Chapter 14
The Perception of Movement
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Why does the perception of movement present a problem? It would seem plausible to believe that when an object moves, its image will move on the retina and this image movement is interpreted by the perceptual system as movement of the object. If this were the case, movement perception would not present a problem. Indeed, insofar as lower animals are concerned, this account may be correct, but as an explanation of the perceptual experience of human observers, it is grossly inadequate.

The perceptual experience of movement is analogous to other qualities of sensory experience such as color or size—we perceive movement as a property of the object. The ability to perceive movement is clearly very fundamental in animals; it is necessary for survival. Various animals react to movement but not to stationary objects. In man, movement of an object in the periphery of the field can be detected before its exact form is apprehended.

Movement is an "either-or" experience. An object either appears to be moving or it appears to be stationary (although of course its perceived speed may vary). There is no middle ground. If an object is moving too slowly—as in the case of the minute hand of a watch—it will not appear to move at all, although after a while a change in position is detected. Thus, there is a threshold below which a given magnitude of objective displacement per unit time will not lead to perceived movement and above which it will. The task before us is to try to identify the conditions of stimulation or central processes that lead to the perception of movement.

Various kinds of conditions lead to movement perception. When we perceive movement where something actually is moving this is referred to as real movement perception. But often we perceive movement where nothing in the real world is in motion. There are several kinds of such illusory impressions of movement, each of which is considered in this

chapter: *stroboscopic movement, autokinetic movement, and the aftereffect of movement*. Then there is the situation that prevails when the observer himself is moving, which may or may not lead to the perception of the environment as moving.

The logical place to begin our inquiry would seem to be with real movement perception. When an object is actually moving, there are several possible explanations of why we see it moving: if the eyes are stationary its image will move over the retina; the eyes move if the observer tracks the object, thus keeping the retinal image stationary; or the image of the object changes its location with respect to that of other visible objects in the field, whether the eyes move or not. In order to separate these various factors and to develop a working hypothesis about the basis of movement perception, we begin with a discussion of the situation that exists when the observer is moving.

*Movements of the Observer and Perceived Movement*

Our perceptual experience during a period of movement in the stationary environment plainly contradicts the hypothesis that displacement of the retinal image leads to perceived movement of objects. When we move, or move only our eyes or head, the images of all stationary objects displace across the retina but things do not appear to move. This fact has been referred to as *position constancy*.

It would seem plausible to suppose that movement is not perceived under such circumstances because the perceptual system takes into account the fact that the displacement across the retina is simultaneous with and, therefore, caused by the observer’s own movement. The image displacement is attributed to movements of the observer rather than to movement of the environment. Of course, for this process to operate, information that the observer has engaged in some movement must be available. Even though the hypothesis does not rest on any one characterization of the information, it is of interest to identify the nature of this information.

In any event, the fact is that displacement of the image does not lead to perceived movement if the perceptual system has information that the observer’s own movement caused the image displacement. Therefore, movement across the retina clearly is not a condition that necessarily leads to perceived movement. There are also instances of the converse situation, namely, one in which the image does not move, but movement of objects is perceived. An example of this is the situation that arises during pursuit movements of the eye when an observer fixates an object and tracks it as it moves across his field. The image of the object will remain more or less fixed in position on the fovea of the retina. Nevertheless, the
object will appear to move. Of course, in this situation the image of the stationary background will displace across the retina so someone might argue that the fixated object is seen to move because there is some image displacement on the retina. Or it may be argued that the displacement of the image of the object relative to that of the surrounding background is crucial here. However, the same observation can be made when the moving object is a single isolated spot in an otherwise homogeneous environment (such as a luminous point in a darkened room). An even clearer demonstration is based on first forming an afterimage and then noting how it behaves when viewed in a dark room (or with the eyes closed) when the eyes move. The afterimage is imprinted in one location on the retina and yet, when the eyes move, it appears to move.

Under certain conditions stationary objects appear to move slightly when the eyes move. When the eyes track a moving target, the stationary background appears to move in a direction opposite to that of the moving point, an effect known as the Filehne illusion. But the magnitude of such perceived movement is slight, and often observers do perceive the background as stationary. This finding perhaps can best be understood as a slight departure from complete constancy of position, analogous to similar findings with other of the perceptual constancies. As with such other constancies, there is reason for believing that the result is based on underregistration of the information that must be taken into account by the perceptual system, in this case of the rate at which the eyes are moving.

If displacement of the image is not the correlate of perceived movement, what is? From the examples considered thus far, the following principles can be formulated. When an object is perceived to undergo a change in its location, it will be perceived to move. If the change in the object's location is based on the observer's movement, it will be perceived as stationary. In the examples thus far considered, location can be defined as radial direction. The reason that stationary objects do not undergo a change in radial direction when the eyes are in different positions is that eye position is taken into account in interpreting the direction signified by particular retinal locations. Conversely, the reason why a fixated object that moves does undergo a change in its phenomenal location when the eyes change position should also be clear. In the case of movement of the observer, stationary objects do change their radial directions with respect to the observer, but this change is fully accounted for in terms of the observer's movement. Therefore, the objects appear stationary.

The Loss and Recovery of Position Constancy

When the observer moves—or just his head or eyes move—the retinal image displaces in a particular direction and at a particular rate. For example,
when the head turns 30 degrees to the right (and assuming the eyes remain fixed with respect to the head) the retinal image of the scene shifts 30 degrees to the right. This shifting of the image is discounted and no movement is perceived.\(^1\) Therefore, we can ask the question, What will happen when the image behaves in a somewhat different fashion when the observer moves? It would seem to follow that if a 30 degree shift of the image to the right following a 30 degree head movement to the right means "world is stationary," any other direction or rate of image shifting must mean the world is not stationary. We have already encountered one such case, namely, the situation that exists when the image (or afterimage) is completely stationary and the observer—or just his eyes—moves. In keeping with the prediction, the afterimage appears to move.

It is possible to introduce a more drastic change in the behavior of the image. In a now classic experiment done at the turn of the century, the investigator, George Stratton, wore a lens system that had the effect of inverting the image and reversing it with respect to right and left [3]. He was interested in the question of whether the world would ultimately appear right side up again. However, the lens system changes the direction of movement of the retinal image based on observer movement. Stratton reported that whenever he moved his head or body, the entire scene appeared to move in the direction he was moving and twice as fast. He called this "swinging of the scene," an effect that follows from the account of movement perception presented here.

To make this clear, note that in Fig. 14.1a the observer fixates point 2. Because the image is not reversed as it normally is, he sees point 3 off to the left although actually it is to the right. Now if he moves his head to the right, b, point 3 stimulates the fovea. Hence point 3 traveled from the apparent left to straight ahead as the head moved to the right. A point changing its location in this manner when the head moves to the right would ordinarily be a moving point. Point 1 is about to move out of the field entirely, but since it has been displacing along the retina to the left, it will shortly be seen moving out of the field to the right, in the direction the head is turning. The observer, therefore, experiences a movement of the entire scene in the direction the head moves. As to the rate of perceived movement: if the image displaced normally, no movement would be experienced; if it were stationary, objects in the scene would seem to move as fast as the head, i.e., to keep pace with it. Because it displaces in the opposite direction by an amount equal to the amount of head displacement, objects in the scene must seem to move through twice the angle the head moves.\(^2\)

A similar effect seems to occur in animals [4]. In one experiment the head of a fly was surgically rotated 180 degrees and kept in that position during the experiment. As a result, the left side of each eye was on the
right side of the fly and vice versa. Consequently, when the fly moved, the images of external objects were displaced in a direction opposite to the customary one, just as in Stratton’s experiment. Before examining the result of this experiment, it is necessary to consider how the fly behaves in the experimental situation under consideration when the head is \textit{not} rotated. If a fly is placed in the center of a striped drum and the drum is rotated around the fly, then the fly typically begins to turn in the direction of the drum’s movement (see Fig. 14.2). (This is a well-known, virtually universal, reflex referred to as the optokinetic or optomotor response. In many species, including man, the eyes will turn slowly with the drum until they have gone as far as they can, whereupon they snap back and the process repeats itself.) If the drum remains stationary and a fly is permitted to move freely around on the platform inside the drum, there is no indication of an optomotor response; yet the image of the drum is sweeping across the fly’s retina precisely as in the first situation. We must, therefore, assume that the drum is not perceived as moving because the brain of the fly receives information that the fly’s own movements are producing the displacement of the image. Discounting occurs.

