THE EFFECT OF INDUCED MOVEMENT AND THE ROELOFS PHENOMENON ON HUMAN LOCALIZATION

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by

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ABSTRACT

Induced movement is the perceived movement of a stationary object in the direction opposite to that of an objectively moving background. Six experiments were conducted to determine if the induction effect could be explained strictly in terms of the object-relative movement between the visual target and its background, or whether the moving background changes the egocentric coordinates of the observer such that the perceived target motion arises from the change in its position relative to the shifting egocentric or subject-relative axes. Subjects pointed to a target light located in their objective median plane (1) in the absence of any other stimulus in the visual field, (2) in the presence of an offset stationary fluorescent frame, (3) while the frame was moving leftward or rightward, and (4) after exposure to identical frame motion occurring immediately prior to the onset of the target light. The results showed that pointing errors with respect to the control readings were smallest with the stationary frame, somewhat larger after frame motion in the absence of the light, and largest during frame motion in the presence of the light (induced motion). In the induced movement condition, the direction of motion affected both the direction and size of subsequent pointing errors.

In contrast, the stationary frame in the presence of the light or frame motion in the absence of the light affected the size but not the direction of subsequent errors. It is argued that both subject-relative and object-relative factors are involved in the perception of induced movement and an alternative interpretation is suggested which incorporates both of these elements. Finally, an argument is made for the importance of stimulus size as a parameter in induced movement.

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LIST OF ABBREVIATIONS

AMP - Apparent Median Plane

ASA - Apparent Straight Ahead

C1 - First Control Block

C2 - Second Control Block

F1 - First Frame Block

F2 - Second Frame Block

FL - Far Left

IM - Induced Movement or Induced Motion

NL - Near Left

OMP - Objective Median Plane

SS - Size of Shift

UV - Ultraviolet Light

INTRODUCTION

Egocentric Orientation

Egocentric orientation refers to the position of a part of the body or of an object in external space with respect to some axis or plane defined solely with reference to the body or some part of the body of the observer. The body may be divided into three principal planes with respect to the mid-body axis, which is the vertical axis passing through the centre of gravity of the body when in its normal standing position (see Figure 1). The median or mid-sagittal plane is that plane containing the mid-body axis which subdivides the body into two bilaterally symmetrical sections. The mid-frontal or coronal plane also contains the mid-body axis and divides the body into front and back by passing through the centre of gravity at right angles to the median plane. The mid-transverse plane subdivides the body into top and bottom and also passes through the centre of gravity. It is at right angles to both the median plane and the mid-frontal plane. Egocentric judgements with respect to the body as a whole or to any of its parts, such as the eyes, head, or trunk, may be defined with reference to these three planes.

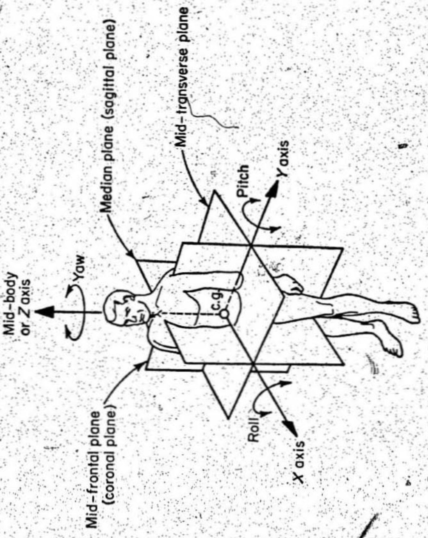

Figure 1. Body coordinate system and axes of rotation.
(Taken from Howard and Templeton.)

Of prime importance to the issue of egocentric orientation is the concept of the "egocentre". This term was introduced by Roelofs (1959) and describes that point, fixed with reference to the body, from which the absolute directions of straight ahead, left, right, upwards, and downwards are judged. For simplicity, it may be thought of as that location in the head towards which a rod or pencil, for example, points when it is judged to be pointing directly at the observer. If one performs this simple task, it can be easily seen that the binocular and monocular egocentres differ slightly. In the present paper, the term egocentre will be limited to the binocular condition. This point is also sometimes referred to as Hering's projection centre or the cyclopian eye.

Man's bilateral symmetry necessitates that he be able to discriminate between the two halves of his body and to be able to identify them by name. Thus, from a behavioural perspective, the most important body landmark is the median plane. Since egocentric judgements are by definition entirely subjective, it is important to know if the apparent median plane (AMP) or apparent straight ahead (ASA) corresponds to the objective median plane (OMP). Howard and Templeton (1966) define the objective median plane of the head as that plane passing through the midpoint of, and perpendicular to, the line joining the corneal surfaces when the eyes are in symmetrical convergence. The apparent median plane is the subjectively-judged position of this plane. In other words, these two concepts of the median plane differ in that the OMP is <u>physically</u> defined and the AMP is <u>perceptually</u> defined, referring to that position in space which is perceived to be straight ahead.

It has been recognized for some time that asymmetrical stimulation of the visual field can alter the position of the apparent straight ahead. This phenomenon was first observed in an experimental paradigm which gave rise to what is now known as the Roelofs effect (also sometimes referred to as the asymmetry effect). This will be discussed in detail in the following section.

The Roelofs Effect

It is commonly assumed that when the eye is in the primary position (the position of physiological rest), whatever is imaged on the fovea is seen as straight ahead. Alternatively, a fixated (foveally projected) stimulus is usually seen as being straight ahead if it is placed in the OMP of the observer. However, Dietzel (1924) and, independently Roelofs (1935), showed that such stimuli are not always perceived to be straight ahead. As opposed to being in a fixed position, the apparent straight ahead seems to depend upon the total pattern of retinal stimulation.

Dietzel found that when the left edge of a luminous figure (viewed in a dark room) was placed in the OMP, the apparent straight ahead shifted towards the center of the figure so that its left edge was then judged to be displaced to the left of the ASA. Roelofs, using a similar technique, positioned a homogeneously illuminated square such that either the left or right vertical edge was in the OMP and had subjects fixate this edge. Although the fixated edge was objectively straight ahead, it was not perceived as such. As with Dietzel's study, the ASA deviated toward the center of visual stimulation, rightward when the square was right of true center and leftward when it was left of center. Thus, the objective and apparent median planes did not coincide.

The first investigators to systematically study the Roelofs effect were Werner, Wapner and Bruell (1953). In their first experiment, the subject, sitting in a darkened room, marked a point on the wall that seemed to be straight ahead. The subject could see a small luminescent square subtending a visual angle of approximately two degrees but could not see his own hand as he pointed. The square, the center of which was presented at eye level, appeared in one of three predetermined locations on a given trial: in the subject's OMP, or 15 degrees to the left or right of the OMP. The subject indicated the apparent straight ahead with a pointing motion while fixating the center of the stimulus.

