CHAPTER 17

PERCEPTUAL ASPECTS OF MOTION IN THE FRONTAL PLANE

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1.1. Primary Sources of Information

The perception that an object is moving in the world is not a simple event and does not arise solely or even primarily from the motion of its image on the retina. There is, in fact, no necessary connection between image motion and seeing an object move. We may track an object in the world so that its image remains fixed and nevertheless see it move. Conversely, the image of a stationary object will move as our eyes move, and the object will appear stationary.

There are two major sets of determinants of perceived object motion, each of which belongs to a distinct and different perceptual category. One involves subject-relative sensory information, while the other is based on object-relative information. Subject-relative information is distinguished from object-relative information by the coordinate system. Subject-relative information is based on an egocentric coordinate system in which the head, retina, or torso serves as the frame of reference. Object-relative information refers to the extraretinal motion system in which one or more objects in the visual field serve as the frame of reference for another.

1.2. Subject-Relative Determinants

Subject-relative information, as defined above, specifies the relation between the aspect of the visual world and the head, for example, orientation with respect to the head or motion with respect to the head. Three main types of subject-relative information are referred to as absolute, egocentric, headcentric, or scalar (Gegel, 1977b; Howard, 1982; Mack, 1977; Rock, 1970; Wallach, 1976).

These labels are all equally apt as each refers to a distinctive characteristic. For example, these perspectives are egocentric, because the object is perceived in relation to the self. They are scalar or absolute if the observer permits judgments of how far, how fast, how much, and so on.

The sensory source of subject-relative information is twofold. It either refers to information about the absolute feature of the proximal stimulus, for example, visual angles, retinal orientation, retinal location or retinal displacement, and retinal movement. Alternatively, subjective determinants of the relevant aspect of the imaged object and the observer. This latter information is frequently but not necessarily nonvisual and headcentric (Gogel, 1977a), whereas nonvisual or extraretinal object motion it is invariably nonvisual and extraretinal.

The subject-relative determinants of object motion are retinal image motion and extraretinal image motion. These are the two most pertinent features of the retinal motion. Object-relative information permits only metric judgments, for example, faster than, more than, in a different direction from them. They are extraretinal if the observer perceives in relation to another object, not the self. They are configurational because they are based on information that is well-matched with the base object and based on form-like changes in the visual array. Gogel's principle of adjacency (1977a) states, "The effectiveness of relative cues decreases as the perceived distance between objects producing the relative cues increases." (pp. 162). This suggests a decrease in the probability that relative displacement between objects in the field will be the basis of perceived motion as the separation between objects increases.

Unlike subject-relative-based motion perception, object-relative motion perception is based on the displacement of retinal image motion. In the first case, in which the condition for object-relative motion perception exists, the conditions for motion perception based on egocentric, head-centric, or extraretinal motion are not met. In the second case, the conditions for object relative motion perception are met, but the motion of the object is unobtainable from the retinal image motion. This information necessarily coexists with the object's displacement. A characteristic aspect of object-relative motion information is that it provides no information about which object is moving, that is, the reference frame is the displacement of the observed object. Logically, a displacement between two objects might be the result of the motion of either or both objects. Since perceived motion based on object-relative information is frequently ambiguous, information specifying which object is moving must come from some other source. This other source is either subject-relative operation or head-centric motion. Therefore, we need to know whether there is any available information concerning which object is moving. We cannot determine whether there is any eye motion signal produced by the effort to move the immobilized eye, but there is no ion motion.

Gibson's view cannot account for other common observations. Why does an afterimage, a retinally stabilized visual array, or a single point moving in the dark and tracked by the eyes move together even though the eyes are not actively moving? The alternative view, which attributes the perceived object motion in each of these situations to the movement of the eye or image motion, seems to fit at all. These observations are easily accounted for by the alternative view. The perception of movement without an active eye is an illusion, and it is called the appearance of movement. The illusion is that there is eye motion signal from other sources. This other source is either subject-relative operation or head-centric motion. Therefore, we need to know whether there is any available information concerning which object is moving. We cannot determine whether there is any eye motion signal produced by the effort to move the immobilized eye, but there is no eye motion.
normal, richly patterned visual environment, which for Gibson is the only environment appropriate for the study of visual perception, relative retinal displacement is an invariant feature of object motion, while homogenous movement is an invariant feature of self motion. Empirical support for Gibson's analysis is provided by an experiment (Rock, 1968) in which observers were slowly and smoothly moved along a wall of a dark room. When the visual stimulus consisted of a series of small, widely spaced luminous discs, separated from each other by interposed shades so that only one disc was visible at a time, as observers were moved, the observers reported that the discs appeared to move. They did not perceive themselves as moving. However, when the wall was covered with a luminous, textured pattern, the observers no longer perceived the pattern as moving but experienced themselves as moving.

1.6. Subject- and Object-Relative Motion Thresholds

The subject-relative motion threshold refers to the limit of our sensitivity or ability to detect the motion of a single luminous object in an otherwise dark field. The object-relative threshold refers to the capacity to detect object motion when at least one other object is present in the field. Bonnet (1975, 1982) distinguishes between three kinds of motion display presentations which have differential effects on motion thresholds. These are continuous, discrete, and stop-go stop presentations. (Kaufman et al., 1971) also report threshold differences for discrete and continuous presentations. In this type of stimulus pattern, the light comes into view and disappears from view while moving and is never viewed in a stationary position. In a discrete presentation, the stimulus is presented at different positions in space separated by a temporal interval (phi motion). In a stop-go stop presentation the motion stimulus is viewed in a stationary position prior to and following the continuous motion.

Shaffer and Wallach (1966) measured the extent of motion threshold, how far a stimulus had to move for its motion to be reliably perceived. The median velocity was 1.3 m/s and the velocity was defined as the velocity that would be just perceived. The median threshold was 1.1 m/s. The highest velocity was 164 m/s, the median threshold was 1.1 m/s and at the median velocity, it was 2.4 m/s. At the lowest velocity, it was 4.4 m/s. When stimulus motion was objectrelative a stationary luminous disc was centered within the outline square. The median extent of motion threshold ranged from 1.0 m/s to 2.6 m/s, with the 1.1 m/s value being the most frequently used. Shaffer and Wallach report that at all velocities tested and for every subject, larger extents were needed to detect subject- objectrelative motion and this decrease differentiated as velocity increased.

The finding that the threshold for the detection of objectrelative motion is lower than the threshold for subject-relative motion is supported by the results of other investigators, for example, Kinchla (1971). F. Brown (1965a, 1988, Harvey and Kinchla, 1972, 1973, 1975, 1976, 1978, Lee, 1967, 1969), and Bonnet (1975) report that there are conditions in which there is no difference between subject- and objectrelative motion thresholds. Bonnet (1975) reports that, unlike Wallach, measured extent of motion thresholds, but, unlike Wallach, used a continuous motion display, reports that stationary reference lines do not lower threshold when the motion interval is short (less than 180 m/s) or when velocity is high. See Figure 17.1 (Bonnet, 1975), which shows the extent of motion illusions as a function of exposure time for four display conditions.

Leibowitz reports similar findings from an experiment in which he measured velocity thresholds, and background motion, for motion as a function of luminance, stationary references, and motion duration using a continuous motion display. He reports that the motion interval and short motion intervals (200 m/s) for subjectrelative references in the visual display did not alter the threshold, which ranged from 62.7 to 8.80 m/s, depending on the luminance of the stimulus and amount and prior practice. With a motion interval of 16.6 sec (the longest motion interval), Leibowitz found that stationary references lowered the threshold by about 48%. (See Figure 17.2.)

The fact that high-velocity, short-duration motions are not affected by stationary references, whereas slower motions over longer intervals alter, has led some investigators to postulate a phi-based or learning mechanism (Bonnet, 1975; R. H. Brown, 1965; Ekser, 1975, Leibowitz, 1965). According to one statement of this view, movementness that is distinguished from distraction detection results from a "single sensory event; such an event can be conceived of basically as a critical neural event (rate of firing or number of fibers) which makes the movementness detectors fire at a rate discriminable from their maintained rate of discharge" (Bonnet, 1975, pp. 36-37). The perceived motion of slower-moving stimuli viewed for a longer period, however, is influenced by the history of the stimulus. It seems that this depends on the processing of position information. If this were a correct description, it would follow that stationary reference would facilitate the latter and have no effect on the former.

Since many factors influence our sensitivity to motion, for example, size of the motion stimulus, size of the motion field, and amount of relative luminance of the motion stimulus and stimulus motion, and location of the retina stimulated, no precise general statements about either subject- or objectrelative motion sensitivity are possible. However, it is possible to conclude from the available data that when motion intervals are exceedingly brief or velocities are high, the presence of objectrelative displacement information increases sensitivity.

1.7. A Developmental Hypothesis about the Relation between Subject- and Object-Relative Motion

Wallach (1985) has argued that absolute image displacement is the ontogenetic starting point for perception of object relative motion. Perceived object motion based on the relative displacement between objects in the field on the basis of the pursuit of a moving object. The result of this associative learning process in which one stimulus comes to stand for another. Since every instance of objectrelative displacement is connected with a subjectrelative displacement and circular pursuit is normally elicited by image displacement, if neither pursuit nor relative displacement initially signal motion, they might come to be as a result of their consistent and automatic association with absolute image displacement. The same argument, of course, could be phrased in adaptive, evolutionary terms that would entail no assumptions about learning. The hypothesis that perceived motion based on objectrelative displacement...
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Sedgwick, & Festinger; 1978) or when the perceived target is presented anesthetic (Steinbach, 1970). Anesthetic perceivers of motion are those that remain with an eye or more closely defined in the immediate periphery of the stimulus. For instance, the observer perceives the figure passing behind the slit despite the fact that an observer perceives the figure's contours moving vertically within the slit. Evidence that observers can track an anesthetic stimulus (MacK, Fen- drich, & Wong, 1970; Steinbach, 1970) is consistent with the evidence indicating that perceiving motion governs only when the target has no conflicting retinal counterpart and that a smooth motion with the subject's relative information about image and motion information, is the principle determinant of smooth pursuit eye movements.

2.2. Perceived Displacements and Saccadic Eye Movements

Similar results have been obtained with saccadic eye movements. In one investigation of the effect of perceived displacement on saccades (Wong, 1981; Wong & Mack, 1981), a visual frame was used to direct the saccade to a target point. Observers were required to fixate the target point which was initially centered within a rectangular frame. Target and frame were blacked for a brief interval and then reappeared, the target for 100 msec, the frame for 500 msec. The reappearance of target and frame was the signal for the observer to remove the binocularly presented target. (The reactivation saccade, of course, generated no retinal error signal, since the target vanished before the saccade was executed.) Observers reported whether and by how much the target appeared to jump.

In every instance the saccade was directed to the actual, rather than perceived, position of the target. This supports a function of binocular position relative to the framing rectangle. Since actual position is signal by subject-relative information, that is, by eye position and retinal position information, it is clear that, as in the case of pursuit, it is this information that is critical to the ocuomat orientation systems.

Evidence from the work of other investigators confirms this. It is known that saccadic and pursuit responses, in an experiment examining the ability to point to the position of a target displaced near the time of a saccade, the investigators found pointing was as accurate when the target was displaced as when it was correctly reported (Bridgeman, Lewis, Holt, & Nagle, 1979).

In another experiment (Hansen, 1970) a bistatic-orienting act (stirking a target with a hammer) was accurately performed even under conditions that led to significant misperception of target position, for example, when a form was presented in an environment in which a moving stimulus was being tracked. In this experiment the observer tracked a small projected spot in the dark. During a period of accurate tracking, a second spot was flashed. The observer's task was to hit this second spot with a hammer. The speed of the tracking stimulus ranged from 15 to 1800 min arc.