When the fly’s head is rotated and it is permitted to move freely around on the table, with the drum stationary, a curious thing happens. The fly begins to circle and continues to circle indefinitely. It would seem that the fly circles because the optomotor response has been triggered. This occurs because the direction in which the images of the stationary stripes displace is opposite to the one that would be discounted. Therefore, the
drum is "perceived" to turn—although it does not—and a drum "perceived" to be rotating induces the optomotor response.3

But now we must take a closer look at the problem of why the scene appears to move when the retinal image displaces abnormally during movements of an observer. It seems self-evident that if, normally, a certain direction or rate of displacement of the image for a given movement of the observer is discounted, i.e., it leads to perceiving the scene as stationary, then any other behavior of the image must lead to seeing the scene as moving. The question then is whether the normal movement of the image—for example from left to right with rightward head movement—is discounted by virtue of some innate linkage or whether it is perhaps learned.

It was noted earlier that the organism discounts the image displacement because information is available that its own movements have produced that displacement. How does the organism distinguish between instances where it has and instances where it has not produced the image displacement? A plausible answer is that self-produced displacement is perfectly correlated with bodily movement. It begins and ends concomitantly with the observer’s movement and its rate is correlated with the observer’s rate of movement. If this concomitance is indeed the crucial factor, then it
would not seem to be necessary that the image displace in a particular direction or rate in order for the discounting process to take place. If the image were to shift from right to left instead of from left to right with rightward head movement, its displacement would still be perfectly correlated with the observer’s movement.

Yet we have seen that under such abnormal conditions, discounting does not take place. The world does appear to move. May it not be the case, at least for human observers, that this effect is the result of a lifetime of experience in which the image always behaves in a particular way for any given movement of the observer? Based on such experience it is possible that we learn the rule that the retinal image moves in the same direction we move and at the same speed. Thus, only the normal displacement of the image comes to signify “world is stationary.”

If this reasoning is correct, it should be possible to undo this learning by requiring an observer to view the world for some period of time through an optical device such as the one described earlier. The observer should adapt to the new state of affairs, and this is precisely what happened in the experiment by Stratton referred to previously. The “swinging of the scene” gradually decreased and, after 3 or 4 days, disappeared entirely. Upon removing the lenses Stratton reported that the scene again appeared to move when he moved, i.e., he experienced a negative after-effect. This means that the abnormal, reversed direction of retinal displacement during observer movement had come to signify that the world was stationary; hence on removing the lenses, the reestablishment of the normal direction of displacement had to lead to an impression of object movement. Other investigators have confirmed Stratton’s observations and recently short-range studies with large numbers of subjects and more objective methods of testing have been conducted [5]. On the basis of this work it is safe to conclude that in man there is no necessary, innately determined, linkage between the specific nature of self-produced image-displacement and constancy of position of objects in the world. Rather, it is clearly the case that position constancy is subject to learning.

**Stroboscopic Movement**

Everyone, it would seem, knows that moving pictures are made by projecting a series of stationary frames on a screen in rapid succession. Yet few people seem to be curious about the basis of this effect and those who are seem to be satisfied with an incorrect explanation. The incorrect explanation asserts that the effect is based on the fact that the cells of the retina continue to fire after a given frame is no longer present. Hence there is no experience of a gap or of a dark screen between successive frames. This is true and it explains why, at the optimum projection speed,
we do not experience a flicker (although in the early days of moving pictures flickering did occur). But this still leaves unexplained why we experience objects presented in these stationary pictures as *moving*.

The fact of the matter is that we do not know why movement is perceived, but psychologists have reduced the problem to its bare essentials in the laboratory. In a typical experiment, two points of light or two lines are projected alternately on the screen (see Fig. 14.3). First *a* is flashed briefly; then *a* goes off and there is a brief period when nothing is visible; finally *b* goes on for the same duration as *a*; followed by another brief interval; then *a* goes on again and so forth. At very slow speeds of alternation, the observer typically perceives two lines alternating, but no movement; at very fast speeds, he perceives two lines both of which seems to be present simultaneously; at some intermediate speed he sees movement, as if there were only one line moving back and forth. The illusion of movement is so strong that it cannot be distinguished from real movement. This is clearly the case in modern motion pictures where the basic effect can be analyzed into several different components all of which are changing location simultaneously (see Fig. 14.4). In the figure several actions are depicted as occurring at the same time. The man's arm 1–2
is moving forward and his leg 3—4 is moving upward. Needless to say, filmstrips can be either drawn to simulate such changes of position (animated cartoons) or achieved by moving picture photography. In the latter case, the camera records successive shots taken at brief intervals.

A further complication arises in the case of moving pictures that is based on the fact that objects rather than single points or lines are changing location. Suppose we consider a triangle and focus our attention on the three corners as illustrated in Fig. 14.5. If in one frame the triangle is in a given place, a, then in the next frame it may be somewhat to the right, b. If only point 1 were visible in a and only point 3' in b, then obviously point 1 would be seen to move to where point 3' is located. This is also true with respect to all other possible changes. But when the entire array 1, 2, 3 is shown in both a and b, 1 is seen to move to 1', 2 to 2', and 3 to 3'.

Therefore, it would seem that in addition to the basic stroboscopic illusion there is a further principle at work, a tendency to see objects move as-a-whole in such a way as to preserve their overall integrity. This fact has been demonstrated even more dramatically in the following type of experiment. In a in Fig. 14.6 three dots are exposed, 1, 2, and 3. In b three dots are again exposed, 2', 3', and 4. However, the leftmost two dots of b, 2' and 3', are in the identical place as the two rightmost dots of a, 2 and 3 (shown by locating the dots within the rectangular frame of the screen in a and b). Given these two arrangements, we should predict that only one dot will undergo a stroboscopic effect, namely the leftmost dot in a, dot 1, should appear to move to the location of the rightmost dot in b, dot 4.
Since there is no change of location of the other two dots, they should appear to flash on and off in the same place. Instead, most observers perceive three dots shifting back and forth. The leftmost dot of $a$ is seen to move to the place of the leftmost dot in $b$, the middle dot in $a$ is seen to move to the middle dot in $b$, and so on. This effect, known as the Ternus effect in honor of the discoverer, illustrates the principle that there is a tendency to see an entire configuration move in such a way that each part maintains its role or function in the configuration (e.g., a center spot remains a center spot, and so on). Ternus referred to this tendency as "phenomenal identity" [6]. Were it not for this tendency, moving pictures would not be possible, the movement perceived would be utterly chaotic.

If, however, the time interval (the ISI) is very brief, phenomenal identity does not occur, and the two overlapping dots do appear to flash on and off in place and only the remaining dot appears to move back and forth over the stationary dots [7].

An interesting effect that many people have noted in viewing moving pictures is that wheels often appear to be rotating backward, i.e., in a direction opposite to the forward motion of the vehicle. This "wagon-wheel effect" as it has been called, is easily explained. In Fig. 14.7a, a wheel is shown as it might appear in one frame of the filmstrip. Suppose the wheel turns approximately 50 degrees between successive frames. Then Fig. 14.7b shows how the wheel will look in the next frame. Thus, in actual fact, the spoke marked with an arrow in $a$ will have advanced to the position that it is in in $b$. If that spoke in $a$ were perceived to move to its position in $b$ (and similarly for all other spokes), the wheel as a whole would appear to roll forward. But the spokes are all similar. The spoke marked $x$ in $b$ is nearer to the place of the spoke marked with an arrow in $a$ than is the correct spoke in $b$. It is known that proximity governs stroboscopic movement, that is, other things being equal, movement will occur between objects that are nearest to one another in $a$ and $b$. There-
fore, under these conditions, movement will be perceived toward spokes in b that are actually counterclockwise with respect to those in a.

Psychologists have been intrigued with this illusion of movement—which has variously been called stroboscopic movement, apparent movement, Beta movement, or the Phi phenomenon—and the overwhelming bulk of research on movement perception has been concerned with this phenomenon. It is believed that a full explanation of this illusion would point the way to an overall theory of movement perception and, in general, would unlock some of the secrets of brain function. There is no movement whatsoever of the retinal image in this situation, thus constituting further evidence against the idea that the perception of movement is based on the movement of the image across the retina.

