

Foreground and background in dynamic spatial orientation

THOMAS BRANDT, EUGENE R. WIST, and JOHANNES DICHGANS

Neurologische Universitätsklinik mit Abteilung für Neurophysiologie, Freiburg i. Br., West Germany

The dependency of visually induced self-motion sensation upon the density of moving contrasts as well as upon additional stationary contrasts in the foreground or background was investigated. Using two different optokinetic stimuli, a disk rotating in the frontoparallel plane, and the projection of horizontally moving stripes onto a cylindrical screen, it was found that: (1) visually induced self-motion depends upon the density of moving contrasts randomly distributed within the visual field and, with a single contrast area of 1/4 %, is saturated when about 30% of the visual field is moving; (2) additional stationary contrasts inhibit visually induced self-motion, proportional to their density; and (3) the location in depth of the stationary contrasts has a significant effect upon this inhibition. Their effect is considerable when located in the background of the moving stimuli but weak when appearing in the foreground. It is concluded that dynamic visual spatial orientation relies mainly on information from the seen periphery, both retinal and depth.

The perception of self-motion is based mainly on the integration of visual and vestibular motion information. It has been shown, for example, that visual information is essential for the perception of constant-velocity self-motion, since the vestibular system detects body acceleration only (Brandt, Dichgans, & Koenig, 1973; Dichgans & Brandt, 1974). The perception of self-motion, resulting, i.e., from rotation of the visual surround about the observer (circularvection or CV), was considered an illusion ("railroad illusion") in the older literature (Fischer & Kornmüller, 1930; Helmholtz, 1896), and as a result its functional importance has been neglected. Clearly, when the body, for example, moves to the left at constant velocity, the visual field moves to the right, thus providing appropriate information concerning the direction and velocity of self-motion. That vision is essential for the sensation of constant-velocity body motion in vehicles can easily be detected if one closes the eyes, in which instance the sensation of motion ceases. Neurophysiological evidence for the underlying visual-vestibular integration has been provided by microelectrode studies of units in the vestibular nucleus in several species. Convergence of visual and vestibular motion information on these units has been found in the goldfish (Dichgans, Schmidt, & Graf, 1973), rabbit (Dichgans & Brandt, 1972; Leopold, Schmidt, Sterc, & Dichgans, 1973), and monkey (Henn, Young, &

Finley, 1973). For all three species, both constant-velocity visual stimuli and angular acceleration of the body were found to modulate unit activity.

In contrast to vestibular information, visual motion information can be interpreted as either object motion or self-motion. The present study is concerned with the critical role of stationary contrasts in determining whether object- or self-motion perception will occur, since under normal environmental conditions both moving and stationary contrasts are typically present. In riding a car, for example, there exist for the observer the potentially conflicting stimuli provided by a stationary foreground (the framed window) and a moving background (the rearward motion of the visual scene outside). Yet self-motion rather than object motion is perceived.

The present study was thus designed to investigate the interaction of simultaneously present moving and stationary contrasts on self-motion perception. Two experiments were conducted. In the first, the effect of contrast density in the moving field in the absence as well as in the presence of stationary contrasts was examined. In the second experiment, the effect of the location in depth of the stationary in relation to the moving contrasts was investigated. Our hypothesis, based on preliminary observations as well as on the above considerations, was that when stationary and moving contrasts are simultaneously present at different distances from the observer, self-motion perception is more affected when either the stationary or the moving contrasts are located in the background as opposed to the foreground. This hypothesis implies that dynamic spatial orientation (in this case, self-motion perception) relies mainly upon background information, whereas object-motion perception depends predominantly upon foreground

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information. Thus, in analogy to the finding that the retinal periphery is dominant in determining self-motion perception (Brandt, Dichgans, & Koenig, 1973; Dichgans & Brandt, 1974), the depth periphery is dominant as well.

METHODS

Subjects

Four male subjects were employed in the first experiment, and five in the second. All had previous experience in motion perception studies.

Apparatus and Experimental Procedure

For technical reasons, the two experiments had to be performed using two separate stimulation set-ups, as described below.