The apparent straight ahead shifted away from the OMP in the direction of the stimulus by as much as 5 cm.

Wapner, Werner, Bruell, and Goldstein (1953) conducted a three-part experiment designed to evaluate the importance of asymmetrical placement of a test figure and light flux on the location of the AMP. In the first experiment they used as a test figure three equidistant horizontal pin-points of light, which represented minimal luminous flux. The subject's task was to fixate either the left or right dot of the three-dot pattern which was in the OMP at the beginning of each trial and to instruct the experimenter how to move the test pattern so that the fixated point appeared straight ahead of the subject. The results indicated that when the test figure extended asymmetrically to the left of OMP, the AMP was shifted to the left; when the test figure extended asymmetrically to the right, perceived straight ahead shifted to the right. Once again, the apparent straight ahead was displaced toward the center of visual stimulation.

In the second experiment, they studied the effectiveness of luminous flux versus asymmetric extent in displacing the ASA by using test stimuli of the same shape, one a solid luminescent square (20 x 20 cm) and the other an outline square. On a given trial, either the left or the right edge of the square was placed in the subject's OMP and the subject instructed the experimenter how to move the figure so that the fixated edge appeared straight ahead.

Both stimuli were found to produce a similar displacement of the ASA towards the square, indicating that the shift was a function of the asymmetry of shape rather than of the asymmetry of light flux.

Their third experiment investigated whether the position of straight ahead was a function of the initial placement of the test figure. Starting position effects were studied with four test figures which differed with respect to asymmetrical extent: (1) a vertical line (20 X .5 cm), (2) a symmetrical double square, (3) a square with the right edge in the OMP, and (4) a square with the left edge in OMP. The fixation point of each stimulus was placed in three starting positions: in the OMP, or 40 cm to the left or right of the OMP. The subject instructed the experimenter how to move the figure so that the fixated part appeared to be straight ahead. For all four test figures, the position of the AMP was displaced in the direction in which the test figure had been placed at the beginning of the trial. Moreover, the AMP was shifted farthest to the left under simultaneous operation of left starting position and left asymmetrical extent, and farthest to the right under simultaneous operation of right starting position and right asymmetrical extent. Shifts in AMP were in between these extremes when starting position and asymmetrical extent had effects operating simultaneously and in opposite directions.

Bruell and Albee (1955) studied the Roelofs effect in more detail by varying the degree of asymmetry of retinal stimulation through variation of the horizontal extent of the stimulus figures. Using test figures of a vertical line (1.5 X 20 cm) and three rectangles 20, 40, and 60 cm wide and 20 cm high (subtending visual angles of 5.7, 11.3, and 16.7 degrees, respectively, at a distance of 200 cm), subjects were tested under seven stimulus conditions: with the rectangles placed one at a time with the right or left edge in the subject's OMP, and with the vertical line in the OMP. The results indicated that the AMP was always displaced in the direction of the stimulus figure, with the magnitude of these shifts being a linear function of the degree of asymmetry of retinal stimulation. The more the stimulus figure extended to one side of fixation, the larger were the displacements of the AMP away from the OMP up to the maximum displacement tested.

The foregoing studies have examined shifts in the AMP under scotopic viewing conditions using a luminous background presented in total darkness, and researchers have generally concluded that the subjective straight ahead tends to be located at or near the center of visual stimulation. In all these cases, the stimulus used to shift the center of retinal excitation was also the sole source of visual input. Brosgole (1967) investigated whether equivalent shifts could occur under photopic conditions by having subjects sitting in a brightly illuminated Ganzfeld (a white featureless field) adjust a target light surrounded by a square outline frame until it appeared to be straight ahead. The square thus served as a frame of reference as it was the only salient visual stimulus, yet changing the position of the frame did not alter the overall extent of the visual field since the entire retina was flooded with stimulation. The results showed that when the frame was placed in one of the three positions tested (either in the OMP or four degrees to the left or right of the OMP), the subject's judgement of the ASA deviated in the same direction. In light of the Wapner et al. (1953) finding that the ASA tends to be biased in the direction of the initial placement of the test figure, one must exercise some caution in the interpretation of Brosgole's results. However, they suggest that shifts in the ASA might occur under illuminated conditions.

Some clinical studies investigating shifts of visual straight ahead have some important implications for the understanding of normal vision in general and the Roelofs effect in particular. Patients with homonymous hemianopsia, a loss of vision in one half of the binocular field, are frequently unconscious of any visual problem until the misjudgement of the position of an object makes them aware of a visual defect. A hemianoptic patient, when reaching for an object which appears to be straight ahead, will frequently miss and reach to one side of the perceived position of the object (Poppelreuter, 1917; Holmes, 1918; Kanzer and Benzer, 1939; Riddoch, 1935). Although investigators agreed that retinal local signs were changed in hemianoptics, Fuchs (1920) was the first to suggest a relationship between the field defect and direction and magnitude of the change in perceived retinal space. He noted that patients with right homonymous hemianopsia would displace all visual objects to the right, and that the converse was true for left field hemiaoptics. Fuchs used stimulus words of various lengths positioned so that the first or last letter of the word (depending on which side the deficit was on) was in the OMP and extended into the intact visual field. Patients reported the letters towards the center of the word, that is, deviating from the OMP, appeared to be straight ahead and that the longer the word, the more the straight ahead shifted away from OMP and towards the center of the wider stimulus word.

Bruell (1958) noted the striking similarity between his studies of the Roelofs effect in normal subjects and what Fuchs found in hemianoptic patients; that is, straight ahead was shifted toward the center of visual stimulation. He argued that when the eyes of normal subjects are in the primary position, the retinal local sign changes instantly as a result of external conditions such as asymmetrical retinal stimulation. Also he noted that peripheral points on the retina can mediate the experience of straight ahead and that the changes in the retinal space values seen in hemianoptic patients are manifestations of a normal visual mechanism.

Bruell suggested that the fovea usually has the local sign "straight ahead" because ordinarily when the eyes are in symmetrical convergence, the visual field extends symmetrically to both sides of fixation. However, because of the asymmetrical placement of the luminous frame in the Roelofs effect, only one occipital lobe in the visual cortex receives stimulation, in spite of symmetrical convergence of the eyes. Bruell thought that the Roelofs effect in normal subjects was analogous to homonymous hemianopsia (in which the retinal local sign of the fovea is not straight ahead despite symmetrical convergence) because in the latter case only one occipital lobe is able to respond to stimulation due to injury in the other half of the visual system. The result in these two cases is the same: fixated objects are perceptually displaced in the visual field.