It was this illusion, among other facts, that led Wertheimer, one of the founders of Gestalt psychology, to conclude that perceptual experience could not be explained on the basis of a one-to-one correspondence between proximal stimulus and sensation [8]. Rather it would seem that the brain contributes something of its own to the raw sensory input. The component sensations are organized, and this organization then forms the basis or correlate of what we experience. In fact, Wertheimer went on to postulate a doctrine known as isomorphism, which holds that underlying every sensory experience is a brain event that, structurally considered, is similar to that experience. In the case of stroboscopic movement, since there is no movement in the proximal stimulation to account for the experienced movement, there must be some process taking place in the brain that has the necessary dynamic properties to give rise to such experience. He postulated that between regions of excitation corresponding to each image (such as a and b in Fig. 14.3), there is a flow of electrical energy that gives rise to the impression of movement.

This theory (or variations of it) has been widely respected, and a good deal of research has been directed at testing it. The feeling has been that the perception of movement under stroboscopic stimulus conditions reflects a fundamental fact of brain action on a primitive level. One reason for this belief is that lower animals and decorticated guinea pigs react as if they saw movement under these conditions [9]. This has been shown by training an animal to discriminate a moving target from a stationary one and then substituting a stroboscopically flashing stimulus for the moving one [10]. The animals tested continued to respond as if a moving stimulus were present. Another method involved the presentation of an array of vertical columns inside a drum (as in the situation employed to induce the optomotor response) [11]. When the columns were flashed in successive positions stroboscopically, the animals reacted precisely as they did when the drum actually rotated. In fact, using the technique that simulates movement in electric signs, it has been possible to show the presence of
the illusion in newly born guppies, newly hatched insects, and human infants [12]. Another reason for the belief that the illusion of motion is based on some basic mode of brain function is the fact, already noted, that it requires rather specific stimulus conditions, such as a particular rate of stimulus alternation. Other factors known to be relevant are intensity of light and the distance between \(a\) and \(b\) [13].

Some evidence supports Wertheimer’s theory or variations of it that holds that there is some interaction in the brain—or in the retina—between the excitations emanating from \(a\) and \(b\). This might be called the spread-of-excitation theory. For example, it has been found that the illusion of motion occurs more readily if both \(a\) and \(b\) are placed so as to fall within one hemisphere of the brain rather than, as is more typically the case, when the observer is fixating a point midway between \(a\) and \(b\). \(a\) is projected to one hemisphere and \(b\) to the other [14]. Also the effect is more readily obtained if both \(a\) and \(b\) fall in one eye as compared with \(a\) stimulating one eye and \(b\) the other [15].

One factor contributing to the plausibility of this theory is that some bridging process does seem necessary to explain an apparent motion between two discrete spatially separate retinal-cortical locations. But suppose stroboscopic movement does not require stimulation of separate retinal locations. Perhaps what is crucial is that \(a\) and \(b\) are perceptually localized in two separate places regardless of where their corresponding images fall on the retina. After all, as noted earlier in this chapter, we know that an object will be seen to move if the observer tracks it with his eyes as it displaces across his field of view despite the fact that the image then remains more or less fixed on the fovea. The experience of movement in this case is based on information from change of eye position that the object fixated is in varying phenomena locations.

May not the same be true for stroboscopic stimulus conditions? To test this, observers were required to move their eyes back and forth synchronizing their movements with the flashing of lines \(a\) and \(b\) [16]. In other words, as \(a\) flashed on, the observer’s eyes were directed at \(a\); as \(b\) flashed on, his eyes just reached the position where they were directed at \(b\), and so forth. Under these conditions, \(a\) and \(b\) fell on the same retinal locus, not a different one as is usually the case. The majority of observers nevertheless experienced \(a\) and \(b\) moving back and forth.\(^5\) In the converse experiment, it was shown that if only a single point \(a\) flashes intermittently and the observer is required to move his eyes rapidly back and forth, then no movement is perceived. Yet the eye movement guarantees that \(a\) falls on separate retinal loci in this procedure. The outcome is predictable in terms of position constancy. Apparently, therefore, spread of excitation is neither a necessary nor a sufficient determinant of stroboscopic movement perception.
From these experiments, one can conclude that what is crucial is the location of $a$ and $b$ in separate phenomenal places in space. Thus, the stroboscopic illusion fits with the principle suggested earlier, namely, movement will be experienced when an object appears to undergo a change in its location. The only difference between stroboscopic and "real" movement is the fact that in the former case the stimulus is not continuously present.

Why is movement seen in spite of the fact that the stimulus is intermittent? We cannot fully answer this question, but it is relevant to point out that the observer tends to identify $a$ and $b$ as the same object. If an object is now here and now there, it is "logical" to assume that it has moved from one place to the other particularly when the object inexplicably disappears from one place and inexplicably appears in another place. Experiments have shown that the illusion is facilitated if $a$ and $b$ are identical rather than different in shape or color. Movement can be perceived if $a$ and $b$ are different, but then one has the impression that $a$ is changing into $b$ during the movement.

Movement of a single object would not, however, be a valid "solution" of the problem of what was occurring in the world, if, when $b$ appeared, $a$ appeared with it. In other words, suppose the sequence were $a; a$ and $b; a; a$ and $b$; instead of $a; b; a; b$; and so on. Under such conditions it would not be plausible to suppose that $a$ has moved to $b$ for the simple reason that $a$ is again present in the place where it had been a moment ago when $b$ appears. If the procedure is varied slightly so that instead of $a$ appearing with $b$, an object similar to $a$ appears, $a'$, then it is an intelligent solution to perceive $a$ as having moved to $b$ and to perceive $a'$ as some new object that appears and disappears in the place $a$ had occupied. The two variations are illustrated in Fig. 14.8. The result of such an experiment is that it

![Figure 14.8](image-url)
is difficult to perceive movement in the first condition but not in the second [18].

It would also follow from the hypothesis suggested here, namely, that the perception of movement under stroboscopic stimulus conditions is an intelligent solution of a problem, that information which suggests an alternative solution to the "problem" of the alternate appearance and disappearance of \( a \) and \( b \), may eliminate the perception of movement. Suppose, for example, information is available that \( a \) and \( b \) have not actually disappeared but rather have been momentarily covered over. One way of achieving this is to move an opaque object back and forth, alternately covering and uncovering \( a \) and \( b \), as shown in Fig. 14.9. Here \( a \) and \( b \) stimulate the retina alternately just as in ordinary stroboscopic movement conditions, but the observer does not typically perceive movement. Rather, he sees \( a \) and \( b \) as continuously present but as alternately covered and uncovered by the moving rectangle [19].

One might wish to argue that the introduction of the large moving rectangle interferes with the perceived movement of the dot, but the following variation proves this argument wrong. Let the rectangle move farther than it does in Fig. 14.9 as shown in Fig. 14.10. Now the rectangle is no longer covering the region where \( a \) or \( b \) had been seen a moment before (marked \( x \) and \( x' \) in the figure). The rectangle moves over that region and beyond it, so that it is evident that it is not covering \( a \) or \( b \). Therefore, logically, the dot should be visible, but it is not (the technical method by which \( a \) and \( b \) are rendered invisible need not be discussed here). Consequently, the "solution" to the problem of the alternate appearance and disappearance of \( a \) and \( b \) can no longer be that they have been covered and uncovered. This leaves little alternative but to "solve the problem" by perceiving movement of \( a \) to \( b \) and this indeed is precisely what happens.
An additional fact that fits with the notion of stroboscopic movement perception as an intelligent solution to a problem is that the kind of movement perceived is tailored to the orientation of \(a\) and \(b\), as shown in Fig. 14.11. Thus, the configuration seen in \(a\) will appear to rotate either in the frontal plane or in the third dimension as it moves to \(b\). Such effects are not predictable in terms of a spread of excitation theory.

Ordinarily, when an object moves very rapidly, its image is little more than a blur across the retina. Perhaps, therefore, even in certain cases in which there is an actually moving object, the more important aspect of the stimulus information is the location of the object in its starting and terminal positions. The intervening stimulation characterized mostly by blur may not contribute much, if anything, to the impression of movement. Precisely this point has now been examined in an ingenious experiment in which the sight of the terminal locations of a moving object was blocked [20]. All the observer could see was the region between the terminal locations through which the object moved. As soon as the speed of the object was quite rapid, on the average beyond 8 degrees per second, it began to appear blurred. At the speed of around 17 degrees per second, a fused blinking line was perceived rather than a moving object. Yet when the terminal locations of the moving object could be seen, a sense of movement did occur at and even beyond these rapid speeds. Therefore,
this perceived movement must be the result of the sight of the stationary positions of the object. In short, at these rapid speeds, real movement perception is based on the same stimulus information that gives rise to the perception of stroboscopic movement.