Rotating disk system for measuring induced tilt. A visual surround rotating around the observer's line of sight induces an apparent body rotation opposite in direction and causes a limited tilt of the apparent upright. The amount of this tilt can be measured in terms of the angle by which the test edge is displaced in the direction of the rotating stimulus, so as to compensate for the perceived tilt in the opposite direction. Therefore, the amount of induced tilt can serve to quantify the potency of the stimulus in inducing apparent self-motion as well as a shift of apparent vertical (Dichgans, Diener, & Brandt, 1974; Dichgans, Held, Young & Brandt, 1972; Held, Dichgans, & Bauer, 1975).

A large, transparent, motor-driven disk, which could be rotated around the observer's line of sight, was mounted 30 cm in front of the subject's eyes (Figure 1a). It subtended 132 deg of visual angle when viewed binocularly with the subject's head aligned with its center. A bite board was used to immobilize the head. The transparent rotating disk's surface was randomly covered by

colored circles (green, red, yellow, and blue in equal proportions), each subtending 1.4% of the total disk area. Five different stimulus displays, carrying a total number of 4, 20, 40, 120, or 288 moving circles, covering 1%, 5%, 10%, 30%, and 72% of the disk's area, respectively, were presented (Figure 2). The disk was rotated at a constant angular speed of 50 deg/sec, while a second, stationary disk was located 5 cm behind it. This latter disk was visible through the spaces between the colored circles on the transparent rotating disk. The effect of three different stationary backgrounds was investigated: a plain white ground (no circles), 8 circles (covering 2% of the area), and 288 circles (covering 72% of the area).

Finally, a third adjustment disk, subtending a visual angle of 18 deg, was mounted on a coaxial shaft at the center just in front of the large disk. It carried a straight edge, produced by dividing its surface into black and white semicircular areas. A fixation point was located at the midpoint of the edge. The orientation of the edge, which served as an indicator for subjective vertical, could be controlled by the observer by turning a potentiometer, the output of which was simultaneously recorded on a strip chart. The resolution of the measurements thus taken was 1 deg.

Measurements of the induced tilt of the apparent vertical were obtained by means of continuous tracking of the visual vertical for a 30-sec stimulation period under 30 randomly presented stimulus conditions: 2 rotation directions (clockwise or counterclockwise) \times 5 rotating disk displays (1%, 5%, 10%, 30%, or 72% of surface covered with circles) \times 3 background conditions (white background, 2% or 72% of surface covered with circles). Four subjects received five trials for each condition; thus 20 measurements for each of the 30 stimulus conditions were obtained. For each 30-sec record, the maximum deviation, which lasted a minimum of 8 sec, was measured in degrees. The mean deviation of apparent vertical (AV) in degrees was calculated from these values for each of the stimulus conditions.

Projection of horizontally moving stripes for measuring circularvection latencies and magnitudes. As described earlier, rotation of the entire visual surround around a vertical axis induces an apparent body rotation (CV) indistinguishable from real (vestibularly detected) body rotation (Brandt, Wist, & Dichgans, 1971). The latencies from stimulus onset and the perceived velocity of circularvection can be used as a measure of the potency of an optokinetic stimulus in inducing self-referred motion perception.

A regular pattern of vertical black and white stripes, subtending 7 deg of visual angle, was projected by means of a Tönnies optokinetic stimulator on a cylindrical screen (Figure 1b). The subjects sat in an upholstered chair fitted with a head support so that the distance of their eyes from the cylindrical screen was equal to its radius of curvature (79.5 cm). The visual angle of the entire visible stimulus field subtended 165 deg horizontally and 100 deg vertically. A small stationary 0.5-deg disk, serving as a fixation point, was fixed in the subjects' median plane at eye level, either on the surface of the screen or 24 cm in front of it.

The perceived distance of the moving stripes was decreased to the plane of the nearer fixation point by means of the Pulfrich effect. As is well known from the work of Lit (1949) and Pulfrich (1922), the magnitude of the change in perceived depth is a function of both filter density (attenuation of luminance in one eye) and stimulus speed. The perceived distance of a unidirectionally moving horizontal stimulus is decreased when the direction of motion is toward the filter-covered eye. Preliminary experiments were necessary in order to determine the stripe velocity at which the individual subject, with one eye covered by a neutral density filter of 1.5 log units of attenuation, perceived the stripes moving in the plane of the nearer fixation point. The angular stripe velocity was determined separately for each subject (range between 85 and 100 deg/sec) and was employed in the experiment proper to insure that the stripes appeared to move in a plane 24 cm in front of the screen. In addition to the moving stripes, a similar, but stationary, pattern of vertical, opaque, black stripes could be affixed either in the foreground (48 cm in front of the screen) or in the background (in the plane of the projection screen).