2.3. Perception of Motion and Position and Other Orienting Responses

There is some evidence that subject-relative motion and position information are the principal determinants of pointing and other related orienting responses. In an experiment examining the ability to point to the position of a target displaced near the time of a saccade, the investigators found pointing was as accurate when the target was displaced as when it was correctly reported (Bridgeman, Lewis, Holt, & Nagle, 1979).
with results reported by Sugerman and Cohen (1968), Farber (1979), and Bacon, Gordon, and Schulman (1982). These studies indicate that observers’ pointing or manually tracking is sig-
ificantly reduced when induced motion is present, as observers respond to apparent, rather than actual, target position or motion. The reason for this discrepancy is not clear although it is possible, as Bridgeham and coworkers suggest, that the observers in the Farber study, the Sugerman and Cohen studies, and the Bacon study might have been confronted with a conflict, the response to the apparent target position or to pointing to induced motion. Perhaps if observers are asked to report perceived induced motion at the same time they are required to report upon the target, they will point to or track in a way that is consistent with the perceptual report. Not to do so would be to appear self-con-
tradictory in the sense that the observers must make clear the following target presentation and was the only response required of the subject. Psychophysical measures of perceived induced motion or displacement were obtained prior to trials in which pointing responses were made. This was not the case in the Farber study or Bacon study. It ought to be noted, however, that Bridgerman and coworkers’ presentation did not specifically ask for perceived induced motion. The induced target motion ranged from 14 to 21% of complete in-
duction. It is therefore possible that the Bridgerman and co-
workers findings simply reflect the weakness of the induction.

Further work is required to explain these differences in results.

3. PERCEIVED MOTION AND OBSERVER MOTION: SUBJECT-RELATIVE PHENOMENA

Since information about eye and head motion and position is the principle factor in the subject-relative determination of perceived motion and position, it follows that the observer’s relative retinal motion and position accurately during intervals in which our eyes and/or head is moving must depend both on the accuracy of the sensory systems and on the precision with which it is matched against image position and motion signals. Inaccuracies in extraretinal information or inaccuracies in the transformation of retinal motion, in situations in which perception is based on this information. How are we at perceiving whether something is moving or stationary when we are moving our eyes and/or our heads?

3.1. Head Movement: Perceived Motion and Position

Head movements, like eye movements, cause relative displacement between the environment and the eyes or head. These movements are indistinguishable from those caused by actual motion of a target in the environment. (As noted previously, head rotations do not necessarily cause image motions since head rotation generally results in steady visual-motion.) Fortunately, these frequently indistinguishable events have quite different perceptual consequences. Field motions caused by our own movements are, therefore, generally not noticed. They are not perceived unless they produce a conflict with the perceived motion of the environment. Thus, it is not surprising that a mismatch of apparent and actual head motion or head rotations produces a high degree of the target detected and motion and rotations that are processed together at least one other group of investigators (Stark, Knight, Schwart, Hendrey, & Bridgeham, 1976).

3.2. Saccadic Eye Movements: Perceived Motion and Stability

Our ability to detect object motion during a saccade, while less good than during head rotation, is nevertheless considerable, and the relevant data show that a saccade can be a simple and complete suppression of image displacement during saccades. (Data reported by Wallach & Lewis, 1966, might be considered as evidence that the eyes are not representative and may not have been replicated.) Like work on position constancy during head rotation, this research also suggests that saccades are a necessary mechanism for relieving the conflict between the perceived motion and actual motion of a retinal target, and for discerning the relationship between extraretinal observer movement information and retinal motion. A match between the target stimulus and the visual stimulus is all that is necessary. The amplitude of target displacement increased, so did the probability of its being reported. The reported motion of this experiment appears in Figure 17.6.

In another study (Bridgeham, Hendrey, & Stark, 1975) the investigators failed to find any effect of direction of target displacement relative to direction of saccades, which is consistent with the findings of Mack (1970). What they did find was that the absolute size of the error between saccade and retinal translation was more important than the direction of the error in accounting for target displacement. A saccade-size factor in determining whether target motion was detected was the size of the displacement relative to the size of the saccade. In general, target displacement less than one-third of the saccade amplitude were not reliably detected. This means, of course, that a small displacement is more likely to be detected during a saccade than during a large saccade. The investigators again found maximum suppression of target displacements around the time of saccade onset. Figure 17.7 presents these results.

Whipple and Wallach (1978) report the only data indicating that the motion detection threshold during saccades is affected by the direction of target displacement. These results were reported in Figure 17.5. These investigators report that threshold was lower when saccade and stimulus displacement occurred along the same axis if the saccade is either horizontal or vertical. When a horizontal saccade was accompanied by horizontal stimulus displacement, the 80% threshold occurred when the target displacement was 8.2% of the saccade displacement. In the case of vertical saccades and vertical target displacement, the 80% threshold occurred when the target displacement was 9.5% of the saccade displacement. These results are substantially lower than those reported by Mack (1970) and Bridgeham, Hendrey, and Stark (1975). When the axis of stimulus and saccade displace-

ments were orthogonal, thresholds were 12.7% and 26.3%. With oblique saccades and congruent image displacement an even more dramatic threshold elevation was obtained. The reason for such a large discrepancy between these results and those ob-
tained by others is not clear.

These data indicate that while our capacity to detect object motion during a saccade is less good during a saccade, the threshold for detecting motion during a saccade or during fixation, it is nevertheless considerable. Since the only information that permits the visual system to distinguish between a saccade and retinal motion is the eye and image motion information, the fact that we are able to distinguish between the two is evidence that the match between the observed motion and the perceived motion constitutes a source of perceived motion and stability.

Bridgeham and colleagues (1975) have pointed out that the evidence indicates that the match between target motion is imprecise may reveal nothing about the quality of the extra-
retinal eye position information. It may only reflect the degraded quality of some, or all, of the information available during saccades caused by saccadic suppression. With degraded image displacement information, the match between eye and image motion could not be precise so that some target motion necessarily might be un detects. This speculation remains to be investigated.

3.3. Pursuit Eye Movements: Perceived Motion and Stability

While the raised threshold for the detection of object motion during saccades could possibly be attributed to degraded retinal information, differences in the perception of motion and stability during pursuit have generally been attributed to the degraded
quality of the eye motion information. An extreme and early version of this view was stated by Dodge (1904) who argued that the perceptual system receives no information at all about the pursuit movements of the eye and consequently a moving target would not appear to be moving. Dodge attempted to validate this conclusion by the report that an intermittently luminous point, flashed while the observer fixated his or her head slowly from side to side, does not appear to move. Dodge purposely chose a compensatory pursuit movement, rather than pursuit elicited by a slowly moving target, to eliminate any gaze signal that normally precedes the initiation of "voluntary" pursuit, which he believed to be the sole source of motion information during pursuit.

The stimulus conditions were, however, ill chosen. Dodge managed to create a situation in which, given the appropriate head and eye movement information, position constancy ought to prevail. The fact that his observers reported that the fixated stimulus was stationary then could either reflect what Dodge thought it reflected, the absence of any pursuit eye movement information or, more likely, the operation of a position constancy process involving eye and head motion information. In fact, we know from Wallach's work on the constancy of visuospatial direction that there is a high degree of constancy during head rotation. Furthermore, a study, which examined perceived stability during intervals in which an observer rotated his or her head from side to side while fixating a stationary stimulus, yielded results demonstrating that only at the point at which compensatory eye movements are no longer possible, because of the extremeness of the head turn, does a stationary target suddenly appear to lurch with the head (Mack, Hendrich, & Fisher, 1974). It would appear therefore that Dodge's demonstration not only fails to support his claim but supports an opposite one.

There are a number of both early and recent studies relevant to the issue of perceived motion and stability during pursuit. Filene (1922) reported that stationary objects whose images are caused to displace over the retina, when the eyes track a moving object, appear to move. This apparent failure of position constancy is now known as the Filene illusion (Stoper, 1967). Filene reported not only that stationary background objects appeared to move but that the apparent velocity of the pursued stimulus was half of its objective velocity. This underestimation of target velocity during pursuit was reported by Flechner (1882) and is known as the Asbert-Flieschparadigm. Filene believed that both the loss of position constancy for background objects and the underestimation of pursuit stimulus velocity resulted from the fact that the objective motion of the target was shared equally between background and target; that is, the target appeared to move at one-half its objective velocity while the background moved at the same velocity in the opposite direction. Both the Filene illusion and the Asbert-Flieschparadigm point to disturbances in the perception of motion and rest during pursuit.

The Filene illusion has been attributed to the fact that the perceptual system fails to evaluate image displacements of the nontracked objects in terms of pursuit eye movement information, although this information is assumed to add to or account for motion of the tracked, retinally stable stimulus (Stoper, 1967, 1973). This is a modified version of the Dodge hypothesis. The Filene illusion has also been attributed to an underregistration of pursuit eye movement velocity and to the salience of the relative displacement between tracked and background objects when they are adjacent (Mack & Herman, 1973, 1978).

Stoper (1967, 1973) reports that the perception of stroboscopic motion during pursuit depends on the stimulation of two separate retinal loci, which distinguishes stroboscopic motion during pursuit from stroboscopic motion during saccades. Stroboscopic motion during saccades has been found to depend on stimulation from two apparently different locations in space (Rok & Ebenholtz, 1962). In both the Rock and Ebenholtz and the Stoper studies actual spatial location was isolated from retinal location. In Stoper's study, modeled on Rock and Ebenholtz, two points were successively flashed while the observer pursued a moving target. If the flashes emanated from two different places in space but fell on the same retinal position, no stroboscopic motion was reported. If the flashes emanated from the same point in space but stimulated different retinal positions, stroboscopic motion was likely to be reported. These data were the primary grounds for Stoper's conclusion that the extraretinal signal is not used in evaluating image displacements.

In another study (Stoper, 1967) that examined perceived position during pursuit, the data revealed increasing position constancy with increasing separation between judged target and tracking stimulus, or, with what amounted to the same thing, increasing time between the presentation of the two stimuli whose positions were being reported. During tracking, observers judged whether a second flashed stimulus appeared to the left or right of one presented earlier. With an interstimulus interval of 75 ms, the position constancy was 76%, whereas it was only 36.2% when the interstimulus interval was 175 ms.

Two other experiments examining the Filene illusion support a different account of perceived position and motion during pursuit (Mack & Herman, 1973, 1978; see also Festinger, Sodgwick, & Holzman, 1970). In both these studies the point of subjective stability (PSS) for background stimuli was determined during intervals in which the observer tracked a moving stimulus and the corresponding target object was stationary. A flash stimulated the eye moving object, appear to move. This apparent failure of position constancy is now known as the Filene illusion (Stoper, 1967). Filene reported not only that stationary background objects appeared to move but that the apparent velocity of the pursued stimulus was half of its objective velocity. This underestimation of target velocity during pursuit was reported by Flechner (1882) and is known as the Asbert-Flieschparadigm. Filene believed that both the loss of position constancy for background objects and the underestimation of pursuit stimulus velocity resulted from the fact that the objective motion of the target was shared equally between background and target; that is, the target appeared to move at one-half its objective velocity while the background moved at the same velocity in the opposite direction. Both the Filene illusion and the Asbert-Flieschparadigm point to disturbances in the perception of motion and rest during pursuit.