In the everday world we can usually determine the veridical location of objects in visual space because the cues originating from the receptors sensitive to retinal, eye, and head position are in accordance with those based on visual symmetry. That is, when we shift our gaze either by rotating our eyes or turning our head, objects directly in front of us retain their perceived location in space because the change in the proximal stimulus is accounted for by the changes in eye and head position. However, the preceding experiments indicate that when these cues are thrown into conflict, changes in the ASA can result simply from stationary asymmetric visual stimulation. This suggests that perceived direction is not determined solely by retinal location of the stimulus together with the position sense of the eye and head.

Brosgole (1968) suggested a possible link between the Roelofs effect, a phenomenon based on an asymmetric but stationary frame of reference, and a similar effect called induced movement, which is based on a moving frame of reference. He hypothesized that the egocentric location of objects in visual space could be manipulated in a continuous manner by a moving frame of reference, thereby giving rise to the impression of relative movement of other figures in the field.

Motion Perception

The Image/Retina and Eye/Head Systems

Prior to discussing induced movement, it is appropriate to present a brief introduction to motion perception in general. It has long been known that our ability to detect motion involves much more than simply the stimulation of successive receptors as the image moves across the retina. The retinal image is constantly in motion because of the ever-present involuntary tremor of optical nystagmus, or due to voluntary saccadic eye movements, and yet we do not perceive constant motion in the visual world. Furthermore, we also perceive motion when the image is relatively fixed on one portion of the retina, such as during tracking eye movements when we are following a smoothly moving object across the visual field. Thus movement of the retinal image cannot fully account for our usually veridical perception of movement. To explain these complexities, it has been proposed that there are two motion perception systems which act together, namely, the image/retina system and the eye/head system (Gregory, 1966). These systems are involved in determining whether movement of the retinal image is due to eye movements of the observer, due to the real movement of a visual stimulus, or both.

In the simplest case, the image/retina system is sensitive to motion of the retinal image when the eye is stationary, whereas the eye/head system detects the movement of an external object when its image remains in a fixed position on the retina, such as during smooth pursuit eye movements. In this latter situation, the only way that the observer can know the speed and path of the object is to somehow monitor the speed and path of the eye movements themselves.

Two basic theories, the inflow and the outflow theory, have been proposed to explain the eye/head system. The inflow theory states that position sense in the eyes is determined via sensory feedback to the brain from the stretch receptors in the six extraocular muscles (Sherrington, 1918). In contrast, the outflow theory states that knowledge of eye position is based upon command signals sent from the brain to the extraocular muscles (Helmholtz, 1866). The bulk of the evidence supports the latter theory (Brindley and Merton, 1960), however experiments by Skavenski (1972) indicate the presence of inflow.

Subject-Relative and Object-Relative Movement Thresholds

The perception of such characteristics as colour, size, shape, distance, and orientation depends on both absolute and relative cues. Absolute cues are those that determine the perceived characteristics of an object independently of other objects, whereas relative cues are those that change the perception of an object when other objects are present. This distinction is very important in motion perception as an object may be seen to be in motion either because it changes position with respect to the observer (subject-relative movement) or because it changes position with respect to other objects in the visual field (object-relative movement). An example of purely subject-relative movement would be a single object traversing an otherwise featureless visual field. However, any object-relative movement also involves a subject-relative component. Thus, to measure accurately object-relative motion by itself, it is necessary to tease these two factors apart.

Despite its relevance to motion perception, the research on movement thresholds is surprisingly scant and is based to a large extent on older studies. An experiment by Aubert (1886) demonstrated that subjects could detect the movement of a luminous dot in the dark, located 50 cm from the eye, when it was moving at a speed of 2.5 mm per second or .2 degrees of visual angle per second. This is, therefore, a subject-relative threshold. When another stimulus is present as a reference (an object-relative situation), subjects are about ten times more sensitive, and can detect movement of about .25 mm per second or .03 degrees of visual angle per second (Graham, 1965).

Shaffer and Wallach (1966) attempted to determine motion thresholds under subject-relative and object-relative conditions. However, for some unexplained reason, they chose different sized stimuli in the two conditions and also used different displacement speeds. This confounds their results, casting some doubt on the exact threshold values that they reported. Although the parameters may vary somewhat depending upon the stimulus conditions and the method of measurement, it is apparent that object-relative thresholds are substantially lower than subject-relative thresholds.

Motion thresholds are also contingent upon the duration and luminance of the stimuli. In general, increasing either the exposure time of the target or its luminance lowers the threshold for motion (Brown and Conklin, 1954; Harvey and Michon, 1974; Henderson, 1971; Leibowitz, 1955b). Target duration is a factor even when reference points are present. In order for reference points to have a substantial effect on motion thresholds, the target exposure should exceed four seconds (Harvey and Michon, 1974; Leibowitz, 1955a; Mates, 1969).

Another critical stimulus parameter for motion detection is the retinal location of the visual target. Sensitivity to slow target movements (up to 1.5 degrees per second) decreases with increasing distance from the fovea (Lichtenstein, 1963; McColgin, 1960). Conversely, the peripheral retina is more sensitive than the fovea in the detection of moderate to fast velocities (Bhatia, 1975; Brown, 1972).

Real and Apparent Movement

The foregoing has been concerned with the analysis of real movement in the external world due to the ability of the visual system to distinguish between retinal image movement arising from objective motion as opposed to image motion resulting from eye movements. However, motion perception is further complicated by the fact that not all that we perceive as movement results from objective motion. This has led to the division of motion perception into two distinct classes: real motion, in which stimuli undergo objective and continuous spatial displacement, and apparent motion, in which motion is attributed to stimuli that are veridically stationary or in which continuous motion is perceived when successive and discrete retinal loci are stimulated. It has been debated as to whether real and apparent motion result from the same process or whether different types of analysis are involved. Kolers (1963, 1964) has argued that there are at least four distinctions between the conditions of real and apparent motion. It is not necessary to be concerned with this issue in this thesis. However, we must note that the real movement of images across the receptors of the retina can give rise to two different illusions of movement called successive motion contrast and simultaneous motion contrast. In simultaneous motion contrast, the inducing and test stimuli are presented at the same time and the illusion of movement is perceived immediately. For example, the slow movement of the inducing stimulus (which might consist of a field of dots, a striped grating, or a luminous outline frame) will cause a small stationary test stimulus to appear to move in the opposite direction. Successive motion contrast, on the other hand, involves the prior presentation of the inducing stimulus for a specific period of time, followed by the test stimulus. Prolonged exposure to a pattern which moves in one direction will result in a stationary pattern appearing to move in the opposite direction. This is commonly known as a movement aftereffect. It is the former, simultaneous motion contrast, with which we shall be concerned in the following section.