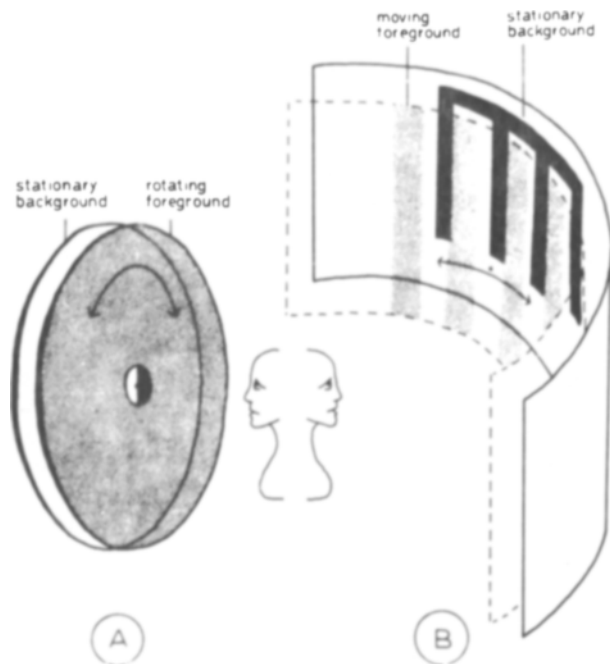
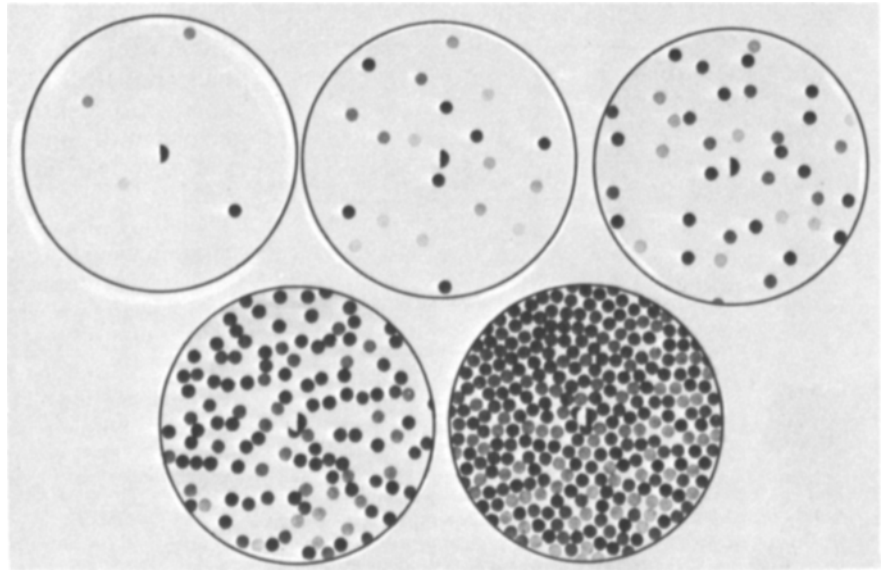


Figure 1. Schematic drawing of the two stimulus arrangements. (A) Rotating disk system with stationary background disk and central adjustment disk for indication of subjective vertical. (B) Projection of horizontally moving stripes in front of a stationary background pattern.

Figure 2. Stimulus displays used in rotating disk experiment arranged in order of increasing density (1%, 5%, 10%, 30%, and 72% of the total surface). Adjustment disk is shown at the center of each display.



This stationary stripe pattern was presented under two conditions: For the *equal angular size conditions*, the physical size of the background pattern was enlarged in order to subtend the same angular size as the foreground pattern (compare F and B₂ in Figure 4). For the *equal physical size conditions*, the angular size of the stationary stripe pattern was reduced in the background (compare F and B₁ in Figure 4).