In fact, in the same experiment, it was shown that when the intervening space between the terminal locations was blocked from view—the conditions for generating stroboscopic movement—observers only began to perceive movement at a speed of the object, where, had the object been visible in the intervening space, it would have appeared blurred. At too great a speed, around 21 degrees per second, the observers no longer see the object as moving, but rather as simultaneously present in both terminal locations. From these findings the investigators concluded that stroboscopic movement perception has different time constants than real movement perception and that, therefore, the mechanism underlying it takes over, as soon as the speed of a moving object is too great for perception to be mediated by the mechanism underlying real movement perception.

The great merit of the notion that the perception of a very rapidly moving object is essentially stroboscopic, i.e., based primarily on the stationary stimulation from its terminal positions, is that it offers an explanation of why a mechanism for perceiving stroboscopic movement evolved. It is difficult to find instances in the natural environment where a moving object gives rise to stroboscopic stimulus conditions. Therefore, one might well ask why such perception evolved if it serves no adaptive purpose. The answer could be that it evolved to mediate the perception of rapid real movement.

Why though, does the perception of stroboscopic movement require just the rate of alternation that it does? One answer, implied by what was stated previously, is that it is based on a separate innate mechanism having its own time constants that is designed to take over when the perception of real movement fails because the movement is too fast. But, based on the hypothesis that stroboscopic movement perception occurs only when such perception is an intelligent solution to the problem presented by the stimulus input, one can argue that at slower rates of alternation, the perceptual system would "expect" to detect the motion from $a$ to $b$. That is, a truly moving object whose speed was less than about 8 degrees per second would travel from $a$ to $b$ at a rate that should make it clearly visible in its intervening region. Therefore, when in stroboscopic stimulation, $a$ and $b$ flash at a rate compatible with such speed or lower, one ought to perceive the object in the intervening space. Since one does not, it constitutes a contradiction to the solution of movement. Thus, only when the rate of alternation is such that one would not expect to detect
movement across this intervening space, is the "solution" of movement a truly good solution.

One can also say something sensible about the other end of the range of speeds at which stroboscopic movement ceases, namely, when the alternation is too rapid. At this rapid rate one perceives simultaneity, no doubt because of the persistence of neural discharge even after a is no longer physically present. The point is that it is not plausible to infer movement of a to b if a is still visible. The abolition of movement perception by the perceptual presence of a when b comes on has already been discussed previously and illustrated in Fig. 14.6. This can also explain cases of failure to perceive the Ternus effect as discussed previously and illustrated in Fig. 14.6.

From this discussion we can readily see that two different theories of stroboscopic movement are possible. One theory claims that the impression of movement is based on an automatic tendency of the nervous system to react to discrete successive stimulation in the same way it would react to continuous movement stimulation because there is some form of spread-of-excitation or neural interaction between the successive stimuli or some other direct sensory mechanism. The other theory maintains that the discrete stimulation lends itself to the cognitive "solution" that movement has occurred and that movement perception occurs only if the stimulus events can best be interpreted in this way.

Although many of the findings seem either to contradict the spread-of-excitation theory or are not compatible with it, and many others support the cognitive theory, a number of other facts support the hypothesis that a direct sensory mechanism is responsible for the perception of movement under stroboscopic conditions. The perception of stroboscopic movement in newly born organisms, such as fish or insects or in decorticated guinea pigs, does not seem to jibe with the notion that a reasoning-like process is responsible for the movement perception although, admittedly, it is possible that the kind of nonconscious, nonverbal, problem-solving postulated could nevertheless occur in these cases.6

Also, as is made clear later in the chapter, there is direct evidence that units in the visual nervous system can "detect" stroboscopic movement because they respond uniquely to a given sequence of discrete stimulation. Therefore, one might conclude that there are two possible bases for the perception of stroboscopic movement, a direct sensory mechanism and a cognitive process of perceptual problem-solving.

The Autokinetic Effect

Another illusion that has intrigued psychologists is one in which a single stationary point of light appears to move. The point must be seen against a perfectly homogeneous background and the easiest way to achieve this
is to view a luminous point in a completely darkened room. Under such conditions, and following some initial period of viewing, the observer typically experiences the point as drifting, either to one side or upward or downward. So real is the experience that the observer finds it hard to believe the experimenter when he is later told that the point has not moved at all.

This effect is considered to be as yet unexplained although many theories have been proposed to account for it. It has often been suggested that the illusion is based on movements of the observer's eyes. There are at least two things wrong with this notion. First, the observer is usually told to fixate the point and to the extent he succeeds in obeying instructions his eyes are, of course, stationary. Indeed it has been shown by photographing the observer's eyes under infrared illumination that they are in fact stationary at the very moment the point seems to be moving [23]. Second, as the reader should now understand, stationary things do not appear to move when the eyes move. The displacement of the image is discounted; position constancy obtains. Therefore, even if the eyes were in continuous motion there is no reason to consider this as an explanation of what is referred to as autokinetic movement.

However, it is possible to defend the eye movement theory if it is stated in a more sophisticated fashion. If, when the eyes moved, there were no centrally registered information to the effect that they had moved, then we would have to predict that the displacement of the image (of a stationary point) would give rise to an impression of movement. Ordinarily, the eyes either move in quick jumps from one location to another (saccadic movements) or slowly and smoothly as they track a slowly moving target (pursuit movements). Obviously, pursuit movements are not occurring in the case of a stationary target, and even if saccadic movements do occasionally occur, they would surely be discounted. But even when fixating, minute involuntary movements of the eyes do occur. They tend to drift slowly and to flick saccadically and in addition, to oscillate rapidly back and forth, a kind of continuous tremor. Collectively these involuntary eye movements are referred to as physiological nystagmus. The extent of these movements is extremely small. In all probability, this type of involuntary movement is not registered centrally and, therefore, would not lead to discounting of the displacing retinal image. Can eye movement of this kind explain the autokinetic effect?

To test this hypothesis, an experiment was performed that made use of a technique whereby an image on the retina is prevented from shifting at all. Various methods to achieve this stabilization of the image have been employed, such as projecting the image onto the retina from a device that is itself mounted on a contact lens placed on the eyeball [24]. Thus, when the eye moves the image moves with it. In the experiment under
discussion the technique was modified in such a way that movement of the image was stopped in the horizontal direction only \[25\]. Therefore, no displacement of the image was caused by slight eye movements only in this direction. The observer, of course, knew nothing about this fact. There were few reports of movements of the target in that direction whereas there were many reports of movement in all other directions.

There is thus evidence to support this modified eye-movement theory.\(^7\) One difficulty with it, however, is that the excursion of the eyes during these involuntary movements is very small (a few minutes of arc) in relation to the extent of autokinetic movement typically perceived (a few degrees or more). The theory would only be tenable if it were claimed that the cumulative effect of these eye movements over a period of time produced a sizable amount of displacement of the image. But there is a difficulty with this formulation because the target typically does not appear to erratically reverse direction (as do the eyes during nystagmus), but rather seems to drift continuously in one direction. Another difficulty for this theory is that nondiscounted image displacements based on such eye movements also occur under typical conditions in daily life whenever the observer fixates a point in the field. Therefore, the entire scene should appear to drift but, of course, it does not. An explanation is thus required of why such a mechanism only yields an autokinetic effect for a single isolated point in an otherwise homogeneous field.

