame effects for the central display as it is for the peripheral display.

Discussion

The result that tilting the body increased errors for the central frame as well as for the peripheral frame does not support the proposed distinction between a central, intravisual RFI mechanism and a peripheral, vestibular RFI mechanism. In contrast, the present data show that vestibular mechanisms are effective both with peripheral and with central frames.

The present data do not fit with previous findings showing lack of vestibular responses, such as eye torsion and induced head tilt, in the case of central RFI (Ebenholtz and Benzschawel 1977; Goodenough et al. 1979c). However, it is resonable that the failure to observe these signs of vestibular involvement was due to the small size of the expected effects (in the case of eye torsion in the range of 1 or 2 tens of a degree). In contrast, the procedure of tilting the observer increases the size of expected effects, thereby maximizing the chance of detecting visual-vestibular interactions also in the case of the small frame.

In any case, before the dual-process model would be rejected, alternative interpretations of the pattern of obtained results should be examined. One might think that the hypothesized interaction between frame size and body orientation did not occur because the small frame used in the present study extended into the peripheral visual system where interactions with vision occur; an even smaller frame might have produced the expected interaction between frame size and body position. This interpretation, although unlikely, might be further investigated. In any case, the evidence from previous studies pointing to the absence of visual-vestibular interactions in central displays is based on central frames of 10 degrees – or slightly larger – like the one we used (Ebenholtz and Benzschawel 1977; Goodenbough et al. 1979c).

Alternatively, one might argue that visual-vestibular interactions do not occur or are minimal in response to stationary central stimuli in upright observers, but they occur when the body is tilted. If so, then tilting the body may uncover previously undetected visual-vestibular interactions even with central displays. In this view, RFI errors increase, even with our small display, because visuo-vestibular effects become more important under tilted body conditions. This interpretation would allow to maintain the dual-process model even though for the conditions of body upright only, thereby greatly limiting the general scope of the model.

In evaluating a possible revision of the proposed dual-process model it seems important to re-examine the neurophysiological evidence on which it is based. Certainly, there is a great deal of evidence to support the idea that visual-vestibular interactions are minimal in central vision (e.g., Liebowitz and Post 1982). However, this comes primarily from studies of inducing stimuli that are moving (e.g., Dichgans and Brandt 1974). One might argue that this conclusion does not apply to stationary stimuli. Certainly, not all variables have mediating effects on vestibular responses that are similar for moving and stationary visual stimuli. For example, Ebenholtz (1985b) has shown that RFI errors are dependent on the spatial frequency of the inducing, stationary display, but circular vection is not dependent on the spatial frequency of the inducing, moving stimulus (Liebowitz et al. 1979). Moreover, Spinelli et al. (1991) found that individual differences in the RFI were not correlated with those in the rotating disk situation. According to this view, verticality judgement under conditions of static and moving inducing displays would be controlled by different mechanisms; for static displays, such as the RFI illusion, visual-vestibular interactions would occur in central as well as peripheral vision.

An additional result of the present study with central frame is the lack of error direction reversal between 22.5 and 45 degrees of frame tilt. In terms of the Fourier analysis this is quantified by the amplitude of the 45 degree component. Perhaps, the failure to replicate Wenderoth's finding of a reversal in error direction is due to the size of frame used here. Most of Wenderoth's data were collected with an unusually small frame subtending only 6–7 degrees. However, in the present work, the decrement of the frame size produces a clear shift in the relative importance of the two (90 and 45 degree) Fourier components. More specifically, the 90 degree component decreases in amplitude from large frame to small frame, but the 45 degree component does not. It is reasonable to expect that the 90 degree wave monotonically decreases with even smaller frame sizes, while the 45 degree wave become prominent, thus leading to a reversal in error direction.

In conclusion, these data suggest that it may be necessary to modify the dual-process model. Instead of looking for some condition where only the intravisual or the vestibular mechanism is effective, it might be speculated that both mechanisms are present in any case, although perhaps in different proportions under different frame sizes. In this regard, it seems reasonable to hypothesize that visual-vestibular interactions become more pervasive under conditions of reduced vestibular sensitivity when the body is tilted.

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