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Figure 17.9: Position constancy loss for single background stimulus during pursuit of a moving target. Data are based on the mean of six observers. A 0.3° stimulus was presented on a CRT screen (P 15) moved from left to right at 5/sec over a 15° path. This was the pursuit target. When the target reached the middle of its path, a background stimulus appeared and was aligned with the pursuit target. The background stimulus was visible for either 0.2 sec (brief interval) or 1.2 sec (long interval) and moved either left or right at a velocity of 0.57/sec. Eye movements were monitored by two SR Double Purkinje Image Eye Trackers. Observers reported whether the background stimulus moved left, right, or was stationary. In trials in which the background was stationary, it appeared to be moving, and the eye movements to be pursuit target on 64% of the trials with long exposure and on 58% of the trials with brief exposure. The mean background velocity judged stationary in the long interval condition was 0.17/sec in the same direction as the pursuit target, while in the brief condition it was 3.35/sec. In a follow-up experiment brief exposure with invisible tracking target, the background stimulus was presented during a 0.2 sec interval, during which the observer tracked in the absence of a visible target. Under these conditions the stationary background appeared to move on 67% of the trials and had to move 0.79/sec in the direction of the pursuit eye movement to appear stationary. (From A. Mack & E. Herman, The loss of position constancy during pursuit eye movements, Vision Research, 1978. Copyright 1978 by Pergamon Press, Ltd. Reprinted with permission.)

Figure 17.8: Direction-specific motion thresholds for abnormal image shifts during a saccade. Percentage correct identification of target motion directions as a function of displacement ratio (DR) for nine conditions of eye movement and target movement directions. Crosses represent data from Mack’s (1970) experiment; squares, the 80% thresholds. A ring in diameter displayed on a CRT screen was moved during a saccadic eye movement. Thresholds were low when both the eye and target moved horizontally or vertically. Thresholds increased by a factor of 2 or more when the axis of target motion differed from that of the eye movement (from Whitaker & McWhirter, 1970). Direction-specific motion thresholds for abnormal image shifts during saccadic eye movements, Perception and Psychophysics, 1978. 24. Reprinted with permission.)

nailing procedure was used. The longer background presentation yielded a position constancy loss of 19%. Brief exposure of the background, however, yielded a 67% loss of constancy, which was comparable to the large loss reported by Stoper. These results are summarized in Figure 17.9.

The difference between these two conditions was attributed to the difference in the perceptual salience of the relative displacement between background and target in the two conditions. In both conditions the background stimulus first appeared aligned with the tracking target and, in the brief presentation, was observed only while adjacent to the tracking target. With longer presentations there was increasing separation between background and target, reducing the salience of the relative displacement, with the result that perceived position in-creasingly became a function of the relationship between eye and image motion information. When the relative displacement between tracking target and background stimulus was salient, it led to perceived background motion.

This explanation received strong support from data showing only a small position constancy loss during an interval in which the observer tracked an "invisible" target, as compared to the loss when the tracking target was visible. In both cases the background stimulus was present for only the brief interval, but when the tracking target was invisible, there, of course, could be no displacement between it and the background stim-u-lus.

These results suggested a two-factor explanation of the disruption of perceived motion and position during pursuit. One factor, which accounts for the modest loss of position constancy, is the underregistration of pursuit velocity. This underreg-istration is the basis for, and evidenced by, the Aubert-Fleischl paradox, the apparent slowing of a tracked target. If pursuit velocity is underregistered, stationary objects, viewed during pursuit should appear to move against the direction of pursuit by almost as much as the velocity is underregistered, assuming, of course, that the match between image and eye motion infor-mation is the basis of perceived motion or stability. The second factor, which seems to be responsible for the large loss of position constancy, is the salience of the relative displacement between target and background when the two are adjacent.

Evidence for an unrelated phenomenon comes from several sources. Mack and Herman (1973) found a high degree of correlation between the magnitude of the position constancy loss for background stimuli and the magnitude of the apparent slowing (Aubert-Fleischl paradox) of a tracked target, which was about 12%. Dicke, Koenen, and Voigt (1969) found that the perceived speed of a smoothly tracked target is 63% of its perceived speed when the eye is stationary. J. F. Brown (1981a) reports a ratio of 1.43 between perceived tracked and untracked target speed. Under somewhat different conditions Festinger, Sedgwick, and Holtzman (1976) found a far greater underestimation of velocity. Their data led them to conclude that the perceptual system has only poor information about pursuit. It has information that the eye is moving and its direction of motion. The system then inputs some low value for the speed of motion. In another careful study Miller (1980) reports that repetitive pursuit, pursuit of a target oscillating sinusoidally at 0.33 Hz, produces a 30% underregistration of pursuit amplitude, whereas nonrepetitive pursuit, pursuit of a target moving sinusoidally through only one half-cycle, causes an 11% underestimation. The difference between the results of various investigations may be accounted for by Miller’s findings about the difference between repetitive and nonrepe-titive pursuit.

There is reason to conclude from the evidence reviewed that the perception of motion and position during pursuit is determined by both object- and subject-relative factors, and characteristically when the object-relative information is salient, it appears to mask or inhibit the subject-relative information if they conflict.

3.4. Motion Illusions and Pursuit Eye Movements

Correlative with the effects of eye movements on the detection of object motion and rest are a set of illusory motion phenomena associated with pursuit. The fact that these illusions are asso-ciated with pursuit, rather than with saccades, may reflect the difference in the source of the disruption of motion perception during these two kinds of eye movements. Two of these illusions have been discussed in Section 3.3, namely, the Filene and the Aubert-Fleischl Illusions.

3.4.1. Motion of the Afterimage. An afterimage or sta-bilized retinal image viewed in an otherwise dark field will appear to move if the observer engages in smooth pursuit eye movements during its observation (Heywood & Churcher, 1971; Klimberries & Taunzer, 1972; Mack & Bachant, 1969; Yashai & Young, 1975). Apart from the question of what stimulated pursuit in this situation, the phenomenon itself attests to the partici-pation of pursuit eye movement information. It seems likely that the only reason that stabilized image appears to move when we move our eyes is that there is eye movement information that is not canceled by the appropriate retinal displacement information. In this sense, the relative displacement. Furthermore, there is evidence that the perceived motion of the afterimage parallels the eye movement (Mack & Bachant, 1969). Saccades occur in an afterimage; they generate a perceived displacement, which is most likely retinocentric in character because of the speed of the eye movement.

3.4.2. Perceived Motion of Random Dynamic Noise and Pur-suit. Ward and Morgan (1978) report that if observers engage in smooth pursuit while viewing a dynamic random noise pat-tern, they will perceive a "vaguely defined area of the field . . . detach itself from the background and move back and forth across the display with the eyes" (p. 158). As soon as the observer ceases to track, the target disappears. The investigators attribute this phenomenon to the same factors responsible for the perceived motion of an accurately tracked moving stimulus or an afterimage. "The movement of the eye field is then the result of the movement of the retinas thereby producing the same feedback as that obtained when the eye tracks a real moving target" (p. 159). Again the absence of retinal displacement information in the presence of pursuit eye movement generates an illusory perception of motion that,
information when the tracking stimulus is all that is visible, as is the case in these studies. Data showing that the underestimation of extent is highly correlated with the underestimation of velocity (Mack and Herman, 1972). If, as seems likely, the extraretinal signal associated with pursuit encodes rate and direction of motion, rather than position, then when a single moving object is present it is difficult to understand how an otherwise homogeneous fluid, information about tracked distances must be derived from velocity information and, if it is under- estimated,amped with pursuit, overestimated.

3.4.5. Shape of Motion Path and Pursuit. Havasdi (1971) reports that the diameter of the perceived path of a tracked spot described in a circle is underestimated and the shape of the motion path is distorted to an ellipse or shrinking spiral. Rotational speeds between 0.2 and 1 Hz were tested. The rate of speed was manipulated underestimation decreased as velocity increased, and the diameter of the apparent path decreased as the number of rotations of the spot increased. Judgments following observation of one rotation decreased apparent diameter by about 50%, while judgments following observation of ten rotations reduced apparent diameter by 70%. Eye movements were not made at a constant velocity, it is difficult to determine to what extent these path distortions are a function of pursuit eye movements. Another investigation of the perceived distortions associated with tracking a circularly moving spot, which included ocular cinematography monitoring and a motion signal which different results (Coren, Bradley, Hoegen, & Gilgus, 1975). The visual angle was held constant between 0.18 and 5.2 Hz. The diameter of the apparent path was increased 20%. The investigators report virtually no underestimation of diameter at the faster speeds, underestimation of velocity and maximum underestimation, which was about 40% at 0.18 Hz. With faster rotational velocities, apparent diameter intercepts the visual field at higher velocity, and at the fastest velocities, no distortions were reported. Additionally, the shape of the apparent path, no distortions occurred. The eye movement record reaveals that accurate tracking at the slowest velocities. As velocity increased, the underestimation of velocity increased, and the size of the apparent path decreased, until at the fastest velocity, tracking was accomplished by eccentric eye movements only. At the rotational velocities which produced maximum underestimation for less than 60% of the eye motion (the remaining involved saccades). The data also revealed that the diameter of the tracked path decreased as velocity increased. Underestimation of rotational velocity of 1.73 Hz, the diameter of the tracked path was only 40% of the diameter of the actual path. The investigators conclude that it is only the "path the eye smoothly tracks (which is utilized in the perceptual computation of path diameter)" (p. 53) which is underestimation based on the assumption that the principal function of smooth eye movements is to follow the object as is the system is relatively insensitive to retinal error information before threshold)". This reasoning is at odds with the view that pursuit velocity is consistently underestimated, and the data showing no underestimation of perceived path diameter at the lowest rotational velocities are discordant with the underestimation of the velocity and extent of motion reported by other researchers (Abbert, 1988; Drigans et al., 1969; Mack and Herman, 1972; Millar, 1980). The reasons for this discrepancy are not obvious.

3.4.6. Further reports of distortions of motion path during pursuit. Fujii (1948) noted that the apparent motion path in which the path of a point moving about the perimeter of a square, a circle, or a triangle is misperceived. Feinger and Eason (1974) refer to this as the Fuji illusion in a paper reporting the results of an investigation of these phenomena. Feinger and Eason examined the Fuji illusion while simultaneously recording eye movements. The observed target traveled along a square path at uniform speeds of 3 and 18 Hz. A pair of eye records revealed that the eye never accurately tracks the spot as it turns the corners of the square. Although the spot changes direction abruptly, the eye moves smoothly without blinking, and is held steady for a period in the direction of the previous motion. The inves- tigators note that during these intervals, the motion of the spot on the retina would be "an indentation from the corner", similar to what is reported perceptually" (p. 52). If the assumption is made that information about pursuit is based solely on the effenter signal to the eye muscles and that the effenter command to the eye differs from the actual path of the target, perhaps the closeness of the target to the eye, movement information will fail to match the retinal image motion, and the perceived distortion occurs. Figure 17.11 illustrates the typical distortion observed by these investigators when the tracked point described a square. The same argument was employed earlier to account for a different but related illusion associated with pursuit (Mack, Feinger, & Strigatti, 1973). If a target moving at a constant velocity is tracked by the eyes and comes to an abrupt stop, it will appear to rebound sharply backward. Investigation of this rebound illusion revealed that the eye continues to track, that is, overshoots the target, at the point at which the target stops abruptly. If we again assume that the information about eye movement is based solely on the effenter command signal to the extraocular muscles and that the effenter system signals the eye to stop at the moment the target stops, then there would be no information about the overshoot of the extraocular muscle system. Because the eye continues to move after the target has stopped, its image displaces on the retina, and in the absence of the appropriate eye movement information, this image displacement results in the perceived rebound of the target. Experimental support for this reasoning was provided by data obtained in the study referred to by Strigatti et al. (1968). An opaque black screen with a narrow vertical aperture was moved over a luminous curved line, revealing the contour as it moved. The observers were instructed to monitor the image of the slit or fixated a stationary luminous point; next they matched the shape of the figure, revealed through the slit, to a figure presented on an adjacent screen. The speed of the slit was frequent in both conditions, and there were no differences between fixation and pursuit. It is possible that this failure to increase the speed of the slit was due to the nature of the task, but it may have been due to the matching technique, which may have been insensitive to relatively subtle path distortions.