Induced Movement

Problems of Definition

Induced movement (IM) may be broadly defined as the perceived movement of a stationary object in the opposite direction to that of an objectively moving background. The most common stimulus array used to study this effect consists of a moving luminous frame (usually moving laterally) which surrounds a stationary luminous spot in an otherwise dark room. Most subjects perceive the spot as moving within a seemingly stationary frame.

The term "induced movement" has also been applied to a wide variety of other stimulus arrays: two independently moving adjacent dots (Duncker, 1929; Gogel and McCracken, 1979; Mack, Fisher, and Fendrich, 1975), two adjacent areas of random dot patterns (Loomis and Nakayama, 1973; Tynan and Sekuler, 1975) rotating displays (Anstis and Reinhardt-Rutland, 1976; Reinhardt-Rutland, 1981; Vetter, 1968), striped gratings (Morgan, Ward, and Brussell, 1976; Over and Lovegrove, 1973), and grids (Wallach, Bacon, and Schulman, 1978). According to the general definition given above, all of these studies can quite legitimately be called IM. This has led to a substantial amount of generalization from one IM paradigm to another. The great variation in the stimulus arrays and the different types of motion that they induce in the test stimuli make it quite probable that there at least some differences in the type of analysis carried out by the visual system. Consequently, one must be extremely cautious in applying the findings of one IM study to another which varies somewhat in its stimulus properties. It is unfortunate that this factor has apparently often been ignored and thus such confusing generalizations have been common.

A parallel problem of nomenclature concerns the term "simultaneous motion contrast". All of the aforementioned paradigms of IM could be classified as examples of simultaneous motion contrast because the test and inducing stimuli are presented at the same time. Thus, IM may be thought of as a subcategory of simultaneous motion contrast. However, these terms have sometimes been used interchangeably, resulting in a similar sort of overgeneralization between induced movement and other types of simultaneous motion contrast. These problems of definition are worthy of note because the rather loose usage of these terms has resulted in a certain degree of confusion in the literature. The term simultaneous motion contrast is best used as a general classification of movement paradigms rather than implying a specific mechanism of visual analysis. For the purposes of the present discussion, the term "induced movement" will refer specifically to the spot and frame stimulus array.

Theories of Induced Movement

The Object-Relative Theory. The first and most common theory of IM is that originally proposed by Duncker (1929) and is sometimes referred to as the "frame of reference" model. He began his study of IM by investigating the effect of moving a small spot of light in a horizontal path adjacent to an identical stationary spot. He found that subjects could not determine accurately which light was moving, irrespective of whether they were fixating the stationary light or the one in motion. This ambiguity disappeared when the spot was inside a larger rectangular background which moved through the same angular displacement. In such cases, the spot appeared to move whether or not it was the spot or the frame that was actually in motion. Furthermore, movement of the spot was perceived regardless of which stimulus the subject fixated.

In order to account for the tendency of the perceptual system to attribute all of the relative displacement to the spot and none to the rectangle, Duncker introduced the concept of the frame of reference. One object was presumed to serve as the frame of reference with respect to which the properties of the other object were judged, in this case, the property of motion. Duncker suggested that the larger or surrounding object always served as the frame of reference for the smaller or surrounded object.

When the rectangle is moving below the subject-relative motion threshold, this model can account for IM because all of the resultant object-relative movement would be attributed to the spot. However, IM is also experienced when the rectangle is moving well above the subject-relative threshold (Rock, Auster, Schiffman, and Wheeler, 1980). By definition, if the speed of the frame is above threshold, it should be detected as moving and therefore the relative displacement between the frame and the spot should be fully accounted for by the perceived movement of the frame. Thus, there is no reason to expect IM of the spot under these conditions. In order to deal with this problem, Duncker (1929) and later Wallach (1959) proposed the concept of the "separation of systems". According to this principle, the motion of an object is determined solely by how it relates to its immediate frame of reference; that frame of reference will in turn be determined by its position relative to some larger frame of reference. The primary assumption is that an object is seen to move because of a change in its location relative to its immediate surround and that this relationship represents a distinct system which is independent of other ongoing events in visual space.

Wallach's evidence for the separation of systems was mainly based upon an experiment in which subjects fixated a stationary spot surrounded by a horizontally moving rectangle, which was in turn surrounded by a vertically moving circle. He reported that the IM of the spot was determined solely by the inner frame and was unaffected by the vertical motion of the larger circle.

There are, however, certain problems with the separation of systems principle. For one, IM cannot be demonstrated in a lighted room and yet if separation of systems assumption was valid, the spot and the frame system should be independent of the frame and the room system, and IM of the spot would be perceived. Furthermore, even in darkened surroundings, Brosgole (1968) has shown that a stationary outer rectangle can prevent the IM of a spot within a moving inner rectangle, and that when both rectangles move in opposite directions, it is the <u>outer</u> rectangle which determines the direction of spot induction. This is in direct opposition to the predictions of the separation of systems principle. Assuming that Wallach's original findings are valid, two possible differences between his experiment and Brosgole's might account for their discrepant results. In Brosgole's study, the two surrounding frames moved in opposite directions rather than orthogonally. The other difference was that Wallach used a circle as the large surround rather than a rectangle. It is possible that one or both of these variations might result in a different type of visual analysis. Day and Dickinson (1977) have provided evidence that circular and square stimuli can produce different induction effects under some conditions.

The Subject-Relative Theory. Brosgole (1968) proposed an alternative theory of induced motion based on subject-relative cues. As noted earlier in the discussion of the Roelofs effect, the subjective straight ahead tends to be localized near the center of visual stimulation. Brosgole viewed IM as a dynamic form of the Roelofs effect in which the apparent straight ahead shifts along with the center of the laterally moving frame so as to remain symmetrically located within the visible field. Thus, the objectively stationary and fixated target is perceived to move because it continuously changes position with respect to the apparent straight ahead. In a series of six experiments, he reported that the motion induced in a stationary object by a moving surround was accompanied by an apparent shift in the egocentric location of the object and that the amount of perceived induced movement significantly correlated with the degree of the apparent displacement. He therefore interpreted induced motion in terms of a subjective change in the location of an object in space as opposed to object-relative displacement.