Measurements of circularvection latencies were obtained by means of a stopwatch. The subject was instructed to start the watch as soon as the stripes began to move and to stop it as soon as he experienced CV. Circularvection latencies were recorded for the following stimulus conditions: no stationary stripes (O), stationary stripes in foreground (F), stationary stripes in background of the same physical size (B₁), or the same angular size (B₂). Each of these four conditions was presented twice, once with the stripes moving to the left and once to the right, for a total of eight conditions (see Figure 4). The five subjects received five trials on each of the eight randomly presented conditions.

Continuous tracking of perceived circularvection velocity over a 1-min stimulation period was achieved by the subject's indicating the magnitude of CV velocity through turning a potentiometer whose output was continuously recorded on a strip chart (Brandt, Dichgans, & Büchele, 1974).

The subject was shown the standard condition consisting of the stripes moving in the plane of the screen with no stationary contrasts present (Condition O in Figure 5). He was told that the CV speed he experienced had the arbitrary values of 10, which was represented by setting the potentiometer dial to a position midway between the zero and maximum positions. He was instructed to indicate his perceived speed of self-motion continuously for the following six stimulus conditions (see Figure 5) by adjusting the potentiometer accordingly: no stationary stripes present with the moving stripes either in the plane of the screen (O) or 24 cm nearer (OF), stationary stripes present in the foreground with the stripes moving within the plane of the screen (FOO) or 24 cm nearer (FOF), and stationary stripes in the background with the moving stripes either in the plane of the screen (BO) or 24 cm nearer (BF). When the stationary stripes appeared in the foreground, their distance from the screen was always 48 cm (i.e., 31.5 cm from the subject's eyes), while the background distance was identical to that of the screen (79.5 cm from the subject's eyes). These six experimental conditions were presented in a random order to each subject. Two trials were given per condition, one with stripe movement to the left and one with movement to the right in a counterbalanced order.

The standard condition (O) served as a modulus. For all measurements, the fixation point was positioned in the depth plane of the moving stripes. Even though it was the case that, with fixation here, the foreground stripes appeared slightly blurred as compared to the background stripes, preliminary studies showed this to have no effect on the phenomena observed. Motion perception was unaltered when fixation was on either the foreground or background stripes rather than on this fixation point.

RESULTS

Magnitude of Induced Tilt as a Function of Number and Total Area of Moving Contrasts

The magnitude of visually induced self-motion as measured by tilt of subjective vertical depends upon the number of moving visual contrasts, randomly distributed within the visual field. It is striking that only four circles attached to the transparent disk rotating in front of an unstructured white background (1% of total area) are able to induce an average shift of 2.5 deg in perceived upright. An additional increase of the percentage of moving circles within the rotating disk leads to a negatively accelerated increase in induced tilt, as can be seen in Figure 3. Tilt reaches saturation at an average deviation from the true vertical of about 13 deg when 30% of the moving disk's surface is covered by colored circles. A further increase of the total number of moving contrasts to 72% does not result in a significant further increase of induced tilt. The tendency of the counter clockwise effect to be slightly larger than the clockwise effect, evident in Figure 3, has previously been observed (Held, Dichgans, & Bauer, 1975).

Simultaneously Presented Stationary Contrasts Inhibit the Apparent Tilt

If the stationary white background disk carries eight colored circles (2% of its surface), then the