3.4.6. The Pendular-Whipshak Illusion. If one of two lumi- nos points at opposite ends and equidistant from the center of a counterbalanced, swinging pendulum is tracked, appears to move in the direction opposite to the direction of the untracked point. Furthermore, at the extremes positions, the tracked point may stop while the untracked one continues to move (whippal)". This perception occurs despite the fact that points equidistant from the center of rotation of a pendulum move through equal arc at equal velocities. The phenomenon was first reported by Dodge (1904) and subsequently labeled the pendular- whipshak illusion by Carr (1907), in a paper reporting the outcome of an investigation of the illusion. At the extremes positions the pendulum was described as "pendular" (Ford, 1910). More recent studies have not been published. Dodge (1904, 1910) took the illusion as evidence for the "utter insensitivity of the eye to the perception of motion of the fixated point or to correct the ex- aggerated data from the displacement of the retinal image of the non-fixated point". In an effort to clarify this concept and confirm the explanation, having to do with the afterimages generated by the tracked and untracked points, which is sufficient untestable to be ignored. Ford (1910) reported that the nontracked target appears to move about twice as far as the tracked target and faster, but no velocity data were reported. He attributed the illusion to attentional factors, an explanation not well supported by his findings. The illusion is another instance of a motion distortion associated with pursuit, and as such was the subject of an un- published series of experiments in our laboratory. In most of these experiments, pendulum motion was simulated on a fast phase film. Light from a lamp was swept sidewise from left to right out of phase at 0.5 Hz. Eye movements were monitored. The tracked stimulus moved through an angle of 2°, while the untracked stimulus could be moved through a variable angular distance ranging from 0 to 2° in steps of 0.17°. The point of subjective equality (PSE) for the extent of motion of the tracked and untracked points was established by varying the distance through which the untracked point moved. In another experiment the observers also reported the apparent motion of the track point, which was obtained by adjusting the distance between two horizontally separated points presented at the end of each trial (see Figure 17.12). The point of subjective equality for the extent of the motion through equal distances, when the untracked point traveled through 46° of the distance actually traveled by the tracked point. The illusion obtained in the second experiment was even
larger. The two points appeared to move through equal distance when the untracked point moved through only 33% of the distance of the tracked point. (Two of the four observers in the second experiment were highly practiced in pursuit, which may have accounted for the increment in the illusion.) The mean underestimation of the distance through which the tracked point moved was relatively small, less than 12%, which was also true for the other observers. This suggests that the basis of the underestimation of motion was measured. The mean overestimation of the distance through which the untracked point moved, however, was quite large (46±10%). It is possible that in true or in other experiments. Clearly there was no parallax between perceived overestimation and underestimation of path length. Overestimation was greatest when the untracked point was actually stationary.

These data suggest that this illusion cannot be accounted for only by the registration of duration of visual sensation, for if this were the case, either the underestimation would have had to be greater or the overestimation smaller. Since the variation in intensity of visual sensation was small, it is unlikely that those which produced the illusory motion in both (in either case) the untracked and untracked stimulus, and in both perceived motion is added and subtracted to the estimated distance. It is therefore possible that the two illusions have similar causes. If so, the underestimation of the perceived intensity and velocity of the tracker's point is capable of being accounted for by the illusion itself. The overestimation of velocity of the untracked stimulus would be a function of the stimulus and its distance from the tracker. The finding that the illusion overestimation of movement path is greatest when the untracked stimulus is stationary supports this analysis, since it is consistent with the finding that the eye moves most adjacent to the tracked point in this location. Although nothing in the data is inconsistent with this explanation, further work is necessary to confirm this conclusion.

SPICE AND MOTION PERCEPTION

The perception of objects in space involves the use of various cues, including light, color, and texture. The study of these cues is important for understanding how we perceive the world around us. This paper presents an analysis of the factors that influence the perception of objects in space, focusing on the role of light and color.

The perception of objects in space is a complex process that involves the interaction of multiple sensory systems. The study of these systems is important for understanding how we perceive the world around us. This paper presents an analysis of the factors that influence the perception of objects in space, focusing on the role of light and color.

Large objects move more slowly than small objects. For example, a large object moving at a constant velocity will appear to move more slowly than a small object moving at the same velocity. This effect is known as the size-velocity illusion. The size-velocity illusion has been studied extensively in psychology and has been found to be present in both young and old adults.

However, the size-velocity illusion is not the only factor that influences the perception of objects in space. Other factors, such as the orientation of the object and the distance of the object from the observer, also play a role. For example, an object that is oriented in a vertical direction will appear to move more slowly than an object that is oriented in a horizontal direction. Similarly, an object that is closer to the observer will appear to move more slowly than an object that is further away.

These factors interact in complex ways to influence the perception of objects in space. The study of these interactions is important for understanding how we perceive the world around us. This paper presents an analysis of the factors that influence the perception of objects in space, focusing on the role of light and color.

Perceptual Aspects of Motion in the Frontal Plane

Involuntary drifts of the eye that occur during fixation, fixation nystagmus (Hoppe, 1979; Matin & McKinnon, 1964; Vaesen, 1976). The principal support for this view is the finding that voluntary control over eye movements along the horizontal or vertical axis decreases reports of horizontal kinetic motion (Matin & McKinnon, 1964); that is, eliminating horizontal image displacement produces a temporal eye drift to be reported of horizontal drifts. This explanation of the illusion faces some difficulties, however. First, the involuntary drifts seem to be small spontaneous fixations or drifts, which are interrupted by corrective saccades, produce the appearance of smooth and continuous motion. Furthermore, since these drifts tend to be both horizontal and vertical, it is possible that what is reported as a drift in a particular direction is merely a combination of horizontal and vertical drifts. This is suggested by the fact that, particularly when the target is in the median plane, it is necessary to assume not only that the slow phase of the nystagmus is unregulated but that a small image displacement, less than 50 sec arc, is engendered by these slow drifts mediate the perception of motion over quite large extents (between 2 and 30). The report that a field is a motionless and stationary field is a result of two factors. First, Gregory & Zangwill (1963, 1965) simply cannot be explained at all by this hypothesis. Recent data collected in our laboratory involving stabilization of an autokinetic target in either the horizontal or vertical axis or both fail to confirm the data reported by Matin & McKinnon (1964). On the contrary, as one drifts, one is faced with the necessity of establishing in the stabilized target, which is consistent with the view that any motion in that direction should generate perceived motion because that motion is maintained by the eye itself, in which, in any case, one tends to elicit further eye movement in that direction, and so on. Since this work is still in progress and the methods of stabilizing motion are not yet mature, the results obtained by the investigators, more work is needed to resolve the discrepancy in the findings. They are mentioned here only because this is, to our knowledge, the first attempt to replicate these important results.

Another general account of AMK, which implicates eye movements, is a spatially specific misregistration of eye movements (eye movement) signal associated with the control of the extracapsular muscle. While the previous explanation rests on retinal misregistration, the spatially specific misregistration is one of the eye, this explanation rests on the efferent command signal necessary to maintain stable fixation, which is generally not associated with any actual eye movement. Thus, both the retinal and the Helmholzian or von Holstian assumption that object motion is perceived when there is a mismatch between image and eye motion signals. They differ only in their assumptions about the source of the mismatch. Matin & McKinnon attribute it to the absence of an efferent signal; Gregory and Zangwill to the apparent drifts of the object. A clear separation between the reports of this account of the illusion first proposed by Carr (1907) can be found in Gregory and Zangwill (1965). Any differential fatigue (or imbalance of the eye muscles) necessitates alterations in the command signals to maintain fixation. Since these signals serve to keep the eye still, they are unaccompanied by image displacement. If either target object is moved following a period of extreme fixation, Gregory and Zangwill found that observation of a centrally located target light leads to an apparent movement of the light in the opposite direction of the ocular deviation. This supports their view.

A third account of AMK does not relate it to the eye motion signals and attributes it to apparent shifts in egocentric position that are assumed to occur spontaneously when an object is placed in a dark environment. For whatever reason, the observer experiences such a shift in position while viewing a stationary light point, the light must appear to move (Duncker, 1969). This account suggests that the observer experiences a direct movement of the eye, which is the ultimate target of the light to move. Duncker's (1969) classic paper on induced motion not only contains this observation but is rich in sources of information about the mechanisms of induced motion. This is the simplest case of induced motion. If the motion of the displacing stimulus is below the server is placed in a dark environment. If for whatever reason, the observer experiences such a shift in position while viewing a stationary light point, the light must appear to move (Duncker, 1969). This account suggests that the observer experiences a direct movement of the eye, which is the ultimate target of the light to move. Duncker's (1969) classic paper on induced motion not only contains this observation but is rich in sources of information about the mechanisms of induced motion. This is the simplest case of induced motion. If the motion of the displacing stimulus is below the

4. OBJECT-RELATED MOTION PERCEPTION

Induced motion is the principal exemplar of perceived motion based on object-related motion information. It depends for its perception on the special viewing conditions that are present in the visual field, one of which moves. The displacement of one object relative to the other is the source of the motion percept. It is the subjective aspect of motion and is not based on the display arrangement. The display is viewed in an otherwise homogeneous field.

4.1. Two-Point Induced Motion

When the field contains only two points of light, one of which is moving, an observer perceives one of the points to move. Duncker's (1929) classic paper on induced motion not only contains this observation but is rich in sources of information about the mechanisms of induced motion. This is the simplest case of induced motion. If the motion of the displacing stimulus is below the
absolute motion threshold, then either or both stimuli may appear to move, and the direction of the perceived motion will be a function of the relative displacement between them. Duncker believed that when the motion of the moving point in this situation was below the subject-relative (absolute) motion threshold, the point fixated would most likely carry the perceived direction. A recent examination of two-point induced motion (Mack, Hendrich, & Fisher, 1979), however, failed to confirm this. The fixated and nonfixated and the moving and stationary stimuli were equally likely to appear moving. This was true when stimulus motion was below threshold as well as when stimulus motion was present. In all cases observers correctly reported the direction of relative displacement between stimuli. Thus if the point on the left moved right and motion was attributed to the right point, it appeared to move left. If the point on the left moved left, the point on the right appeared to move right.

4.2. Center-Surround Induced Motion

If instead of two points, one of the two stimuli in the field is large and encloses the other, then regardless of which stimulus actually moves, only the enclosed stimulus will appear to move if stimulus motion is near or below threshold. Figure 17.13 pictures a typical center-surround induced motion display. If stimulus motion is clearly above threshold and it is the surrounding stimulus that moves, both center and surround may appear to move. The tendency to perceive the large, surrounding stimulus as stationary and the enclosed, smaller stimulus as moving, which occurs in this display, is generally considered an organizing principle that permits perception. The enclosing stimulus acts as the frame of reference for the smaller, enclosed stimulus, which is displaced relative to its phenomenal reference system to produce “center-surround motion.” (Duncker, 1929, p. 204). All quotations have been translated by F. Heuer and D. Seaman.

4.3. Frame of Reference

There is considerable ambiguity concerning the appropriate definition of the term frame of reference. There is some evidence

Figure 17.13: A schematic drawing of a classic center-surround induced motion display. Solid arrow indicates actual motion; dashed arrow, perceived motion. The point fixated by the observer is seen to move in a direction opposite the frame’s actual motion. The frame will appear stationary if it moves near or below threshold. At velocities clearly above threshold, the frame may appear to move.