Thus the major distinction between these two theories lies in what is thought to constitute the frame of reference. According to the object-relative theory, the frame of reference is some object or part of the visual field that surrounds the fixated target, whereas in the subject-relative theory, this function is served by the spatial coordinates associated with the egocentre of the observer.

Lateral Inhibition. Tynan and Sekuler (1975) proposed a third possibility, explaining the induced motion observed in their experiments in terms of lateral inhibition between motion analyzers responsive to opposite directions of motion. Sekuler (1975) admitted that this explanation of induced motion was quite speculative. Although this explanation of induced motion may have its place, it would appear to be of little relevance in the current investigation because, as will be discussed in the Procedure, the spot and frame were separated by a substantial distance. Informal observations cast more doubt on the role of lateral inhibition in induced motion because it was found that IM could be produced with the frame in the extreme periphery of one eye and the spot in the extreme periphery of the other eye. It is unlikely that lateral inhibitory effects would act across the two halves of the cortex.

Undetected Eye Movements. Several investigators have postulated that eye movements may be involved in the perception of induced movement. That is, although instructed to fixate the spot, there might be a tendency for the subject to unconsciously track the laterally displacing frame. Such an undetected shift in eye position would result in a change in retinal location of the stimulus and might produce the perception of target motion, thereby accounting for the effect.

Brosgole, Cristal, and Carpenter (1968) recorded the corneo-retinal potential of subjects watching induced motion and found that eye movements did not correlate, either in direction or magnitude, with the perceived movement and therefore could not be a significant factor in IM. Basilli and Farber (1977), using a dichoptic display, also discounted eye movements as a factor in IM, as did Duncker (1929) and Shaffer and Wallach (1966) in earlier studies.

Relevant Stimulus Parameters

In addition to the problems of definition mentioned earlier, a second problem in the induced movement literature is the fact that such potentially relevant parameters as frame size, degree of displacement, and velocity have not been investigated in any systematic way. The marked differences of the stimulus properties chosen in various experiments make comparisons difficult and tenuous at best because the power of the effect might vary considerably depending on the type of stimuli used. The next section of this paper will review some of the known stimulus properties accounting for IM.

Enclosure. Although Duncker intimated that stimulus size had some bearing on IM, he nevertheless viewed the two main determinants of the effect as (1) the greater tendency for motion to be perceived in the fixated rather than the non-fixated stimulus and (2) motion is attributed to the enclosed rather than the enclosing stimulus. His principle of enclosure was derived directly from the frame of reference model. Although Duncker did not state explicitly that an object must completely surround or enclose another object in order to serve as its frame of reference, this has been the most common interpretation. Despite the fact that enclosure of the spot by the frame may be the single most salient feature of the typical IM stimulus array, viewing the effect solely in these terms has limited experimentation to a rather narrow path. Furthermore, there is an obvious confounding between stimulus size and enclosure simply because any stimulus which encloses another must also be larger. It could well be size difference, as opposed to enclosure itself, which produces the induction effects.

As a Gestalt psychologist, Duncker interpreted this work in the context of figure-ground and inner-outer (enclosed-enclosing) relationships. Unfortunately, the specific studies which he conducted in this vein are omitted from the translated version of his original paper which only states that he found the figure showed better IM than the ground and that the best IM occurred when the figure was enclosed. Although this implies that he found evidence for some IM with a nonenclosed spot, almost all subsequent studies have used the enclosed spot array.

Brosgole and Whalen (1967) attempted to measure the effect of enclosure on the amount of perceived IM but their experiment suffers from a major methodological flaw. Instead of comparing the amount of IM of an external spot to that produced by an internal spot in the presence of a moving frame, they compared the induction effect of a spot enclosed by a frame to that produced by another equal sized spot moving through the same distance as had the frame. Their conclusion that enclosure produced a twofold increase in IM is very speculative because it cannot be determined whether these results were due to enclosure as such or merely because the enclosing stimulus was the larger of the two stimuli.

In a series of experiments, Day, Miller, and Dickinson (1979) re-examined the question of enclosure. They asked subjects to report whether it was the frame or the spot that appeared to move in each of four conditions: the spot moving inside or outside a stationary frame and a stationary spot inside or outside a moving frame. They concluded that enclosure of a moving or stationary spot did not significantly affect the frequency with which either induced or real movement of the spot was perceived compared to nonenclosure. They also found that perceived movement of the frame was as probable as that of the spot.

It is important to note that in this experiment, an extremely small stimulus array was used, with the frame subtending a visual angle of .3 x .2 degrees and the spot being only .072 degrees. These dimensions were chosen so that the total lighted area of the stimuli were equal (that is, the sum of the lines making up the border of the frame and the area of the circle). This does not mean that the area subtended by each of the two stimuli were equal. The frame, of course, was still larger than the spot but because of this type of control, the size of the enclosed spot relative to the rectangular area within the frame was considerably larger than in most IM experiments.

The authors recognized the possibility that the effect of enclosure may only occur when the spot is much smaller relative to the enclosed area of the frame. They therefore reduced the size of the spot even further (.01 degrees in diameter) and repeated the experiment. In this case, enclosure did not result in greater frequencies of either perceived induced movement or real movement compared to nonenclosure but perceived real movement of the spot occurred more frequently than did IM. One must interpret these results with great caution due to the extremely small size of the stimuli. The role of frame size will be discussed in the following section and a case will be made for its importance as a parameter in IM. Suffice it to say at this point that the stimulus array used makes it unlikely that optimal IM effects could be observed in this experiment and therefore the comparisons of enclosure to nonenclosure are somewhat questionable.

Another aspect of enclosure concerns whether a complete frame is necessary for IM to be perceived. Duncker (1929) conducted several experiments in which he removed part or all of the side farthest from the spot but his results were omitted from the translation of his paper. However, studies in this laboratory clearly show that IM can be obtained without a complete frame.

Spatial Separation of the Spot and Frame. Several studies have examined the effect of separating the spot and the frame in the third dimension to determine if there was any decrement in the strength of IM. Gogel (1965) has proposed what he calls the "adjacency principle" which states that the strength or effectiveness of the relative cues between objects decreases as a function of the perceived increase in directional or depth separation of the objects. Although this definition also encompasses spatial separations in the frontoparallel plane, Gogel and his colleagues have confined their investigations in the spot and frame paradigm to adjacency in depth. A comprehensive examination of the adjacency principle in the frontoparallel plane would necessitate the use of a nonenclosed spot to determine if increasing the spatial separation between the spot and the frame resulted in a decrease in the strength of IM. According to this principle, such a decrease would be predicted, but as mentioned earlier, such a design has rarely been used. It should be noted that the adjacency principle makes no statement regarding the causes of IM. Instead, it simply states that whatever the factors involved, their effectiveness will decrease with increasing separation between the test and inducing stimuli.