The author would like to suggest a different approach to the problem of the autokinetic effect. As is brought out in the next section of this chapter, a very important source of information concerning movement is the change of location of one thing relative to other things. Therefore the opposite is also true, that when an object does not change its location relative to other objects this is information that the object is not moving. But it is precisely this kind of information which is lacking in the autokinetic situation because only a single point is visible. Therefore what one perceives in this situation depends entirely upon the accuracy of the following information: the displacement or nondisplacement of the retinal image and the movement or non-movement of the eyes. Let us assume for the moment that the eyes are stationary because the observer is fixating the point of light (and let us assume that the slight involuntary movement of the eyes is not relevant, contrary to the hypothesis explored in the preceding paragraphs). Then the retinal image does not move. Therefore it would seem that the only basis for perceiving the point moving rather than stationary is some failure of the perceptual system to appreciate that the eyes are indeed stationary. Perhaps, for reasons not yet clear this is the case, so that the system interprets the stationary eyes as slowly drifting. If they were really drifting slowly then a fixated point would have to be interpreted as moving, since the eyes would be tracking it.
There should be no record of eye movement if, with the eyes stationary, no "commands" are issued to the eye muscles to move.\textsuperscript{8} But if for some reason an observer momentarily had the erroneous impression that he was viewing a moving point, then this impression would suffice to induce a feeling that his eyes were tracking it. It is known that effects of this kind occur, as, for example, when one has the illusory impression that an object that one is looking at is moving although it is actually its surroundings that are moving. (See the discussion of induced movement that follows.) False impressions of eye movement under such conditions can be thought of as instances of visual capture. Admittedly, it is not clear in the autokinetic situation what triggers the initial "belief" that the point was moving. But once that "belief" took hold it is understandable that the perceptual system could erroneously interpret the eyes as slowly tracking the point.\textsuperscript{9} However, to repeat, this is only possible, because information concerning the point's fixed location with respect to other objects in the field is lacking.

The reader might object that to suffer the illusion that one was tracking a stationary point which was drifting by several degrees implies that the perceptual system would interpret a straight-ahead position of the eyes as turned to the side. Does this implication do violence to what is known about the precision with which the direction of the eyes is registered? Not necessarily. In studying the perception of radial direction, it was noted that observers are neither perfectly accurate nor consistent in setting a target to the straight-ahead position. They can perform this task only within a range of a few degrees of error. This suggests that at any given moment the eyes can deviate a few degrees from the true straight-ahead direction and still be interpreted as straight-ahead: conversely they may be straight ahead and still be interpreted as slightly off to the side. Therefore, if in the autokinetic situation the perceptual system were at a given moment to "interpret" the eyes as slightly turned (although they were not) the observer would have to see the fixated target off to the side.

\textit{Relative Displacement and Induced Movement}

When an object moves across the field, it changes its location with respect to the observer but it also changes its location relative to all other visible things. What importance, if any, is this relative change? A simple experiment will make clear that relative change plays an important role in the perception of movement [28]. First, a single luminous point, \(a\), is set to move at so slow a speed that it does not appear to be moving, i.e., it is below the threshold for the detection of movement (see Fig. 14.12). It is the only thing visible. Now a second stationary point \(b\) is introduced (see Fig. 14.13). Immediately the observer sees movement. The conclusion is
inescapable that the change in relative distance between points $a$ and $b$ leads to perceived movement. We refer to this as object-relative change in contrast to change of position in relation to the observer or subject-relative change. The threshold for object-relative change is lower than that for subject-relative change. Had point $a$ been moving at a speed above the subject-relative threshold, the conclusion about the important role of object-relative change would not be warranted because the perceived movement could be a function either of $a$’s change of location with respect to the observer or with respect to point $b$. There are thus two separate and independent factors that can lead to the perception of movement: subject-relative change of location and object-relative change of location.

In fact, in the experiment described, it is not necessarily point $a$ that is seen to move when stationary point $b$ is introduced; $b$ may be seen to move or both $a$ and $b$ may be seen as moving apart. This ambiguity is precisely what we should expect if the crucial information is relative, i.e., the increasing or decreasing separation between points $a$ and $b$.\(^\text{10}\) That information does not specify which point is moving.

Now let us change the experiment in one respect. Let the second object be a luminous rectangular perimeter, $b$, which surrounds $a$ rather than a point (see Fig. 14.14). In this situation, all observers will see $a$ as moving; the outcome is no longer ambiguous. Moreover the same is true if it is $b$ that is made to move and not $a$ (see Fig. 14.15). Whether $a$ or $b$ is actually moving, the observer will see $a$ moving. If $b$ is moved to the left, $a$ will be seen moving to the right. When one objects moves and the observer sees
a stationary object near it as moving, the illusory effect is called induced movement.

Apparently a further principle is operating here in addition to the principle that change of relative position is a determinant of movement perception. That object that surrounds the other or otherwise dominates—such as by its greater size—tends to become a frame of reference and, as such, to be seen as stationary. The relative displacement is then interpreted as movement in relation to it. A good example of this effect in daily life occurs when the moon appears to be moving through the clouds (Fig. 14.16). The moon does change its location in the sky relative to us but at such a slow rate as to be far below our movement threshold. A cloud, however, is changing its position at a faster rate although this too may be below threshold. In any case, the relative change of position between cloud and moon provides the crucial information; the cloud serves as a frame of reference and it, therefore, induces movement in the moon. Induced movement is one more illustration of the fact that displacement of the image is not a necessary condition for perceiving movement. The image of the surrounded object is stationary and the object nevertheless appears to move.\(^\text{11}\)

Induced movement can occur even when the object which is actually moving is displacing at a rate that is above threshold. In other words, a cloud that is moving so rapidly that when it is seen alone would clearly be perceived as moving, will nevertheless induce movement in the moon. This is surprising since the relative displacement between moon and cloud
is now fully accounted for by seeing the cloud move. Duncker suggested that the surrounded object is seen entirely in terms of its behavior in relation to its immediate frame of reference. What it does in relation to more remote reference systems is not relevant. Thus, although the moon is stationary with respect to a tree or with respect to the observer, this does not significantly interfere with the induced movement created by the immediately surrounding cloud. All that matters is that there is relative displacement between moon and cloud and that the cloud serves as frame of reference in the moon-cloud system.

The experience of the cloud on the other hand is a function of its behavior in relation to its immediate frame of reference, such as the buildings in Fig. 14.17. Or we may think of the frame of reference in terms of the subject-relative system of radial direction—straight ahead, left, above, and so on—which is present even when no objects other than the clouds are visible. Duncker, therefore, argued that there is a separation of systems: in our example the first is the moon-cloud system, the second is the cloud-building system or cloud-ego system. In this way one can explain why there is more movement perceived than is warranted on the basis of the relative displacement taking place. To repeat, when the cloud moves above threshold, its displacement relative to the moon is fully accounted for by the fact that it is seen to move; yet the moon is seen to move in the opposite direction by an equal amount. There is thus twice as much perceived movement as we might expect.

An interesting application of the concept of separation of system was made by Duncker in relation to the way we perceive movement of points on a wheel [28]. Consider a point $a$ on a wheel rolling along the ground (Fig. 14.18). The dotted circles represent successive positions of the wheel.
and in each the location of point $a$ is shown. In Fig. 14.19 only the path taken by point $a$ is shown. It can be seen that point $a$ describes a path through space that is not circular; a path that mathematicians call a cycloid. If only point $a$ were visible—made luminous in a dark room—and the wheel rolled forward the observer would then see this cycloid path.

The fact is, however, that ordinarily when we look at a rolling wheel, although every point on it (except the very center) describes a cycloid, we do not see this. We see points on the wheel turning in a circular path about the hub and we see the entire wheel moving forward along a straight path. Apparently, the hub of the wheel is the reference system for movements of points on the wheel; the background (or possibly the egocentric system of the observer) is the frame of reference for the wheel as a whole. Thus there is a separation of systems.

Returning to the phenomenon of induced movement, the question arises as to why the surrounding moving object is seen as stationary (at least when its movement is below the subject-relative threshold) and thereby serves as frame of reference for the surrounded object. Either could be seen as moving. Duncker attributed this fact to an innate selective principle of organization or preference of the perceptual system. It is also possible to argue that the principle is learned, since ordinarily it is the smaller object within the perceived environment that undergoes displacement.

The importance of object-relative displacement as a determinant of movement perception is made clear in the research of Johansson involving an array of separately moving elements [31]. In one experiment, two elements are moving at right angles to one another as shown in Fig. 14.20a. Since the elements both are moving well above the subject-relative threshold, and since there is no frame of reference present to
create a separate system, one would think that there is no good reason why the path of each element should not be veridically perceived. But, in fact, what one perceives is shown in Fig. 14.20b: the elements appear to be approaching and receding from one another along an oblique path. This is the dominant impression. In addition, however, the two elements, as a group, appear to be moving in the opposite oblique direction.