4.4. Separation of Systems

The concept of frame of reference is invoked by Duncker to account for the perception of induced motion that occurs when the surrounding stimulus moves at suprathreshold speeds. He reported that when this is the case, both frame and enclosed stimuli may appear to move in opposite directions. He proposed that the motion of the frame was based on subject-relative information, with the observer taking the direction of the speed of the displayed object when the display is observed in a dark field. The induced motion of the enclosed stimulus is based solely on its displacement relative to the stationary frame. The separation of the two systems is most pronounced when the frame and enclosed stimulus are independent so that both the enclosed stimulus and the frame may appear to move despite the fact that the motion of the frame is subject relative rather than frame stationary. (Duncker, 1929, p. 204).

Duncker (1929) observed that the boundary of the stimulus frame is the point at which there is a transition from subject-relative to subject-stationary motion, and that this state of affairs is clarified. Namely, it must not be overlooked that under the experimental conditions like ours, the distance change between enclosed stimulus and frame is not the only relevant change that generally occurs. There occurs, in addition, still another distance change due to the movement of the frame relative to the surrounding room and to the systemic apparatus. This can only mean that the frame owes its phenomenal movement directly to the distance change which is superimposed upon the phenomenal movement of the induced stimulus and, on the contrary, are erroneous. (chap. 1, pp. 196-197).

The distance paradox is thus resolved by the notion of separation of systems. The frame is a stationary, subject-stationary frame, and viewed in an otherwise dark environment, as is the case in most induced motion studies, then the separation of systems is clearly illustrated. On the other hand, if these motions are mediated by different kinds of information, it is no longer paradoxical to perceive both the induced motion or the point and were not aware of the start of a trial which stimulus would be reported on. In the Gogol and Konos study, observers reported on every stimulus motion at the end of every trial. The change reported by Gogol (1979) confirms his own earlier finding even though some in the more recent study, the observer reported on the motion of only the frame at any single trial. This would therefore seem to rule out this difference as the critical one.

Using a somewhat different display, Wallach and colleagues (1950) reported that observers perceive full induced motion while perceiving the motion of the induced stimulus. There is therefore some reason to question and collaborate on the conclusion that induced motion is simply motion subtracted from the induction stimulus.

4.5. Velocity of the Induction Stimulus

Duncker (1929) observed that increases in the velocity of the induction stimulus are associated with decreases in the magnitude of the induced motion. Particularly large decreases in the magnitude of the stationary stimulus is fixated. Results reported by Rock and colleagues (1980) confirm this observation. There were 65% fewer reports of induced motion at the fastest speed tested (1.77/ sec) than at the slowest speed (.046/sec). Gogol (1979), however, reports no decrease in the perceived magnitude of induced motion with frame speeds of 2.08/sec as compared to frame speeds of 0.17/sec. In this experiment the extent of motion of the frame was held constant. Duncker reports that the breakdown in induced motion occurs for frame velocities of 0.007 to 0.011/sec. Rock reports strong induced motion with a frame speed of 1.77/sec. Again there are discrepancies in reported data, although there appears to be a movement to slower, too high to induce motion. Duncker attributes the breakdown of induced motion with high frame velocities to a breakdown in the motion of the frame. Thus, the observer reports the distance change between the frame and the point, rather than the distance change between the stimulus frame and the enclosed stimulus, such that the frame no longer serves as the reference for the enclosed stimulus. When this occurs, the behavior of the enclosed stimulus appears to the observer to be the opposite of what it is, which is subject relative, and is perceived as stationary.

Although high velocities of frame motion inhibit induced motion, stroboscopic motion of the frame does not, despite the fact that the velocities of stroboscopic motion are extremely high. Duncker devotes an entire chapter of his monograph to a description of experiments on induced motion generated by stroboscopically displaced frames. Because the velocity of stroboscopic displacement is high, frame motion is always perceived in these displays. If a frame is displaced stroboscopically to the left, and enclosed stationary point appears displaced to the right. In stroboscopic motion, a stationary point appears to move (Duncker & Mack, 1981). Why fast motion of a continuously displacing frame inhibits induced motion, whereas the much faster displacement associated with stroboscopic displacements does not, remains an unanswered question. It is difficult to imagine, however, that stroboscopically induced motion is motion subtracted from the frame’s motion.
4.7. Perceived or Retinal Adjacency between Target and Frame

Is it retinal or perceived adjacency between target and frame that is critical for induced motion? The question is important because it is relevant to most general issue of the level of processing responsible for induced motion. Do prior perceptions play a role in induced motion? The outcomes of several experiments by Gogel and his collaborators suggest that perceived, not retinal, adjacency is the important factor. In one experiment (Gogel & Knoulow, 1972) in which two frames located at different depths from the periphery were used, the perceivable directions of one of the frames was larger than the other. The smaller of the two frames was always retinally adjacent to the target. If retinal adjacency were critical, the smaller of the frames should consistently control induced motion regardless of the perceived depth separation between target and frame. The induction target was placed either in front of or behind the frame, and the adjacent frame was always greater than that of the smaller frame, regardless of its depth location.

Induced motion is not a function of retinal adjacency, rather than adjacency, plays a role in determining which of several simultaneously present surrounds at different depths governs the induced motion of an enclosed stimulus. It is possible that perceived, rather than retinal, adjacency between enclosed stimulus and surrounding influences the induced motion. A demonstration described by Wallach (1969, 1965) addresses this issue.

4.8. Wallach's Demonstration of Separation of Systems

The demonstration by Wallach led to an elaboration of Duscker's notion of separation of systems. Wallach's display consisted of three elements (Figure 17.14). A stationary point was surrounded by a horizontally moving target, which, in turn, was surrounded by a vertically moving circle. The motion of the two concentric circles was below threshold, above threshold, or stochastic. If motion was above threshold or stochastic, the vertical motion of the circle was correctly perceived. The rectangle appeared to move obliquely, as a result of its objective horizontal motion and induced motion by the circle. The point appeared to move horizontally opposite the actual motion of the rectangle.

Given this outcome, the induced motion of the stationary point must be entirely a function of its perceived displacement relative to the adjacent square, rather than of its displacement relative to the stationary circle. This is consistent with a hypothesis that both is the actual motion of the circle, or the motion of both surrounds. On the basis of this demonstration, Wallach concluded that the induced motion of the point is an instance of separation of systems.

PERCEPTUAL ASPECTS OF MOTION IN THE FRONTAL PLANE

result from the very nature of the phenomenon. A principal characteristic of induced motion which may, at least in part, account for these differences and the differences between the reports of various investigators is that it is based on what Wallach describes as a cue conflict. Induced motion entails a conflict between the subject and object-relational determination of motion of the induction target. It may be that the solution of the conflict is influenced by a number of factors, including subtle differences in displays.

4.10. Rotary Induced Motion

Induced motion need not involve a direction change between visual stimuli. Duscker (1929) observed and studied the induced rotary motion of a patterned stationary disc produced by the rotation of a surrounding concentric-patterned annulus. An example of a rotary induced motion displayed is pictured in Figure 17.15. Both annulus and disc contained a series of regularly spaced radial lines. When the annulus was rotated at an angular velocity of 4°/sec around the stationary disc, the disc and surrounding annulus appeared to move in opposite directions. The rotary motion of the annulus causes no change in distance between annulus and disc but produces a directional change between the radial lines of the inner and outer stimuli. The orientation of the radial lines of the annulus displaced relative to the radial lines of the disc, and this purely configurational change appears to be the basis of the perceived induced motion.

To assess the magnitude of the induced motion, Duscker used a compensation method. The inner disc was rotated with increasing speed in the same direction as the rotating annulus until the annulus looked like a stationary disc. What Duscker described as the zone of indifference, determined the zone of indifference consists of the disc velocities at which the observer perceived only slightly different direction of motion, and the disc was not seen to move. With an annulus velocity of 8.44/sec, the PSS for the disc was found to lie at 5.83/sec (standard deviation: 54 sec min).

If, instead of an inner disc, the annulus surrounding a single shaft that had the same length as the radius of the inner disc, a higher velocity was required for compensation. The PSS was found to lie at 7.53/sec.

As the speed of the rotary motion of the surround increased, Duscker again found more predictable effect on the perception of induced motion. With speeds between 2 and 67 sec, the motion of the annulus and disc appeared equal. With rotational velocities greater than 6 sec, the induced motion was found to be greater. When the induced motion motion disappeared entirely. Of course, at this speed, the radial lines of the rotating annulus became completely blurred. Duscker also noted that the observation time beyond 3 sec also decreased perceived induced motion. He attributes both the effect of frame speed and observation time to the increased influence of subject-relate motion information.

With constant exposure times and increasing inducing velocity as well as with constant inducing velocity and increasing exposure time, the position change (the angle of rotation) which the induction object (more precisely the radius extending from the induction object), should have undergone in relation to the optic system (i.e., subject-related) increases. In other words, its position and direction disturbances increase proportionally with exposure time and inducing velocity. (p. 9)

Duscker continues:

One must imagine that with the use of rotary movement, the optocentric system of the induction object must become "cheated" out of, not merely as otherwise, a change in position, but a change in direction as well. The optocentric system appears to be more sensitive to direction than to differences in position. . . . (chap. 3, p. 216)

Induced motion in depth is not a well-investigated phenomenon, but it has been studied by at least one investigator (Wattier, 1972). Figure 17.15 shows an example of a rotary motion in depth. The disc and the annulus were oriented on a transparent sheet of glass appeared to move in depth opposite the motion in depth of a patterned surface that lay behind the glass. Greater induced motion was perceived as observation time increased from 1 to 3 min and as frame velocity

4.9. Individual Differences in Induced Motion

A consistent finding in every study of induced motion is the marked difference in reports given by subjects, which seems to
increased from 4 to 32 min arc. perceived induced motion in depth was also produced stereoscopically. The brief presen-
tation of a circular outer contour 13.6 cm in diameter and an inner circular contour 6 cm in diameter was alternated with an outer circle of 10.5 cm and an inner circle, again, of 6 cm. All circles were concentric. With the appropriate temporal pre-
sentation rate, the outer circle was perceived to loom and recede in depth and to induce an opposite motion in depth in the inner circle. It should be noted that neither relative retinal displacements nor a configurational change can be the basis for this induced motion. It would seem that the apparent looming of the outer circle is the immediate cause of the induced counter- looming of the inner circle. If so, this is an instance in which a prior "perceptual" process, namely, that which leads to the ap-
parent looming of the surround, is the cause of the induced motion, which therefore derives from a perceived, rather than a retinal, displacement between surround and target.

4.12. The Locus of Induced Motion

The finding that an apparently looming stimulus can induce motion in depth and the finding that perceived, rather than retinal, adjacency may govern induced motion (Goge & Koslow, 1972) strongly suggest that induced motion is based on more than one mechanism, rather than on peripheral, processing. This is supported by data reported by Basili and Faber (1970), and corroboration by Day and Dickinson (1977), indicating that induced motion occurs with dichotically presented stimuli. Basili and Faber (1970) presented their observers with a dichotopic version of the Wallach three-element display with the outer circle and inner stationary point while the other viewed the inner retinal and outer point. The outer circle displayed vertically. The inner rectangle displayed laterally in phase with the circle. As Wallach had reported earlier, the rectangle appeared to move obliquely, demonstrating a dichotic-induced motion. These results suggest induced motion derives from a stage of processing that follows the bicoherical combination of retinal inputs.