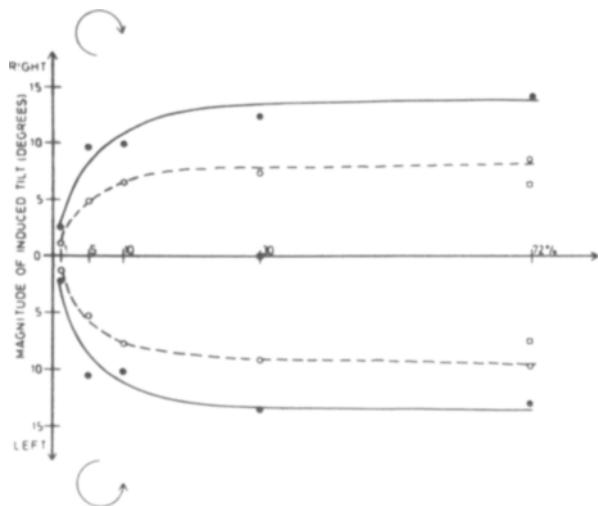


Figure 3. Mean magnitude of induced tilt of apparent vertical as a function of the density of the colored circles on the rotating disk. Abcissa represents the total area of the disk in percent covered by the colored circles. Each circle constituted 0.25% of the total area of the disk. Results for three background conditions are shown: solid circles for plain white background; open circles for 2% background (8 stationary circles); open squares for 72% background (288 stationary circles). Since, in preliminary experiments, no measurable change in induced tilt or CV could be found for the 72% background condition in the presence of 4, 20, and 40 moving circles (1%, 5%, and 10%, respectively), these conditions were omitted here. Top: clockwise data. Bottom: counterclockwise data.

amount of induced tilt produced by the simultaneously presented rotary stimulus is significantly reduced. This inhibition is about one-half for the 1% and 5% stimulus conditions and at least one-third for the 30% and 72% conditions (Figure 3). No apparent tilt could be observed up to 120 circles (30%) rotated in front of 288 (72%) stationary ones. The inhibitory effects of such a powerful stationary background could be weakened only if the total number of moving contrasts was also increased to 288 circles. It must be taken into account that in this stimulus situation 72% of the stationary background was occluded by the moving contrasts, thus restricting information about the stationary visual environment.

Increase of Circularvection Latencies as a Result of a Simultaneously Presented Stationary Background

The results of the first experiment show an inhibitory effect of stationary contrasts on self-referred motion perception. The differential effect of additional stationary contrasts located either in the background or foreground of the CV stimulus was tested in the second experiment. As can be seen in Figure 4, the mean CV latency of 7 sec for the control condition (O, no stationary contrasts present) remains unaffected when the moving pattern is viewed through a stationary foreground (F). If, however, the stationary pattern is affixed to the screen in the

background, then CV latencies are significantly ($t = 3.59, df = 4, p < .5$) enhanced to mean values of 12-13 sec (B_1), thus indicating an inhibitory effect on CV due to the presence of stationary contrasts in the background. CV latencies are further increased if the physical size of the stationary background pattern is increased (B_2) in order to maintain the same angular size as for the stationary foreground pattern.

Visually Induced Self-Motion is Inhibited by a Simultaneously Presented Stationary Background

The inhibition of circularvection by additional stationary contrasts in the background can also be seen qualitatively in the tracking experiments (Figure 5). While a stationary foreground only slightly diminishes the perceived velocity of CV, it is markedly reduced with a stationary background (compare Figure 5: FOF vs. BF). With stationary background stripes, not only are latencies enhanced, but once CV has been induced it is weak and unstable, interrupted by intervals in which exclusively object motion instead of self-referred motion, is perceived.

No interruptions in CV were found for the top three conditions in Figure 5. The total duration of CV inhibition (interruption after CV onset) within each of the 60-sec records for the bottom three conditions in this figure was calculated. Mean CV inhibition durations were 4.09, 1.25, and 24.5 sec for Conditions FOF, BO, and BF, respectively. t tests for related measures indicated that significantly more CV

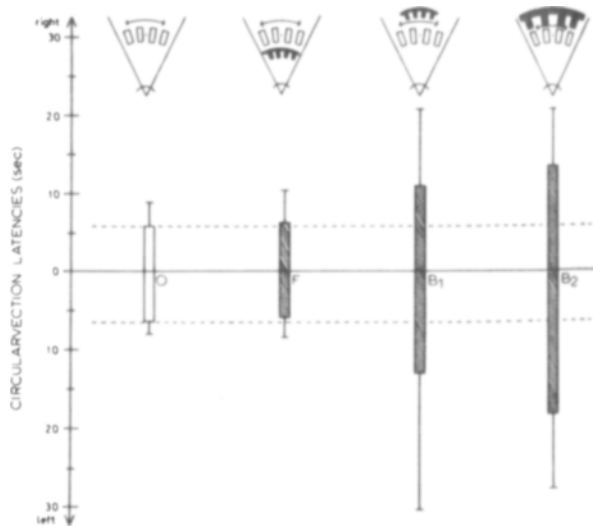


Figure 4. Mean latencies (bars) and standard deviations (solid lines) of circularvection onset for vertical stripes moving to the left or the right for the four different stimulus situations involving stationary contrasts. On abscissa: O = moving stripes only, in plane of screen; F = moving stripes in plane of screen with stationary foreground stripes; B_1 = moving stripes in plane of screen with stationary background stripes of same physical dimensions as in F; B_2 = moving stripes in plane of screen with stationary background stripes of same angular size as in F. CV latencies are maximal with the stationary background (B_1, B_2).