This outcome becomes understandable if one assumes that object-relative displacement exerts a stronger effect on perceived movement than does subject-relative displacement whenever a conflict between the two determinants exists. Ordinarily, the two are not in conflict but rather lead to the same perception, as when a single object moves in a stationary scene. But in the case of induced movement or the experiment illustrated in Fig. 14.20, a conflict exists. What the two elements are doing in relation to each other is not the same as what they are doing in relation to the observer. The former is apparently dominant, so that one primarily perceives the elements gliding toward and away from each other along the path of shortest distance between them, namely an oblique path. However, once that is perceived, there remains a component of the motion of the elements not accounted for (32). If one analyzes the path of motion in terms of vectors, as Johansson does, then given the perception of motion along the common oblique path, the component not accounted for in this perception is indicated by a vector at right angles to this path (see Fig. 14.21). In other words, the true motion is dissociated by the perceptual system into two components.

Another example is shown in Fig. 14.22a where one element moves in a vertical path and a second element moves in a circular path. The motions are in phase in the sense that both dots reach the top and bottom of their paths simultaneously. What one typically perceives is shown in b: the dominant impression is of the element on the right approaching and receding from the one of the left along a horizontal path; secondarily one sees the two elements as a pair moving up and down. One does not perceive the element on the right traveling in a circular path although that in fact is what it is doing; a dissociation of motion occurs.12

The example of the perceived motion of elements on a wheel described earlier can be understood in terms of this analysis. The cycloid paths of the
elements of a rolling wheel are perceptually dissociated into two components: an impression of their motions relative to one another, namely rotation about a center and an impression of the residual motion that all elements share, namely a rectilinear translation across the field.

What general conclusions can we reach from the work on relative displacement and induced movement? It would seem that the generalization made earlier remains valid, namely, that whenever an object seems to change its phenomenal location (at a rate above threshold) movement will be perceived. However, it is now necessary to add that phenomenal location may be defined not only egocentrically, in relation to the observer as origin of directions, but also objectively, in relation to other objects (which may or may not serve as frames of reference). We thus see that change of relative position is a potent source of formation in the perception of movement. This fact places the autokinetic effect in a context that makes it somewhat more intelligible: There are no reference objects for the single point of light. Ordinarily, the absence of change of relative position is information that objects are not moving. Such information is not available in the autokinetic situation.

*Induced Movement of the Self*
Among other objects in the visual field is the body of the observer. Parts of the body are, of course, often visible. But even when the body is not seen, it has an inferred location in relation to the scene, that is to say, we
are always aware of precisely where in the visual field we ourselves are located. Considering the self, therefore, as an object in the visual field, what should we predict if the observer is surrounded by a moving frame of reference? We should predict that the observer will perceive himself moving although he is stationary; induced movement of the self.

This is precisely what happens. A laboratory technique for studying this effect is shown in Fig. 14.23. The observer is seated on a stool in the center of a large drum (the drum can be a lightweight construction somewhat like a lamp shade). The drum is made to rotate around the observer. Ideally, the observer should not be able to see beyond the drum or above or below it. Within 10 or 15 seconds after the rotation begins, the observer typically experiences himself as rotating and the drum as stationary or as turning much slower than it actually is. This effect attests to the efficacy of the frame of reference in governing movement perception and also to the dominance of vision over proprioception. Cues concerning felt position such as the vertibular cues from the inner ear are informing the observer that he is stationary. Yet he feels himself turning (still another example of visual capture).

There are examples of this phenomenon in daily life, the best known being that of perceiving one’s own train as moving when in fact it is not, as a result of the movement of a train on the adjacent track. This usually occurs when we are seated next to the window facing the other train. That train then fills most of the visual field. Induced movement of the self
here includes one's own train. (If, however, we are looking through the window from across the aisle, our own train fills most of the field. In the latter case we might erroneously see a stationary train in the adjacent track as moving when our train is moving. This would be induced movement, but not of the self). Another example is that of experiencing one’s own stationary automobile as rolling when we stop for a light as a result of viewing an adjacent car that in fact is rolling. When this happens one is inclined to jam on the brakes. Induced movement of the self also occurs in looking down at a moving current of water, either from a bridge or from a stationary boat.

It is probable, however, that induced movement of the self has applicability to a wider range of phenomena than these occasional instances in daily life would suggest. It is likely that in many situations where the observer is actually moving he would not experience himself as moving—and the environment as stationary—were it not for the induced movement effect. The reason for this deduction is as follows. In discussing position constancy earlier in this chapter, we noted that information to the effect that the observer is moving must be centrally registered before we can expect discounting of displacement of the retinal image to occur. One kind of information (relevant at least to active eye movements) is a record of outgoing signals to the musculature. Another is vestibular information that we can assume is present during acceleration and deceleration and in turning movements. Suppose, however, that neither of these is applicable as when the observer is a passenger in a vehicle moving at a constant speed along a straight path.

There would seem to be no information in the latter case. An experiment has confirmed this by showing that if an observer is moved in a wagon at uniform speed in a dark room, he will erroneously see a stationary spot of light on the wall as moving and experience himself as stationary. If, however, a pattern of luminous lines is displayed on the wall instead of the spot, the observer now veridically experiences the lines as stationary and himself as moving [33]. The only difference would seem to be that in the second situation the observer is surrounded by the displacing pattern, whereas in the first situation he is not. Therefore, the perception in the second situation would seem to be a manifestation of induced movement of the self. From this it follows that in many if not most instances of transportation in a vehicle, perception of one’s self and vehicle as moving is a function of the inducing effect of the displacing field that surrounds the observer. This is a paradoxical conclusion—possibly confusing to the reader—because the observer is in fact moving. Yet, as the experiment cited shows, he would not perceive this were it not for the sight of the displacing environment. It is not beyond the realm of plausibility that even in the case where the observer is more actively
Can a Movement-Detector Mechanism Explain the Perception of Movement?

Units of the visual nervous system have been discovered in several species that respond to or "detect" movement of a contour over the appropriate region of the retina [34]. These units respond optimally to movement of a contour in a particular direction and not at all to movement in the opposite direction. Can such a detector mechanism explain the perception of movement?

One phenomenon of movement perception that has not yet been mentioned may be explained by this kind of sensory mechanism. If one observes a pattern, such as stripes, moving in a particular direction for a period of time, and then looks at a stationary pattern, for example the same stripes, the stationary pattern will now appear to move slowly in a direction opposite to the one in which it had previously moved. This effect is known variously as the aftereffect of movement, the waterfall or spiral illusion (because we can easily observe it after first viewing a waterfall or a rotating spiral). It is difficult to explain this kind of effect in terms of any of the principles considered in this chapter. In fact, in this aftereffect, stationary objects appear to be moving but do not seem to change their location, a paradoxical experience and contradictory to the main thesis developed in this chapter that movement perception results from a change in an object's perceived location.

However, it stands to reason that those neural units that are sensitive to a particular direction of movement would become fatigued by the continuous motion of the pattern in one direction. The possible consequences of this effect can best be elucidated by analogy to the negative afterimage that occurs when retinal cells sensitive to a given wavelength are fatigued. As a result, a subsequently viewed gray region takes on a color complementary to the one previously inspected. Hence, one might expect such an aftereffect of motion. In the example of the negative afterimage, the presumption is that cells sensitive to the opposite wavelength are now no longer balanced by equal activity of those sensitive to the color previously inspected. Therefore, they respond more than others and produce the impression of the complementary color. Thus, in the case of movement, it might be assumed that neural units sensitive to a direction opposite to the one just seen now respond more than any other directionally sensitive receptors. There is direct physiological evidence that this is the case. It was shown that the rate of discharge of ganglion cells
of the retina of the rabbit decreases when the appropriate region of the retina is exposed to a pattern moving in a particular direction. When the pattern stops moving the rate of discharge from these cells falls below the so-called maintained or resting level of discharge that these cells typically display \[35\]. Consequently the negative aftereffect of movement may be based on the relatively greater frequency of maintained discharge of those cells that are sensitive to movement stimulation in a direction opposite to the one just encountered. There is now an imbalance between units that signal movement in opposite directions. In further support of this conclusion is the finding that after viewing a moving pattern, the threshold for detecting stripes moving in the opposite direction is lower than for stripes moving in the same direction as that of the just seen moving pattern \[36\].