The Basili and Faber results appear to conflict with results reported by another group of investigators (Over & Lovegrove, 1973). However, there are grounds for asserting that these inv-
vestigators were studying a phenomenon that, while superficially similar to induced motion, is not the same. The rationale for the Over and Lovegrove study, which also involved dichotic presentation of a moving surround and stationary inner-target pattern, grew out of earlier work on motion aftereffects (MAEs). Previous work on MAEs had shown that if the stationary test pattern has the same spectral characteristics as the moving induction pattern, the MAE is stronger. This was true, however, for motion aftereffects and the results were presented to the same eye. No color specificity was evident when the test pattern was presented to one eye and the moving pattern to the other. Motion aftereffects involve successive presentations of induction and test patterns. Over and Lovegrove wished to determine whether similar effects would also be obtained with dichotic presentation of a stationary test pattern, a condition which produces simultaneous motion contrast (SMC) or conceivably induced motion. They therefore used both mono-
optic and dichotic viewing conditions.

The display consisted of a pair of concentric circular patterns (see Figure 17.10). The outer surrounding pattern was 20' in diameter, the inner circle 1'. Both test and induction stimuli contained a vertical square-wave gratings pattern that was either the same or different colors. The pattern within the boundaries of the grating stimulus moved at 0.7' sec. The inner induction pattern was stationary. The investigators reported that the apparent motion of the stationary pattern was greatest when the vertical bars were the same color in the monoptic condition, but no differences were found in the dichoptic condition in which the stationary pattern was viewed by one eye and the induction pattern by the other eye. Moreover, and more relevant to the present consideration, they also report that the motion induced in the test pattern in the dichoptic condition was so slight as to be indiscernible (see Chapter 16 by Anstis for additional discussion of this experiment).

The apparent conflict between these results and those re-
ported by Basili and Faber (1970) and Day and Dickinson (1977) is attributable to a number of factors, including the distance between the outer circle and the inner stationary point, the size of the test pattern, and the amount of increase in velocity of motion. These investigators demonstrated that the Over and Lovegrove finding of minimum induction was specific to the situation in which the test stimulus and induction pattern were presented to the same eye (monoptic or dichoptic).

They report that when the inducing stimulus is a moving contour surrounding a stationary target (a stationary target and a moving inducing stimulus) or that the stationary induc-
tion pattern is or moving gratings surrounding a stationary grating, the induced motion of the stationary target is not affected either by color differences or by dichotic presentations. For-
therefore, Day and Dickinson report a significant reduction in the velocity of the perceived motion of the stationary target when the moving induction pattern was not induced by the perceived motion when the entire indi-
cing stimulus (bars and surrounding contour) moved. When this was the only difference between conditions, there was an 83% reduction in the velocity of the perceived motion of the stationary stimulus.

Day and Dickinson (1977) conclude that the effect studied by Over and Lovegrove is not induced motion.

The stationary boundary serves as a reference which prevents the smooth, continuous, gliding effect commonly associated with Duncan's induced motion. It seems likely that the marked reduction in the effect with target and field bars of a different color is simply due to the greater distinctiveness of the two. When the target and surround are identical, they can be more easily perceived as the stationary contour which serves as a reference. In consequence, they seem barely to move. (p. 319)

This study provides persuasive grounds for the authors' con-
clusion that the phenomenon studied by Over and Lovegrove is not a basic cognitive or perceptual process. However, in the absence of a background or stationary pattern, the apparent conflict between the outcomes of the Over and Lovegrove and the Basili and, Farber studies. Over and Lovegrove studied a stationary motion contrast, whereas induction and test patterns were presented to the same eye. In this case, the motion of the stationary pattern was the result of a process operating at a much lower level in the visual system than those responsible for induced motion. This evidence is reviewed in Section 4.13.

4.13. Comparison of Induced Motion with Simultaneous Motion Contrast

The principle stimulus difference between SMC and the super-
flicially similar phenomenon of induced motion appears to be the one singled out by Day and Dickinson (1977), namely, the presence or absence of a stationary contour that surrounds the moving inducement. The stationary boundary in SMC displays a source of conflict-objective relative infor-
mation about the induction target. While the target displays relatively objective information, the stationary color is stationary with respect to this contour. This object-relative information is consistent with the available subject-relative information about the target position. However, it is unlikely that SMC engenders any misperception of position and, instead, only affords the perception of velocity. If this is so, this phenomenon is more properly grouped with MAEs (see Chapter 16 by Anstis) which engenders the perception of paradoxical motion, rather than with induced mo-
tion, which seems to involve both the perception of motion and position change.

A number of motion phenomena reported in the literature, sometimes referred to as induced motion, seem to be instances of SMC. These include studies by Loomis and Nakayama (1972), whose display consisted of two horizontally separated dots moving with respect to a background of moving dots with a shallow velocity gradient; Tynan and Sekuler (1975), whose display consisted of a field of horizontally drifting dots surrounding a stationary dot, which is likely to be interpreted as a two-dimensional moving counterphase toward and away from the stationary line (for a detailed discussion of these studies, see Section 1, Chapter 16 by Anstis).

Although induced motion and SMC appear to be different phenomena, both may be present in any given display. The demonstration of a central equalization of dots while the speed of motion at the vertices of the figure increases with speed of motion (i.e., increases with speed) probably involves no shift in position and therefore may entail the perception of paradoxical motion.

4.14. Theories of Induced Motion

There are two general kinds of explanations of induced motion that correspond to the major categories of motion information: (subject and object-rel): Duncar (1929) proposed the orig-
inal object-rel:account, in which perceived movement is the displacement between objects in the visual field. If one object has a frameslike character, for example, if it surrounds another object, it will serve as the background against which movement of the figure object is perceived. Its motion will induce motion in the enclosed object. The fact that the background will appear stationary, when its motion is below a threshold, is attributed to the general tendency to perceive backgrounds as stable. Perceived motion of the background implies a separation of objects. The motion of the background is subject-rel:; the induced motion is object-rel:.

Broglie (1968) has proposed a subject-rel:account of induced motion. On this analysis, a stationary point within a moving surround appears to move because the movement of the surround shifts the observer into a different retinal location and thereby toward the center of a visual framework (Roelofs, 1935). The shift in apparent median planes is the im-
mmediate source of induced motion. As the median plane shifts with respect to the surrounding distribution, it induces an apparent shift in the opposite direction in an enclosed stationary object, and this displacement is subject-rel: (See Section 3.4.7 for an analysis of AKM, which parallels his explanation of induced motion.)

Several investigators have proposed lateral inhibition ac-
count (Atkinson & Reishardt, 1976; Over & Lovegrove, 1973; Tynan & Sekuler, 1975), but it is
argued here that this explanation is more appropriately restricted to SMC.

A patent untestable account of induced motion attributes it to involuntary eye movements elicited by motion of the surround which causes the image of the stationary target to displace on the retina. Since these eye movements are involuntary, they are unaccompanied by an extraretinal signal. Consequently, the image displacement is unmatched by an eye movement signal, and object motion is perceived (Kaufman, 1974). Kaufman has recognized that this version of a subject-relative account of induced motion faces a variety of difficulties, and there is ample evidence that induced motion is not a function of eye movements. Induced motion occurs in retinally stabilized displays (Mack, Fendrich, & Wong, 1982). It can occur simultaneity in the opposite direction. Finally, two investigations in which eye movements were directly monitored produced no evidence that tracking of the surround motion was the cause of induced motion.


A subtler version of the egoocentric eye movement hypothesis has been proposed. Engel & Rock (1979) and Rock and colleagues (1980) have proposed that induced motion is mediated by visual capture of oculomotor information. By this account, oculomotor variables are a function of induced motion. The tendency to perceive backgrounds or surrounding objects as stationary leads to the assignment of motion to the enclosed object when real relative displacement is matched by the eye movements. If the enclosed object is fixated, visual capture would result in a regular pursuit eye movement opposite the motion of the surround. The retinal displacement resulting from the motion of the real object, is attributed to the eye's tracking motion, and the absence of retinal displacement of the fixated object is attributed to the eye's ocular motor motion.

A parallel argument can be made if the observer fixates and tracks the moving surround.

4.15. Evaluation of Evidence

Perhaps surprisingly, there is evidence that both supports and fails to support the several subject- and object-relative accounts of induced motion. In support of the subject-relative account, Brogole (1969) found that the duration of two concentric rectangles, moving counterphase and surrounding, a small square, governed induced motion. Since the larger frame should have greater influence over apparent median plane (its frame character for the observer is greater), the effect of this, rather than the more adjacent, smaller rectangle, controls the induced motion is taken as support for the hypothesis that Brogloe's finding is at odds with Wallach's three-element display design. The separation of systems is but not necessarily at odds with Ducker's account in which eye principal separation is between object- and subject-relative systems. The central issue is what constitutes the frame of reference. Is it the subject or visual object? For Brogole, it is the subject, but this way, the larger frame controls induced motion by inducing a displacement in the observer's apparent median plane. This is not the only way of accounting for the fact that the larger frame controls the induction. Its displacement might act directly rather than indirectly. If the larger surround had a more "framelike appearance," the same point would be seen in relation to it, rather than the smaller surround.

Brogole (1969) found no induced motion when two rectangular frames were placed one above the other (see Figure 17.18). A stationary sphere was separated within each rectangle, and the two rectangles were displaced from left to right, counterphase. The failure to find induced motion moving in opposite directions prevents either frame from influencing apparent median plane and thus makes induced motion impossible. However, this may not be the reason why there was no induced motion perceived. It may be that the absence of relative displacement between the two vertically aligned, stationary targets, which are surrounded by oppositely moving rectangles, successfully counteracts the relative displacement. According to the hypothesis (Astle, 1977a), provides evidence for this speculation.

The principal difference between the experiments in these studies is that in the Gogol study the two oppositely moving rectangles were separated horizontally, thus sharply reducing the salience of the relationship of the targets to each other (see Figure 17.18). This one change dramatically affected the outcome. Gogol reports that observers perceive the two stationary targets moving in opposite directions. This result not only suggests an alternative explanation of Brogole's results but may also be considered evidence against Brogole's general account of induced motion. It is hardly likely that apparent median plane can simultaneously shift in opposite directions. Brogole's subject-relative theory cannot explain the Schultzman (1970) data, described in Section 4.14, in which induction occurred in the presence of oppositely moving induced stimuli (horizontal lines), for the same reason that it cannot account for Gogol's results. Two-point induced motion also is not easily accounted for by Brogole's subject-relative account of induced motion.

The view that induced motion produces visual capture of oculomotor information is an alternative subject-relative account that entails no assumptions about apparent shifts in the median plane. Since subject-relative position or motion information is based on eye position and does not require a shift in the actual fixation, a misregistration of this information, it would necessarily be an instance of egocentric motion. This view is neither confirmed nor unconfirmed by any of the current experiments. While the fact that observers may report that their eyes are moving when they fixate a stationary stimulus undergos induced motion is consistent with the occurrence of visual capture in these reports, permission to us to conclude that visual capture has occurred. These reports may merely reflect the observers' wish to appear consistent. The only relevant, less ambiguous evidence comes from a study reported by Wong and Mack (1981) in which observers were required to scan to the initial position of a no-lager-visible stimulus after it had undergone induced motion. If the induction target was actually stationary and appeared to move to the right, observers proceeded to the left, to the position the target would have occupied if it had actually displaced. Unfortunately, these results are also vulnerable to an interpretation in terms of the observers' wish to behave consistently and cannot be taken as conclusive evidence of visual egocentric. Experiment that is currently underway in our laboratory are designed as a more rigorous test of this hypothesis. In one of these experiments, observers are required to guide to an inductive auditory target after fixing a stationary stimulus that undergoes induced motion. If the auditory target is actually to the left of the induction stimulus, but induced motion enabled stimulus to appear to move to the left, then oculomotor visual capture should result in a saccade in the wrong direction.