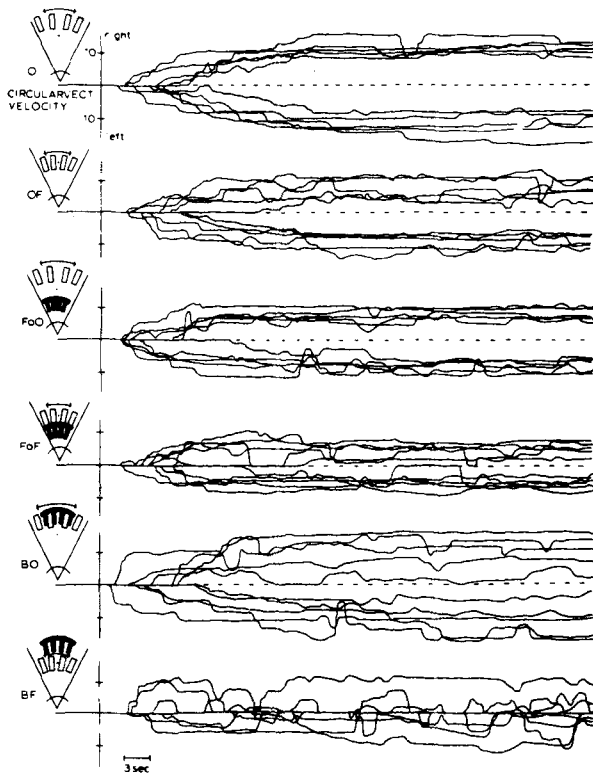


Figure 5. Individual records of continuous tracking of circular velocity with stripe movement to the left or to the right ($N = 5$). The stimulus conditions are depicted schematically at the left. Open bars in each symbol represent the moving stripes either in front of or in the plane of the screen, while the dark bars represent the stationary stripes in either the foreground or background. Condition O served as the standard situation in which the mean perceived velocity is indicated with an arbitrary value of 10. These records show that background information is critical in determining visually induced self-motion. CV is relatively stable over the entire 1-min stimulation period in the absence of stationary contrasts (O, OF) and even in the presence of a stationary foreground (F0O, F0F). However, if the stationary contrasts appear in the background (BF), CV is weak and unstable and frequently interrupted by periods of object-referred motion perception.

inhibition existed when the stationary contrasts were located in the background (BF) than when they were located in either the foreground (F0F) ($t = 2.90$, $df = 4$, $p < .05$) or in the plane of the moving stripes (BO) ($t = 3.12$, $df = 4$, $p < .05$). No significant difference in CV inhibition duration was found between Condition F0F, in which the stationary stripes appeared in the foreground, and Condition BO, in which they appeared in the plane of the moving stripes ($t = 1.36$, $df = 4$, n.s.).

A comparison of Conditions F0F and BF shows that the obtained inhibitory effect of the stationary background contrasts on CV was not a matter of the occlusion of moving by stationary stripes. This comparison makes clear that the occluding stationary stripes located in the foreground cause very little CV inhibition. In contrast, the stationary background, when passed and not occluded by the projected

moving pattern, produces marked CV inhibition. Finally, a comparison of BO and BF, in which the monocularly projected retinal images are identical, indicates that the *inhibitory effect is determined by the perceived depth interval between the moving and stationary contrasts*.

As can be seen from the individual tracking traces in Figure 5, the perceived velocity of CV decreases if the perceived distance of the moving stripes is decreased by use of the Pulfrich effect, although angular speed is held constant (O vs. OF). This finding confirms the results and conclusions of an earlier study (Wist, Diener, Dichgans, & Brandt, 1975), that linear rather than angular velocity is perceived.