In fact, it had been claimed in an early investigation that the aftereffect of motion depends on the displacement of the image of the moving pattern over the retina rather than on the perception of the motion per se \[37\]. If during the inspection phase one tracks the moving pattern, no aftereffect occurs, although the movement of the pattern was, of course, perceived. Here there is no image displacement during the inspection period. Conversely, if one moves one's eyes smoothly across a stationary pattern of stripes by tracking a moving fixation mark, the aftereffect does occur. Here there is image displacement during inspection phase, but no perceived movement of the stripes. Therefore, if these findings held up, the phenomenon can be said to be misnamed the aftereffect of movement; it would rather be an aftereffect of image displacement. However, later research failed to confirm these findings and, to the contrary, indicate that it is indeed the perception of motion of the pattern that matters in the aftereffect. In fact it was found that it is the perceived direction of the pattern, rather than the direction of motion of its image over the retina, that governs the perceived direction of the aftereffect (see chapter 18). Hence the neural units that are fatigued apparently are at a higher level than was originally thought to be the case. At any rate, the fact is that the perception of movement of contours in a specific direction fatigues the neural units that are sensitive to the direction of motion occurring, and that as a result units sensitive to movement in the opposite direction dominate for a short period thereafter and give rise to an impression that stationary contours are "sailing" in the opposite direction.\[15\]

However, the aftereffect of movement is clearly a very special case of movement perception. It is obviously caused by some changes of the neural medium and belongs in the category of other aftereffects of prior stimulation. The central question, therefore, is whether the perception of movement in general can be explained in terms of the activity of neural units that are fired by contours moving over the retina. It would seem
that the answer to the question is negative. After all this kind of explanation may be reduced to one based on movement of the image, and virtually all of the evidence covered in this chapter contradicts that thesis. Movement of the image is neither necessary nor sufficient for the perception of movement.

We are left then with the puzzle of accounting for the purpose of these detector mechanisms if they cannot do justice to the perception of movement. Do they explain movement perception in animals lower in the phylogenetic scale, remaining as vestiges in higher animals? This argument presupposes a perfect correlation between image displacement and perceived movement in such species and it is doubtful this is the case. For example, all animals must discount image motion when they bring it about by their own movement and relevant experiments on the fly were discussed earlier in the chapter.

Perhaps the "detectors" are simply the mechanism which informs the perceptual system that a displacement of an image has occurred without any further implications about movement per se? Some of the investigators who have made these physiological discoveries favor this latter interpretation. According to this view, one could argue that displacement of the image is not necessary for the perception of movement but, if it occurs, it is detected by the neural units in the eye or brain. The information thereby obtained is then assessed by the perceptual system in terms of other information before a decision is reached as to whether or not motion in the environment is occurring. One might think of the discharging of these detector cells as primitive motion signals which then may be cancelled or "vetoed" on the basis of other information (for example if the observer's own movement occurs simultaneous with such signals).

But there are difficulties even with this interpretation. In the case of induced movement it would have to be argued that the motion signal emanating from the displacing image is transferred to the stationary image. Furthermore, the speed of the displacing object may be below threshold, in that with no other object visible no motion is perceived. Yet when the stationary object is introduced, induced movement occurs. Therefore here there is apparently no signal activating detector cells produced by the displacing image which can then be said to be transferred. Rather the information about the displacement is a function of the change of location of the objects relative to one another. Therefore activation of detector cells is apparently not the only source of information about image displacement. A related problem concerns the direction of perceived movement. As noted previously, a dissociation of perceived motion may occur, such that one perceives motion in directions which differ from those of the displacing retinal image.

Stroboscopic movement perception would seem to be another example which cannot be accounted for on the basis of detector units since there is
no image displacement over the retina. However, it has been discovered that units of the visual nervous system will respond to discrete successive stimulation of the retina in addition to continuous displacement across it [38]. Can this mechanism then explain stroboscopic movement perception? It can not, for the following reasons:

1. Stroboscopic movement can be perceived across a very wide visual angle, 30 degrees or 40 degrees, and the mechanism discovered does not encompass separations of that magnitude.

2. Stroboscopic movement can be perceived when the identical region of the retina is stimulated successively, provided it "represents" two phenomenal locations in space (so here the activation of this mechanism is not necessary); conversely, when two regions of the retina are successively stimulated that represent only one region in space, no movement is perceived. (Here the activation of the mechanism is not sufficient.)

3. One can perceive movement when the image of the first stimulus falls in one eye and is projected to one hemisphere of the brain and the second falls in the other eye and is projected to the other hemisphere (hold up a finger so that it appears slightly left of a fixation spot on a far wall as seen with the right eye only; with the left eye only it then appears to the right of that spot; then open and close the eyes alternately at a rapid rate—the finger will appear to move back and forth. It is not likely that a mechanism of the kind described exists to cover this example). (See chapter 16 for a description of research using this method.)

4. Such a mechanism itself has little bearing on many of the factors that affect the perception of stroboscopic movement such as the similarity of $a$ and $b$, the tendency to see the array moving as a whole (Ternus effect), the effect of presenting $a$ and $b$ by a covering and uncovering procedure, etc.

In conclusion then, the motion-detector mechanism may be sufficient to explain the aftereffect of movement illusion but not the other phenomena of movement perception. The purpose of such neural units, therefore, is not yet clear but perhaps it is to provide information that displacement or rapid change of location of an image is taking place. That information is then interpreted by the perceptual system as signifying movement or not depending upon a variety of other factors. But it does not necessarily follow that the activation of "motion detector" cells is the only source of information concerning image displacement.

Summary

What conditions of stimulation or what central events lead to the perception of movement? Many facts contradict the hypothesis that movement is perceived as the result of displacement of the image of the moving object over the retina.
When the observer moves, the images of stationary objects in the world shift across the retina, but these objects appear to be stationary (position constancy). Conversely, a stationary image on the retina will give rise to an impression of movement when the eyes move. Therefore, it would seem that the perceptual system takes eye or body movement into account when assessing the significance of the behavior of the retinal image. It was suggested that we perceive movement when an object appears to undergo change in its location in relation to ourselves.

Ordinarily, when the observer moves, the image of stationary objects displaces by an equal amount and in a particular direction. If conditions are such that this image displacement is of a different magnitude or in a different direction, then the world will seem to move when the observer moves. However, experiments have demonstrated that we can adapt to this new state of affairs, so that in time the world will appear stationary once again. Therefore, it would seem plausible to hypothesize that in principle any displacement of the image concomitant with observer movement will be discounted by the perceptual system, but that by virtue of past experience, only a particular displacement of the image during observer movement signifies a stationary world.

Stroboscopic movement perception is another fact which contradicts the hypothesis that image displacement underlies the perception of movement. The fact that it occurs only at certain rates of alternation, and that animals and infants perceive it, has suggested to many that it is based on a primitive tendency of the nervous system to react to a spread of excitation from one locus to another.

But a number of other facts seem to call for a different kind of explanation. For example, a necessary condition is that the first object suddenly disappear for no apparent reason and that the second object suddenly appear in a different phenomenal location. Thus the perception of stroboscopic movement can be thought of as a "plausible solution" to the "problem" of a sudden change in an object's location. Stroboscopic movement perception is similar to real movement perception when the object is moving rapidly. In fact, experimental work suggests that the perception of real movement at fast speeds is based on the same mechanism as stroboscopic movement since it depends only on sight of the object in the beginning and end positions.

A single stationary point of light in an otherwise homogeneous field such as a dark room will generally appear to drift. Various theories have been advanced to explain this autokinetic effect. There is some evidence to support the hypothesis that rapid fluttering of the eye that occurs even when the eye is felt to be at rest may be the cause. However, there are difficulties with this hypothesis. The central fact about the autokinetic stimulus situation is that there are no other visible objects present that
ordinarily would clearly indicate that a change in position of the point has not occurred. Under these conditions, therefore, the perceptual system might easily be “deceived” into inferring that the point was drifting and that the eyes were slowly tracking it.

The change of location of an object relative to other objects in the field is an important determinant of movement perception. If the moving object surrounds the stationary one (so that it becomes the frame of reference), it will generally induce a sense of movement in the stationary object. Induced movement of the self also occurs when we misperceive our own bodies to be in motion as a result of movement of a surrounding reference system. The importance of change of location relative to other objects is also shown in situations where two or more objects are both moving in relation to one another. The actual path of movement is then often dissociated into two perceptual components, the more salient one being that based on the objects’ approach to or separation from one another. Therefore, most of the facts about the perception of movement can be subsumed under the principle that movement is perceived when objects change their phenomenal location (above some threshold rate) where “location” is defined either subject-relatively or object-relatively.