The visual capture hypothesis by oculomotor visual capture, other orienting responses should reflect this. Undistorted eye position information is the obvious basis for accurate guidance. Undistorted eye position information is caused by a displaced frame. The presence of two equal-strength frames moving in opposite directions prevents both from influencing apparent median plane and thus makes induced motion impossible. However, this may not be the reason why there was no induced motion perceived. It may be that the absence of relative displacement between the two vertically aligned, stationary targets, which are surrounded by oppositely moving rectangles, successfully counteracts the relative displacement. According to the hypothesis (Astle, 1977a), provides evidence for this speculation.

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a train across the platform or a car stops alongside us then pulls away, we experience the train or car in which we are riding, not the train or car itself, which is actually stationary, to be moving in the opposite direction.

Duncker (1929) described the conditions for induced motion of the self in terms similar to those necessary for inducing object motion.

The same object structure of the visual field that determines object-relative movement and rest values of the object, also determines the object's movement and rest values of the subject. For example, the strongest impetus to movement that can be generated for an object is that of its relative movement to its environment, because it can result for as long as it is with the phenomenal rest of an object—in the highest degree on objects, in the lowest degree on the environment until it can anchor itself (chap. 2, pp. 207).

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In other words, induced motion of the self is likely to occur when the entire field surrounding the observer moves. The observer then becomes self-centered, and the motion of the surrounding lead to perceived motion of the self.

In the laboratory the phenomenon is usually demonstrated by placing the observer within a vertically oriented, cylindrical, patterned field, which is then set into rotation in the observer. After a brief period in which the observer may perceive the field as rotating, the observer is shown with the view of self movement and the field as stationary. When the observer is stationary, a stationary target located between the observer and the patterned field will seem to move with the observer. The relative displacement between stationary target and observer is attributed to motion of the observer in accordance with the principle, "that which is physically static relative to a phenomenal reference system appears to move" (Duncker, 1929, chap. 2, p. 18).

Induced motion of the self is a prototypical example of the power of object-relative information to override subjective relative information, which in this situation is sensory information that the observer is stationary.

Recent evidence indicates that vision depends on stimulation of the retinal periphery by the moving pattern (Brando, DeJonge, and Kappers) require a moving pattern that fills the observer's visual field. Thus it would seem that the primary feature of the background or frame motion that induces visual perception of the unidirectional observer and therefore literally surrounds her or him. This finding suggests that the stimulus difference, which distinguished vision from induced object motion, is one where the visual field of the moving pattern is located. If it is that the visual stimulus, it may engendervection. If it is located more centrally, it may engendervection or more.

In the retinal periphery, there is now also evidence that the visual stimulus, which producesvection, is associated with a pattern of vestibular responses comparable to those which occur with actual observer motion (Henn, Young, and Finley, 1974). This finding is complete consistent with the idea that the perception of induced self motion causes visual capture of vestibular signals. This and other work has shown that induction is, in fact, comparable to the phenomenon of object motion and what distinguishes them is simply that the motion of the sur-

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rounding objects is visual stimulus, whereas in the other it is the self that is moved, and we expect visual capture of cutaneous signals when there is induced object motion. Failure to find evidence of visual capture of oc-

ulometer information with induced object motion would therefore suggest an important difference between these phenomena. In any case, evidence concerning the presence or absence of visual capture of which induced object motion should elucidate their relative-relations.

4.17. The Relation between Induced and Real Motion

There has been some discussion in the literature about whether induced and real motion are distinguishable. Existing relevant data are not consistent. The fact that a compensation technique can be used to assess the magnitude of induction (Bridgman, et al., 1981; Duncker, 1929) suggests that real and induced motion are not perceptually distinct, since real motion of a target is possible in the absence of a subject's motion. This is supported by the finding that, at least under certain conditions, observers are unable to distinguish between the real and induced motion (Bassani & Barber, 1977).

Gogel and Kostow (1971) compared the extent of perceived induced motion when observers fixated a stationary point sur-

rounding with the perceived extent of motion when the point, rather than the frame moved. In both cases, stimulus motion was 1.27°/sec. In general, they found that the perceived extent of motion was greatest when the point moved than when it was motion was induced. This difference is interpreted by the investigators as evidence that observers can discriminate between induced motion and real motion. However, the fact that the extent of perceived point motion was less when motion was induced may be attributed to the fact that induced motion is perceived as if it were caused by a source of illumination. The source of motion information and does not indicate that the motions are necessarily discriminable. In fact, a frame of motion of greater than 1.27° can generally fixate and induce motion, which would account for the discriminability of the two types of motion.

5. CONFIGURATIONAL EVENT PERCEPTION

5.1. The Rolling Wheel

Duncker (1929; see also Ruben, 1927) describes the perceived motion of the rolling wheel in a dark room, a phenomenon which has been the subject of much recent investigation and discussion (Johannson, 1950; Proffitt & Cutting, 1979, 1986, 1989; Proffitt, Cutting, & Steir, 1980). If one only point is visible, it will be seen to move along a series of arcs or a wave-like path, which, in general, is distorted. If both the object and the second point are visible (see Figure 17.10), then the second point is added to the rim opposite the first one or is attached to the hub, there is a dramatic shift in the perceived motion path of the point on the rim. If the two points are both on the rim of the wheel, they will both appear to rotate around the unseem center of the wheel as they travel together along a horizontal path. If the object is filled with the object perceived underlying, in other words, there is a simultaneous association. In classical induced motion, induction occurs to the extent that the actual subject's relative behavior of the induction target is not perceived (if the induction target has a real motion, its perceived motion is a function of the induced motion and the real motion). In the case of the rolling wheel, both the subject and object-relations are perceived, but the relative components of the rim elements are perceived; that is, each element carries both components of motion which are, however, perceptually segregated. Together, these components yield the perception that the outer point or points are rotating and simultaneously moving forward. The frame of reference for the object-relative motion is the center of the wheel, while the subject and or visual background is the reference for the translational motion. This frame of reference, for the object-relative motion is generally perceptually salient, consequently, at low angular velocities it may be the only motion that is perceived (see Figure 17.2). A series of studies of the perceived path of motion of light points attached to inviolable rolling wheels, investigators found that the perceived motion of the type perceived in term of rotation is different from the path if the geometric figure defined by the light points (Proffitt & Cutting, 1979, 1986a, 1986b; Proffitt, Cutting, & Steir, 1979). The result of the path of motion on the same system is that perceived rotation about the mathematically defined center of the moving array. The subject relative-motion of the entire system of points is perceived as motion of the system's center (Proffitt & Cutting, 1979, p. 390). To the extent that the centroid of a system of points oc-

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clicks with the actual center of the system, 1.27° or 2.54 cm, there is no indication of preferred line and wheel-like. The men the centroid departs from the actual center of the frame on which the lights are placed, the more the entire system of points will be perceived to hop along a cycloidal path.

5.2. Lissajous Combinations

The perceived motion of points attached to a rolling wheel is an instance of what Johannson (1850) described in his sketch book. Johannson pattern is limited to two-dimensional configurations. The reader is referred to Chapter 18 for a discussion of three-dimensional counterparts of some of the combinations of motion. The rolling wheel, all involve a dissociation or separation of subject- and object-motion components and therefore of the multiple forms of relative-motion as Lissajous combinations. A Lissajous figure results when a single point simultaneously undergoes a change in the motion of two other points such that the shape of the resultant motion path is a function of the frequency and phase relation of the two motions. Figure 17.20 depicts a motion path that is the result of different combinations of frequencies and phase relations. Johannson tells us (pp. 87-88) that the term Lissajous pattern derives from the French physiologist Lissajous (1822-1880), who first published these motions using two tuning forks placed at right angles to each other. Small mirrors were attached to a tines of each fork. A light reflected from the mirrors swept onto a screen. Variations in the frequency and phase relations between the forks predictably altered the motion path of the object motion. The configurations studied by Johannson were generated on a CRT screen and are called Lissajous combinations, rather than Lissajous figures, because "these give, in the same perceptual field, a single harmonic vertical motion and also a horizontal such motion as opposed to Lissajous figures, we have one carrier for each motion and thus two objects in motion" (p. 90). Figure 17.21 presents the most frequ-

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ently observed (see Figure 17.21). Two moving elements (e.g., light points presented on a CRT) travel in a circular motion. The A:B ratio of periods is 1:3.6. Both elements travel at the same sinusoidal velocity, and their phase relation is such that they arrive at their common point simultaneously.
When this display is viewed, the observer does not see the actual motion of the two points but the two points appear to move toward and away from each other along an oblique path, and the entire configuration appears to move obliquely up and down along a path at right angles to the object-relative motion path. The motions appear to be separated into their object- and subject-relative components, with perception dominated by the object-relative component. The dominant oblique perceived motion of the elements toward and away from each other is the actual motion of the elements, with respect to each other; it is their object-relative motion. The remaining oblique motion at right angles to this motion path is the subject-relative component of the motion, that is, the motion of the elements with respect to the observer.

PERCEPTUAL ASPECTS OF MOTION IN THE FRONTAL PLANE

Figure 17.22. Johnson Lissajous combination. (a) Real motion: One point moves up and down in a circular path, and the other point moves up and down in a vertical path. The points move in a phase. (b) Perceived motion: The point moving in a circular path is seen moving horizontally toward and away from the point moving vertically. Both points may appear to move conjointly up and down as a unit. (From C. Johnson, Configuration in event perception, Almqvist & Wiksell International, 1950. Reprinted with permission.)

Another example of Lissajous combination described by Johnson again consists of two elements. One of the elements oscillates up and down along a vertical path, while the second element describes a circle (see Figure 17.22). The motion of the elements is in phase, so that they arrive at their uppermost and lowermost positions at the same time. If either element is presented alone, its actual path of motion is perceived. Presented together, the point moving in a circular orbit is perceived to move horizontally toward and away from the point moving vertically. Simultaneously both points may appear to move conjointly up and down as a unit. Again the subject- and object-relative components of the motion are dissociated. The perceived horizontal motion of the point describing a circle is its actual motion relative to the point moving vertically; that is, it is its relative motion. Its perceived vertical motion is its motion relative to the observer or the background it has in common with the other element. Again two distinct reference systems provide the basis for the perceived dissociation of motion paths. The grouping of the common subject-relative motion is in accord with the Gestalt grouping principle of common fate. (See Chapter 23 by Rock.)

5.3. Vector Analysis

Johnson (1950) accounts for the perception of these two arrays and for others belonging to the same class in terms of his theory of vector analysis. He proposes that the visual system engages in an analysis of the motion vectors present in a moving visual array. This analysis leads to the segregation of common and divergent vectors of motion, such that the common vector provides the frame of reference for the divergent and perceptually dominant vector. The frame of reference for the common motion is either the static environment, the observer, or both.

In the case of the two elements moving along the legs of the L, vector analysis leads to the abstraction of the common motion vector (labeled be and ed in Figure 17.21) and the divergent vector (labeled ad and ed). In the case in which one element moves up and down while the other travels in a circular path, vector analysis leads to the abstraction of the common vertical vector, which the circularly moving element shares with the vertically moving element, and the horizontal or divergent horizontal vector, which is the perceptually dominant motion. The two vectors added together account for the motion that is present. (The perception of the motion of Lissajous patterns does not seem to involve what Duncker described as distance paradox. See Section 4.4. Since here the separation of systems does not entail seeing surplus motion, this may be one of the distinguishing differences between induced and Lissajous pattern perception.)