DISCUSSION

In the present study, it was demonstrated that the magnitude of induced self motion as measured by tilt angle increases with an increase in the proportion of moving circles within the visual field. This relationship may not be simply a matter of the number (density) of moving contrasts, but might be also due to an increase of the total moving area, causing a summation of simultaneously excited movement-detecting receptive fields. An *area effect* has been previously obtained in experiments using restriction of coherent areas of the moving stimulus (Brandt, Dichgans, & Koenig, 1973; Held, Dichgans, & Bauer, 1975). The present results—although using a different stimulus display—closely correspond to the earlier findings, showing that the tilt effect increases linearly with a logarithmic increase of the total moving area. This correspondence, however, holds only up to a percentage of the total area of 30%. At this point, saturation was reached with the randomly distributed moving contrasts in our experiment. But this was not the case in the experiments of Held et al. (1975).

The important difference between the two experiments is that the latter involved annular displays, in which the highly structured stimulus area was confined to a specific location within the visual field. Within this area, the number of contrasts per unit area was held constant. In the present experiment, area was increased by augmenting the number of small discrete contrasts randomly distributed over the visual field. This procedure, besides stimulating a greater number of motion receptive fields within a given frame, possibly involves an additional mechanism different from the area effect: Increasing the proportion of moving contrasts in the visual field increases the density of the elements. Therefore, the results may also be due to a *spatial frequency effect*. Such an effect may be inferred from Brown's (1931) results, showing that moving detection thresholds are lowered as a function of increasing spatial frequency. A spatial frequency effect has also been shown to exist for subjective

velocity of object-referred motion (Diener, Wist, Dichgans, & Brandt, Note 1). A more precise specification of the relative contributions of stimulus area and the number of moving contrasts (spatial frequency) cannot be made on the basis of the present data.

The inhibitory effect of simultaneously presented stationary contrasts was expected. It simply reflects the two visual mechanisms of static and dynamic spatial orientation. In a normal environment, both mechanisms interact. The interaction, as has been shown, is determined by the proportional distribution of stationary and moving visual contrasts. Furthermore, in addition to this proportional distribution, spatial arrangement in depth is critical.

In accordance with the hypothesis presented in the introduction, background information is of greater significance than foreground information. Movement in the background induces apparent self-motion, while, if the foreground moves, the stationary background markedly inhibits CV. In the reversed condition, the stationary foreground causes much less inhibition of the background induced CV. Therefore, it is appropriate to extend the earlier findings of a dominance of the retinal periphery (Brandt, Dichgans, & Koenig, 1973; Dichgans & Brandt, 1974; Held, Dichgans, & Bauer, 1975) for induction of circularvection and tilt of perceived vertical to the third stimulus dimension: depth.

Consequently, visually induced self-motion and spatial orientation rely mainly on the information from the seen periphery, both the retinal and the depth periphery.

The existence of such a mechanism is obviously biologically adaptive. Self-motion should be perceived when sizable portions of the depth and/or retinal periphery are in motion, since this is the inevitable consequence of movement of the body in space, even if the foreground is stationary as in passive movement in a vehicle. Stationary contrasts in the retinal and depth periphery, with movement restricted to contrasts in the foreground, will normally exist when an object moves, and should thus be associated with object-motion perception. The foreground within the center of the visual field should typically be reserved for the observation and fixation of moving objects localized in body rather than external spatial coordinates, thus allowing for reaching and grasping as well as avoidance movements. Interesting in this regard is the observation made in the present study that stationary contrasts located in the foreground are perceived to move with the observer during CV, thus indicating a localization in terms of body coordinates. Fischer and Kornmüller (1930) also reported this phenomenon. This conceptual scheme implies, then,

that the two functions of *spatial localization* and *spatial orientation* are associated with different regions in space, the former mainly with the central foreground and the latter mainly with the retinal and depth periphery. Periphery-determined spatial orientation would appear to take advantage of the physical fact that the density per unit visual angle of objects in the background is greater than in the foreground (Texture gradient, Gibson, 1966), and consequently provides a larger and therefore more reliable sample of the visual surround.

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