Can the perception of movement be explained in terms of units in the visual nervous system that “detect” the displacement of the image over the retina? Such mechanisms have been discovered in various species. One phenomenon that may be explained along these lines is the aftereffect of movement. However, this phenomenon is a special case. Most of the other facts concerning the perception of movement such as are described in this chapter argue against an explanation along these lines since image displacement is neither a necessary nor a sufficient condition for seeing movement. Therefore, although the role of these so-called neural movement detector mechanisms is to detect the displacement of an image over the retina, information concerning image displacement may or may not lead to movement perception depending upon a variety of other factors.

The apparent velocity of a moving object cannot be a function of the rate at which its image displaces because perceived velocity is more or less constant despite the distance of the object from the observer. Two factors have been isolated. Perceived velocity is a function of the phenomenal extent traversed per unit time; in other words, it is based on size constancy. But perceived velocity is also a function of the rate of relative displacement per unit time. If a frame of reference is transposed in its linear dimensions, the velocity of the object must be transposed by a like amount in order that the phenomenal velocity in the two cases be identical. Constancy of speed in daily life is most likely a function of both factors.
Notes

1. The term discounted is used here to mean that no movement is perceived in the environment because the image displacement is fully accounted for by the movement of the observer. It has no other theoretical implications.

2. If the observer wearing lenses or prisms in goggles holds his head still and moves only his eyes, the scene does not appear to move. For example, if the observer desires to fixate an object that appears to be off to his left, he will turn his eyes to the left. The image of the object will then move toward the fovea just as it normally would. Of course, in doing so the observer will be turning his eyes away from where the object actually is, to his right. Only if prisms were attached directly to the eyes would the scene appear to move during eye movements.

3. It is possible that the optomotor response is based on the fact that the stationary animal perceives itself as turning in a direction opposite to that of the rotating drum. (See the discussion of induced movement of the self later in this chapter.) If so, the animal would try to “undo” this unwanted effect by rotating in the direction of the moving drum. However, it is unlikely that such an explanation could account for the forced circling of the moving fly when the head is rotated because here, to explain the result, it would have to be argued that based on induced movement of the self the fly perceives itself as turning in a direction opposite to the one in which it is actually turning. As noted previously, a human observer looking through reversing prisms or lenses perceives the scene as moving whenever he moves so that no induced movement of the self seems to occur.

The complicating factor in the experiment with the fly is that the drum surrounds the fly, so that conditions exist to generate induced movement of the self. However, the same kinds of effects could in principle be obtained with only a single visual object: when the object moves, it will be perceived to do so; when the fly moves, the object will appear to be stationary; when the eyes are rotated and the fly moves, the object will appear to move and at a rate faster than the fly.

4. Since factors such as brightness and distance between a and b affect the outcome it is not possible to state what these rates are as a general rule. But typically, when a and b are a few degrees apart and are each on for around 50 milliseconds, the optimum interval or off-period, the later-stimulus interval (or ISI) when neither a nor b is on, is around 50 to 100 milliseconds. If this period is much greater, a and b will be seen to appear successively; if it is much less, they will appear to be simultaneously on; and in neither case will movement be perceived. However, the period between the onset of a and onset of b is now thought to be important. If a is on for 100 milliseconds or longer, optimum movement will be perceived when there is no off period at all between a and b.

5. It is important to make clear that eye movements per se cannot explain the stroboscopic illusion.

\[ \cdot \longrightarrow \cdot \]
\[ a \]
\[ \cdot \longrightarrow \cdot \]
\[ d \quad \quad c \]

This was once a popular theory but was disproven by Wertheimer [8] who showed that observers could simultaneously see a moving to b and c moving to d, i.e., in opposite directions. The eyes cannot move in opposite directions at the same time. Also, Guilford and Nelson [17] showed by photographing the eyes of their subjects that the eyes were often more or less stationary while they nevertheless experienced movement between the two stimuli. The experiment cited here is based on the argument that it
is not eye movements that cause the impression of movement but that when the eyes happen to move in the manner indicated, so that only one region of the retina is stimulated, movement is nevertheless perceived.

6. It has been suggested that in fact there are two distinct kinds of stroboscopic movement perception [21] [22]. Short-range movement occurs with very brief ISIs and very slight changes in position of $a$ and $b$, whereas long-range movement can occur with very appreciable change in position and greater ISIs. The claim that there are two such different kinds of stroboscopic motion is controversial but, if correct, could explain several of the different findings referred to here, some of which fit better into a lower-level sensory theory (short range) and some of which fit better into a higher-level cognitive theory (long range).]

7. In a subsequent study, an attempt was made to stabilize the retinal image in all directions by requiring the observer to view a small afterimage [26]. To prevent eye movements which would lead to an impression of motion of the afterimage for reasons unrelated to autokinetic movement, the observer fixated a small red dot and attempted to maintain the dot in the center of the circular afterimage. Apparently observers were able to do this while nevertheless frequently experiencing autokinetic movement of the afterimage. One investigator has proposed that “commands” to move the eyes are issued in viewing the stationary point. This might result from a state of fatigue of the muscles on one side that would then require abnormal command signals to hold the eyes stationary. These signals are those that ordinarily would signify that the eyes are moving. It was demonstrated that following a period of straining the eye muscles in one direction for 30 seconds, the stationary point subsequently appeared to move in that (or the opposite) direction but not in any other direction [27].

8. It is interesting to note in this connection that the autokinetic effect is highly susceptible to suggestion, and therefore the phenomenon has been studied by social psychologists under conditions where planted “subjects” claim to see the point moving.

9. Change of an object’s position relative to another can be thought of as a change in configuration or form. That there is merit in this way of looking at object-relative change is borne out by the demonstration that an object moving below the subject-relative threshold and rotating around a stationary point will also be seen to move (or the stationary point will). In other words, although there is no change in the relative distance between the two points in this case, there is a configurational change: the orientation of the imaginary line connecting the two is changing [29].

10. Other factors that determine which of two or more objects will tend to serve as frame of reference in addition to that of enclosure are relative size, intensity, orientation, and constancy. Other things being equal, the larger or more intense, or vertically oriented, or constant rather than changing object will tend to serve as frame of reference [30].

11. Johansson’s theory about these effects is somewhat different from the one proposed here. He believes that the central factor is the tendency to group elements together and to perceive them as belonging together as a rigid entity on the basis of that vector component of their motion that they share in common. This reduces to the grouping principle of common fate, except that here the perceptual system must first “seek out” and “detect” the common vector and only then can a grouping occur on the basis of it. Once that grouping occurs (for example, two elements moving up and down together in Fig. 14.22) the residue of the motion of the elements is perceived in relation to that moving system as a frame of reference.

12. It was also shown, in a third situation, that the spot of light was seen as stationary and the self as moving, if the observer were continuously accelerated and decelerated.

13. When moving at high speed in a vehicle many observers report that objects such as trees, telephone poles, and the surrounding ground appear to be moving in the opposite
direction. This would imply a failure of position constancy. However, it is possible to argue that what one experiences here is the rapid displacement of objects out of the visual field, rather than a genuine movement of objects in the world. The term pseudomovement has been used to describe this kind of experience. It may occur at slower speeds too and may even explain the Filehne illusion discussed earlier. This experience is analogous to other sensory impressions that are correlated with the proximal stimulus such as extensity in size perception.

15. The same reasoning can be applied to the perception of a rotating spiral. Depending on the direction of rotation, the spiral appears either to be moving radially outward from the center or inward toward the center. But no part of the spiral is moving in this direction, since it is rotation. Thus, the perception of the direction of movement during rotation is illusory and is an example of the barberpole illusion. In the aftereffect, the stationary spiral is perceived to be moving in the direction opposite to that experienced during its rotation. Observers often perceive the rotating spiral in depth, turning toward or away from them, and, in that case, the aftereffect also has a three-dimensional character.

References


[18] Sigman, E., and I. Rock. Unpublished experiment. However, the reader is referred to a recent book in which, contrary to what is claimed above, it is reported that a condition of presentation such as that shown in Fig. 14.8a sometimes lead to an impression of movement. See P. Kolers, *Aspects of Motion Perception*. Pergamon Press, Inc., 1972. Perhaps the difference can be explained by noting that observers can perceive movement under certain conditions where A reappears with B but naive observers do not tend to do so very much of the time. Another relevant factor is the spatial separation between A and B.