Gogel and Koslow (1971) measured the strength of IM as a function of the perceived depth between the test stimulus and the inducing stimulus. The frame was placed at three separate distances and the amount of induction was measured in a spot situated in the same plane, as well as at the other two distances. In general, they found that the strength of IM decreased when the spot was in front of the frame, with little or no decrease when it was placed behind the frame. They interpreted these results in terms of the combined effects of two factors: first, the adjacency principle and secondly, the tendency for the magnitude of IM to adhere to the size-distance invariance hypothesis such that for a given visual angle, the apparent amount of displacement would increase in proportion to the apparent distance of the spot from the subject. Although they intended to provide the subject with only stereoscopic cues, the size of the spot was not matched for visual angle at the different distances, thereby providing an additional unintentional distance cue. It is not known if this had any effect on their results.

In a later study, Gogel and Koslow (1972) carried out a variation of their former work in which they examined how the simultaneous presentation of two frames at different distances affected the magnitude of IM of a spot presented at three distances. Although they claimed this study supported the adjacency principle, their results are far from clear as both frames had an effect on the perceived IM. Furthermore, if adjacency in the frontoparallel plane without regard to separation in depth had an effect, the smaller frame, being more adjacent to the spot, should have exerted more influence on it than the larger frame. However, this was not found to be the case. In order for the adjacency principle to be considered as a valid stimulus parameter in IM, the contribution of adjacency in depth and that of lateral displacement would have to be quantified, as well as any possible interaction that might exist between these factors.

Whether the adjacency principle has any real importance to IM or visual perception in general is open to question. In essence, it simply states that objects closer together in visual space tend to interact more than ones farther apart. It seems unnecessary to propose a unique "principle" to that effect. Moreover, it is not necessary to invoke the adjacency principle at all to explain the observation that the perceived amount of IM is less when the spot is in front of the frame while there is little or no decrease as the light is displaced behind the frame. Subject-relative cues which take into account the combined factors of motion constancy and the decrease and eventual elimination of stereoscopic cues with increased distance can more simply and just as adequately account for their results.

If the adjacency principle plays any role in conventional IM, it is probably a minor one because in most studies, the test and inducing stimuli are in the same plane. This would eliminate any effects that might result from separation of the test and inducing stimuli in the third dimension. As mentioned earlier, lateral adjacency (in the frontoparallel plane), has not been systematically investigated in induced motion.

Frame Size. It is somewhat ironic that what might well be the single most important stimulus parameter in IM has also been one of the most overlooked. This is even more surprising in view of the fact that numerous investigators have found greater IM effects with large frames, and yet no one has categorically stated that it is an important determinant of IM.

Duncker (1929) noted that when the observation distance to the stimuli was reduced, his subjects experienced self-motion as if they were moving along with the system. This effect, known as induced self-motion, was in some cases so strong as to cause dizziness in his subjects. When some part of the room environment was visible, the veridical motion of the frame was usually perceived, eliminating the impression of self-motion. The increase in the magnitude of the effect with decreasing observation distance could have been due to one of two factors: the decrease in the viewing distance itself or the increase in the size of the frame.

Brosgole (1968) reported that a two-fold increase in the strength of IM resulted with a larger moving frame, even though the only difference between the two frames used in this experiment was in height. Also, when the subjects detected the movement of the frame, it was in the presence of the small rectangle far more frequently than the big rectangle. Furthermore, in his experiment in which a large frame surrounded a small frame and each moved in opposite directions, induction of the spot was determined by the large frame, contrary to the predictions of the separation of systems principle. While all subjects perceived the small frame to be in motion, fewer than one-third detected any motion in the large one. Apparently Brosgole was not concerned about the possible significance of frame size as a determinant in IM. It seems that he mentioned it only because it provided support for the subject-relative theory as opposed to a object-relative theory of IM.

Other experiments have found greater IM effects with larger frames (Gogel and Koslow, 1972; Rock, Auster, Schiffman, and Wheeler, 1980). It seems that the movement of a large frame is more difficult to detect and is therefore more effective than a small frame in inducing movement in the spot.

Ebenholtz (1977) demonstrated the importance of frame size in the rod-and-frame effect, in which the subject's task is to set a luminous rod to true vertical in the presence of a tilted surrounding luminous frame. This display is somewhat analogous to the Roelofs effect, differing in that the former stimulus involves tilt of the luminous frame whereas the latter involves lateral displacement. He found that the magnitude of the effect was determined solely by the retinal size of the stimulus and not by convergence, apparent size, or apparent distance. Further support for the role of stimulus size was provided by Witkin and Asch (1948), who first investigated the rod-and-frame effect and reported that a tilted room produced even greater effects than a luminous frame. Ebenholtz attributed the importance of retinal size to the marked effect of the peripheral retinal stimulation on apparent body tilt and regarded the rod-and-frame effect as possibly a static version of the induced self-motion and tilt reported by Dichgans and Brandt (1974). Although the rod-and-frame effect may not be strictly analogous to IM, it is arguably of the same class of phenomena, and suggests the possibility that the same factor, retinal size, may also be a key determinant in IM.

Frame Velocity. Another stimulus parameter which has not as yet been adequately quantified is that of frame velocity. For instance, Gogel and Koslow (1971) used a frame velocity of 1.5 degrees per second whereas Brosgole, Cristal, and Carpenter (1968) used a velocity of .33 degrees per second. These differences make it difficult to determine if the particular speeds chosen in a given experiment are optimal to motion induction.

It is likely that IM must have some limiting speed at which the effect begins to deteriorate. Duncker (1929) must have recognized this because he noted that if the background was moved back and forth rapidly, the spot would appear to be stationary. Brosgole (1968) found that when he used two different frame velocities, the higher velocity resulted in a decrease in IM. Other studies have found similar differences attributable to frame speed (Day and Dickinson, 1977; Rock, Auster, Schiffman, and Wheeler, 1980). In light of the previous discussion on frame size, it would appear that the frame velocity at which IM begins to deteriorate might also be partly dependent upon frame size simply because the motion of small frames is easier to detect than that of large frames.

There are numerous other stimulus parameters that could be discussed, but it is apparent that although there are some important clues to the problem, we simply do not know the necessary and sufficient conditions for the production of IM. The next section will deal with how IM might be explained from a physiological perspective and may shed some light on how the underlying mechanisms of IM might fit into an overall framework of motion perception and visual spatial orientation.