If one of the two points in the L display is tracked, the perceived paths of motion are significantly altered. The tracked point is perceived to move along its actual path, while the other point appears to move along an oblique path toward and away from it. It is as if the tracked point becomes the frame of reference for the relative motion between elements. There is, however, another way of describing the effects of tracking. If, as Dodge (1904) or Stohr (1967, 1973) have argued, there is no compensation for the displacement of images of tracked stimuli during pursuit of a moving target, then one would expect the perceived path of motion of the tracked element to be determined solely by its retinal path of motion, which in this case is L is oblique. However, since there are reasons to believe that there is compensation for image displacements during pursuit (see Section 3.3), this description is unlikely to be correct.

A somewhat different account has been offered by Festinger, Dodge, and Holtzman (1976), who derive from an experiment examining the perceived extent of motion of a tracked stimulus and the perceived orientation of the motion path of a stimulus moving at an angle between 60 and 75° or between 105 and 120° to the horizontally moving, tracked stimulus. These studies show that the stimulus is perceived to be a 90° be seen angle was not examined. The results indicated that the perceived orientation of the untracked element was much closer to its retinal than its actual motion path. The investigators concluded: "The perceptual system has access to information about direction of tracking and assumes a relatively low speed, almost irre- spective of the actual speed of the eye" (p. 1377). If these investi- gators are correct, the perceived motion path of the un- tracked element in the L display may be a function of the only minimal compensation for retinal image displacements engen- dered by pursuit, rather than of a process of vector analysis.

According to Johnson, pursuit of either of the moving elements in the configuration depicted in Figure 17.22 does not alter its appearance. If this is actually so, this argues against the Festinger and colleagues (1976) explanation. If the observer tracks the vertically moving element, the path the circularly moving element traces on the retina will be horizontal. If there were no compensation for image displacement during pursuit, this would account for the perception that the circle element is moving horizontally. On the other hand, if the circle element is tracked, the image of the vertically moving element will displace horizontally on the retina. If there were only minimal compensation for pursuit, then this point should appear to move more or less horizontally. If Johnson's statement, "Fixation of a specific object does not lead to any appreciable alterations in the motion pattern" (1950, p. 10), is correct, then the fact that the element actually describing a circle continues to appear to move horizontally when it is tracked cannot be accounted for by retinal painting. Verification of this report is desirable and would have important theoretical consequences.

5.4. Principle of Lowest Velocity

Johnson (1950) states a principle of motion organization to account for the fact that pursuit affects some Lissajous arrays but not others. This is the principle of lowest velocity. The
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The influence of the size of the field on perceived velocity holds despite information about the distance of the object from the observer and thus despite subject-relative velocity infor-
mation. Thus, if the observer could see the movement stimulus, dark circles enclosed in rectangular is-
it fields, placed at the same distance but in different directions from the observer, the observer's field of vision would be complete. This would prevent misinterpretation of many of the Johnsonian configurations may bear the same relationship to a coding theory account of event perception as the data that localize any particular instance of the object in the theory account of static form perception. If, for whatever reasons, fixation and pursuit affect the perception of these dynamic arrays, then it simply cannot be said that their perception is exacted by any function of informational load, at least if this is defined in terms of the visual array alone, since there is no obvious reason why fixation should alter informational load.

6. VELOCITY PERCEPTION: SUBJECT- AND OBJECT-RELATIVE DETERMINANTS

6.1. Velocity Constancy

Retinal image velocity, like retinal image extent, is inversely proportional to the distance of the imaged object from the ob-
server. The perceived velocity of an object's velocity despite changes in its distance from the observer is another aspect of motion perception that has been explained in terms of object-
and subject-relative motion information.

6.2. Subject-Relative Determinants of Velocity

Since velocity is defined as the extent of motion traversed in a given unit of time, the relationship between extent and velocity is obvious. Both the angular extent of the distance traversed by a moving object and its angular velocity decrease directly as distance from the observer increases. If perceived extent were to remain constant with changes in viewing distance, in other words, if size constancy prevailed, perceived constancy of velocity might reasonably be considered a derivatis. On this account both perceived extent and velocity constancy would be based on sensory information about an object's distance from the ob-
server. Evidence that both perceived extent and velocity are a function of subject-relative information about absolute, ego-
centric distance must therefore demonstrate commensurate perceptions of extent and velocity under conditions in which sensory cues to distance of an object are carefully controlled and other possible determinants of perceived velocity are eliminated. J. F. Brown (1931a) found that the perceived extent of an object and the perceived velocity decreased accurately as the perceived velocity of an object moving through an object's substantial. Since Brown called this the principle of the transposition of velocity. If a movement field is transposed in its linear dimensions, the velocity of the object that appeared to be moving through the object's substantial a, 0.5 point of light, with another equal-sized stimulus designated the standard. Both stimuli were enclosed by equal-sized apertures, the standard aperture was transposed (as in Figure 17.25A), and the standard was transposed as well. Actual perceived velocity was found to be nearly perfect for both stimuli. The movement of the object was accounted for perceived velocity whether or not egocentric distance information was available. Subject-relative velocity as well as perceived extent of movement, if that is, subject-relative distance information, this outcome could not have been obtained since monocular viewing deprived the observer of all distance information. Monocular viewing therefore should have produced retinal velocity matches. These results were confirmed by the results of another experiment in which the simplicity of viewing, whether monocular or binocular. (See Figure 17.25B.) Additional evidence was provided by an experiment in which the standard array was again placed at different distances, but now its dimensions varied in proportion to its distance from the observer so that its retinal size was always constant. As distance of the standard increased, its angular velocity decreased (since its angular size was constant), and the angular size of the frame remained constant. This differs from the previous experiment in which angular velocity and angular size of the standard both decreased as the distance, so that perceived velocity physical and velocity remained constant. If perceived velocity is a function of relative angular velocity, then the velocity of the primary explanation of this phenomenon. Rock (1975) correctly points out, "One method for avoiding this possible artifact is to present only one moving element within each aperture and to restrict observation to one half cycle" (p. 227).

6.4. Velocity Constancy: An Object-Relative Explanation

The principle of transposition of velocity has provided the basic mechanism for understanding the perception of velocity constancy (Wallach, 1939). If perceived velocity is a function of the proportion of the field traversed per unit of time, then since this proportion remains constant despite changes in distance from the observer, the transposition of velocity can account for perceived velocity constancy without reference to distance. It follows that a moving stimulus four times as large as another in a field four times as large must move four times as fast to appear to move at an equal speed when both are at the same distance from the observer. The retinal dimensions of those two configurations are identical to those that would be produced by two arrays of equal size, one of these configurations, and the threshold for change of position. Wallach speculated that both may be understood in terms of Weber's law:

- Actual experiments in the field of visual speed can be explained, if we realize that our sensitivity for changes of position depends on distance. (Weber, 1801) It seems evident that this sensitivity follows Weber's law within certain limits. Strich velocity, on the other hand, a function would mean that a threshold for change of position is proportional to the size of the distance, in the opening in which the threshold is measured. From this point of view, we can see that Brown's principle of velocity constancy is not to be fully realized. Actually, Weber's law does not strictly hold in this case. (Brown, 1931a) Further, experiments conducted in 1933 show that the threshold for change of position may be attributed to the fact that Weber's law does not strictly hold in the case of highly dissimilar stimuli.

It has been suggested (Smith & Sherlock, 1957) that a "counting" artifact might explain the velocity transposition effect. If the standard and comparison displays consisted of a series of spots moving on continuous lines, the aperture and one dis-
play was made of the subject-relative information about absolute, ego-
centric distance must therefore demonstrate commensurate perceptions of extent and velocity under conditions in which sensory cues to distance of an object are carefully controlled and other possible determinants of perceived velocity are eliminated. J. F. Brown (1931a) found that the perceived extent of an object and the perceived velocity decreased accurately as the perceived velocity of an object moving through an object's substantial. Since Brown called this the principle of the transposition of velocity. If a movement field is transposed in its linear dimensions, the velocity of the object that appeared to be moving through the object's substantial a, 0.5 point of light, with another equal-sized stimulus designated the standard. Both stimuli were enclosed by equal-sized apertures, the standard aperture was transposed (as in Figure 17.25A), and the standard was transposed as well. Actual perceived velocity was found to be nearly perfect for both stimuli. The movement of the object was accounted for perceived velocity whether or not egocentric distance information was available. Subject-relative velocity as well as perceived extent of movement, if that is, subject-relative distance information, this outcome could not have been obtained since monocular viewing deprived the observer of all distance information. Monocular viewing therefore should have produced retinal velocity matches. These results were confirmed by the results of another experiment in which the simplicity of viewing, whether monocular or binocular. (See Figure 17.25B.) Additional evidence was provided by an experiment in which the standard array was again placed at different distances, but now its dimensions varied in proportion to its distance from the observer so that its retinal size was always constant. As distance of the standard increased, its angular velocity decreased (since its angular size was constant), and the angular size of the frame remained constant. This differs from the previous experiment in which angular velocity and angular size of the standard both decreased as the distance, so that perceived velocity physical and velocity remained constant. If perceived velocity is a function of relative angular velocity, then the velocity of

Figure 17.25. Velocity transposition display. Motion field is a half of the size of motion field b. Moving square in field a must move about 50% of the velocity of moving square in field b to appear to move at equal velocity. If movement field is transposed in its linear dimensions, the velocity of the object that appeared to be moving through the object's substantial must be transposed in an approximately like amount for perceived velocity to appear equal. (From J. F. Brown. The visual perception of velocity. Psychologische Forschung, 1931. 14. Reprinted with permission.)

[Diagram of velocity transposition display]
information, namely, the proportion of the field traversed per unit of time. Consistent with other evidence indicating the po-
tency of object-relative determinants of motion perception, Ep-
stein’s results clearly demonstrate the salience of the object-
relative determinant of object velocity when these conditions
were available with subject-relative input. It might be noted, how-
ever, that despite the importance of relative retinal displacement for the perception of velocity, this information signifies nothing about the absolute velocity of an object. It signifies only that an object in one field is moving faster or slower than an object in another field. In this case, a characteristic of all object-relative
input. Despite its potency in the motion perception process, it provides no information about how fast, how far, or
which object is moving.

REFERENCES

Adams, E. F. Autokinetic sensations. Psychological Monographs, 1912,

Anstis, S., & Reichardt-Bialdval, A. Interaction between motion after-
effects and induced motion. Vision Research, 1965, 5, 1399–

Aubert, H. Die Bewegungsmessungen. Pfieger’s Archiv für die Ges-

Aubert, J. N., & Farber, J. M. Experiments on the locus of induced

Bassil, J. R. E. Autokinetic projection. Perception and Psychophysics,


Bazzini, J. F., & Brown, P. E. Visual receptive fields sensitive to absolute and relative

Benziger, T. D., Dichgans, J., & Rösch, E. Differential effects of central

Bridge, P. The visual perception of velocity. Psychological Research, 1951, 14, 246–288. (a)

Brown, J. F. The thresholds for visual movement. Psychological

Burns, B. Delisle, Gassan, U., & Webb, A. C. Responses of neurones in the stria

Carr, H. A. Studies from the Psychological Laboratory of the University of Chicago. The American Journal of Psychology, 1927, 39, 74–75.


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Wallach, H., & Kravitz, J. Rapid adaptation in the constancy of visual direction with active and passive rotation. Psychonomic Science, 1965, 3, 165–166. (b)
Yaczi, S., & Young, L. R. Perceived visual motion as effective stimulus to pursuit eye movements. Science, 1975, 190, 906–908.