Evidence for Two Visual Systems

Why should a visual stimulus, in this case a stationary or moving luminous rectangular frame, be able to alter the perceived location of another stimulus in visual space? Perhaps an answer to this question may be found in the recent psychophysical and physiological findings that suggest the operation of two distinct modes of visual information processing depending upon which area of the retina the image falls. Dichgans and Brandt (1974) provided strong psychophysical evidence for the existence of "two visual systems" in their investigation of visually-induced self-motion and tilt. It has been known for some time that when a subject is exposed to a large horizontally moving visual pattern, he experiences self-motion in the opposite direction to that of the moving stimulus, while the moving pattern appears to be stationary (Gurnee, 1931; Helmholtz, 1896; Mach, 1886). When perceived self-motion is around the body's central axis, it is called circular vection and cannot be subjectively differentiated from true passive body rotation. Moreover, the visually-induced pseudo-Coriolus effect that follows cannot be distinguished from the true Coriolus effect in which the head is bent toward the shoulder during true self-motion as a result of endolymph acceleration in the semicircular canals of the inner ear. The ensuing perceptual effects of apparent tilt, dizziness, drowsiness, and nausea (collectively known as motion sickness) are qualitatively the same as during real acceleration (Dichgans and Brandt, 1974).

Their apparatus consisted of a rotating chair inside a cylindrical drum painted with vertical black and white stripes subtending seven degrees of visual angle. Both the chair and the drum could be rotated independently. Stimulus area and location within the visual field (which could be controlled by the use of masks attached to the chair) were found to be the major determinants as to whether the sensation of self-motion occurred or whether the visual pattern was perceived to be moving relative to the observer.

Brandt, Dichgans, and Koenig (1973) found that stimulation of the central 30 degrees in diameter of the visual field rarely induced circular vection, and only moderate effects were produced with up to 60 degrees of visual stimulation. However, masking up to 120 degrees of the central visual field caused only a slight reduction of circular vection.

The dominance of the periphery was also demonstrated in an experiment in which two stimuli, each 30 degrees in diameter, were exposed simultaneously to the central and peripheral areas of the retina. The results indicated that peripheral stimulation produced stronger effects (Brandt et al., 1973). All their results supported the hypothesis that dynamic spatial orientation is determined by peripheral stimulation, while central stimulation results in the perception of movement relative to the observer. This illustrates the different functions of the central and peripheral retina.

Further psychophysical evidence for two visual systems was provided by Johnson, Leibowitz, Millodot, and Lamont (1976) who found that refractive correction does not improve peripheral visual acuity, in marked contrast to the improvement in foveal vision.

There is also an accumulating body of neurophysiological evidence supporting the notion that vision involves two parallel processes. Trevarthen (1962) noted that a split-brain monkey is capable of double perceiving and learning for some visual stimuli but not for others. On the basis of his findings, he introduced the terms "ambient" and "focal" vision. He hypothesized that the ambient system maps the space around the body whereas the focal system deals with fine visual discrimination within a small area of space. Any part of the visual field can be a part of the ambient system but focal vision is restricted to the fovea and parafoveal region. In contrast to focal vision, ambient vision has low angular resolution for stationary features, low sensitivity to relative position, orientation, luminance or hue, but is highly sensitive to a change in any of these parameters. Furthermore, these characteristics of the ambient system remain even under scotopic conditions.

Neuroanatomical studies show that the superior colliculus receives direct projections from the extreme peripheral retina (Apter, 1945; Forrester, 1967) while neural projections to the lateral geniculate body come mainly from the fovea and parafovea (Freund, 1973). Furthermore, half of the visual cortex in primates is devoted to the central 10 degrees of the visual field, with scarcely any representation of the peripheral monocular fields (Trevarthen, 1968). It is clear that the central and peripheral retina are devoted to quite different types of visual analysis.

The psychophysical and physiological evidence for two visual systems is potentially relevant to the perception of IM because it indicates that the eye's sensitivity to different stimulus properties (such as movement) can vary according to the part of the retinal on which the image falls. In IM, the image of the frame falls on a more peripheral portion of the retina. If the eye is less sensitive to slow motion in the periphery as indicated by the evidence, this provides a plausible explanation of why the movement of the frame is undetected by the observer.

Introduction to the Experiments

The following experiments attempted to determine which of the two main theories of IM, the object-relative or the subject-relative theory, best accounts for the effect. It will be recalled that Brosgole viewed IM as essentially a dynamic form of the Roelofs effect, such that the apparent straight ahead was shifted along with the moving frame and the spot was perceived to move with respect to this shift in the apparent straight ahead. In order to test the subject-relative theory, one can compare the size and direction of errors in the perceived location of a spot in the presence of a stationary frame to those produced when the same frame is moving. If the subject-relative theory is an adequate description of IM, these localization errors should be the same in both direction and magnitude.

In order to test the object-relative theory, one can compare the errors in locating a spot under typical conditions of IM (when frame and spot are seen together), to those in which frame and spot do not undergo any object-relative displacement. This can be achieved by not having the spot illuminated in the presence of the frame. That is, the frame moves through the same path as in the induced motion condition but the spot is not illuminated until immediately after the frame has been extinguished. This allows for frame displacement without object-relative motion between the frame and the spot and is hereafter referred to as "non-relative induced movement".

In most studies of the Roelofs effect, there was no separate fixation point and the subject simply fixated one of the vertical sides of the luminous frame, which was then adjusted until the subject judged this edge to be in the OMP. In the present experiment, a separate fixation point was used which also served as the target at which the subject pointed on each trial. The introduction of the target light enabled direct comparisons of the Roelofs effect and IM because the only difference between these experiments was whether the frame was stationary or moving. Although the addition of the fixation point changed the design slightly from other studies of the Roelofs effect, the spatial shifts in egocentric localization attributable to the frame should be present with or without the fixation point.

In the present experiment, the spot was always located <u>outside</u> the borders of the frame. As noted in the section on enclosure, the induced movement literature contains very few examples of experiments using a nonenclosed spot (Brosgole, 1968; Day, Millar, and Dickinson, 1979). Since many investigators seem to have a strong belief in the power of enclosure or surroundedness, it is worthwhile testing this notion simply to determine if it is a valid assumption. Furthermore, if this belief is unfounded, there are several advantages to the use of an nonenclosed spot design. The enclosed spot design greatly limits the amount of lateral movement of the frame because the spot must always stay within its boundaries, and the smaller the frame, the less the range of lateral movement. With a nonenclosed spot, there are no such restrictions with either large or small frames. In the present experiment, this allowed for the placement of the frame at different points in the visual field to determine if the perceived location of the spot was changed by this. It also allowed for longer exposure times and greater displacements of the moving frame such that the magnitude and direction of the errors in spot localization could be more fully assessed.

In all experiments the dependent variable was the subject's angular error in pointing to the fixation point which was always located in the OMP. Pointing has so far been used in very few studies on induced movement (Sugarman and Cohen, 1968). However, it is argued that pointing should accurately reflect the perceived location of the target in visual space. It also has the advantage of being a behavioural response that can be easily performed by the subject and easily measured by the experimenter.

Accuracy of Pointing to a Visual Target

Since the dependent variable in this experiment involved pointing to a visual target in the dark, it is appropriate to include a brief discussion on how well subjects can perform this task and what other factors might affect their accuracy. Fitts (1947) and Fitts and Crannell (1949) found that when subjects reached for visual targets at shoulder height without visual guidance, accuracy was affected by the target position, by the distance to the target, and by the starting position of the arm.

Edgington (1953) examined the effect of the starting position of the arm in more detail by having subjects point with their unseen hand to a visual target placed in various positions in a horizontal arc. Accuracy was measured after the subject pointed by (1) moving his hand away from his body, (2) swinging his arm out from the straight-ahead position, and (3) swinging it in from an 85 degree lateral position. Subjects used their right arm when the target was to the right of straight ahead and their left arm when it was left of straight ahead. The results indicated that in all cases, the arm was stopped short of the actual position of the target. That is, when swinging their arm inwards, subjects' judgements were more lateral than the true position of the target, and when swinging outwards, judgements were biased on the straight-ahead side of the target position.

Sandstrom (1951) reported that the accuracy of pointing to a visual target was not affected by the subject's level of dark adaptation. He also noted that although the patterns of errors were similar regardless of which hand was used for pointing, mean errors were to the left when the left hand was used and to the right when the right hand was used.

Experiments on prism adaptation often use pointing with the unseen hand as a measure of visual of kinesthetic involvement. These studies suggest that a careful subject can perform such a task with errors of about plus or minus two degrees (Craske, Note 1).

Unique Aspects of Pointing in the Present Experiment

There were several ways in which pointing to the visual target in the present experiment differed from normal pointing. First of all, under most circumstances, one points to an object simply to indicate its general location, whereas in this experiment the subjects were attempting to perform at a high level of accuracy. In most situations where greater accuracy is required, one can either close one eye and sight down the pointing arm (or at the pointing finger) or else sight binocularly using the dominant eye for reference. Both cases involve a visually guided behaviour with immediate visual and kinesthetic feedback. In the present study, however, subjects could not use either of these sighting methods because pointing was done in the dark. Therefore, subjects received no visual feedback on their accuracy, either during or after the judgement. Finally, subjects in this study were deprived of their normal frame of reference (the conventional visual field) and were only able to see two visual stimuli, the frame and/or the target light.

In the everyday world, monocular and binocular judgements give slightly different locations of a stimulus. However in this instance, pointings were carried out binocularly because without visual reference points of the body (a finger, hand or arm), monocular judgements were of no help to the subject. Since the target light was aligned with the perpendicular bisector of the interocular axis, this line (the OMP) was defined as 0 degrees and all errors in pointing were measured in degrees of visual angle relative to this plane.

It may at first seem unusual to use the OMP as the reference point to measure kinesthetic errors originating about the shoulder axis. That is, it might seem more appropriate to use the shoulder joint itself as the point about which the angular error is measured. However, it was decided that the OMP was a better reference point for several reasons. Since the light was situated in this plane, under binocular viewing conditions the subjective and objective straight ahead corresponded. Also, the task was predominantly visual in nature, that is, the Roelofs effect and induced movement are visual not kinesthetic illusions. Thus the arm served to indicate the amount of apparent visual movement.

Most studies of cross-modal effects have found that when two sensory systems give conflicting information about the world, vision predominates (see review in Howard and Templeton, 1966). In the present experiment, sensory discordance was not a major factor because of the absence of visual feedback to the kinesthetic system. Since the primary interest was the change in pointing relative to the control scores, whether the reference point was based around the visual axis or the shoulder axis was not of great consequence. However, the inter-ocular axis seemed to be preferable in the present task. Thus subjects were instructed to align the fingertip with the imaginary line running from the target light to the point midway between eyes.

Questions and Experimental Hypothesis

Since the dependent variable in this experiment was the subject's visual error of location as given by pointing to the stationary target located in the OMP, the first question to be answered was whether a measurable Roelofs effect could be produced with the nonenclosed spot and frame stimulus array. Secondly, would the strength of any resulting Roelofs effect vary as a result of changes in the location of the stationary frame across the visual field? Thirdly, would these errors correspond in size and direction with those resulting from a matched condition in which the frame moved? The results would provide a basis for determining if either the subject-relative or the object-relative theory was an adequate explanation of IM.

It was hypothesized that the subject-relative theory would be unable to account for the predicted results. We know from both clinical and normal populations that visual stimulation of the left visual field, for example, results in a visual target being perceived to be to the right of its true location (Bruell's hemianoptic patients, 1958; and Brosgole's subjects in the Roelofs effect, 1968). Thus one would predict that the presence of a luminous frame at some position in the left visual field would cause a subject attempting to point to a target located in the OMP to point to the right of its true location. In contrast, it would be predicted that a luminous frame in the left visual field moving rightward toward the spot would cause induced movement of the spot leftward, resulting in pointing errors to the left of the spot. The same frame moving leftward away from the spot would cause induced movement rightward, and hence subsequent pointing errors would be expected to be to the right of the spot. Should these predictions be verified, it would indicate that pointing errors arising from IM depend not only on the position of the frame within the visual field but also on the direction of movement.

METHOD

Subjects

There were 20 subjects, ten females and ten males, who were paid for their participation in the experiment. All were either undergraduates or graduate students. The same subjects served in all six experiments. However, of the 20 subjects in the first three experiments, only 15 were able to participate in the final three. (For further details, please refer to Appendix A - Considerations on the Choice of Experimental Design.)

Apparatus

All experiments were conducted in a light-proof laboratory. An open steel frame structure (2.3 m x 1.65 m x 1.53 m) housed the main apparatus and the subject sat within this structure during the course of the experiment (see Figure 2). A table (137 cm x 61 cm x 77 cm) was positioned so that the side opposite the subject was aligned with the front edge of the steel frame and centered. A plywood board (122 cm x 92 cm x 2 cm) positioned 9 cm above the surface of the table served as a platform on which the rest of the

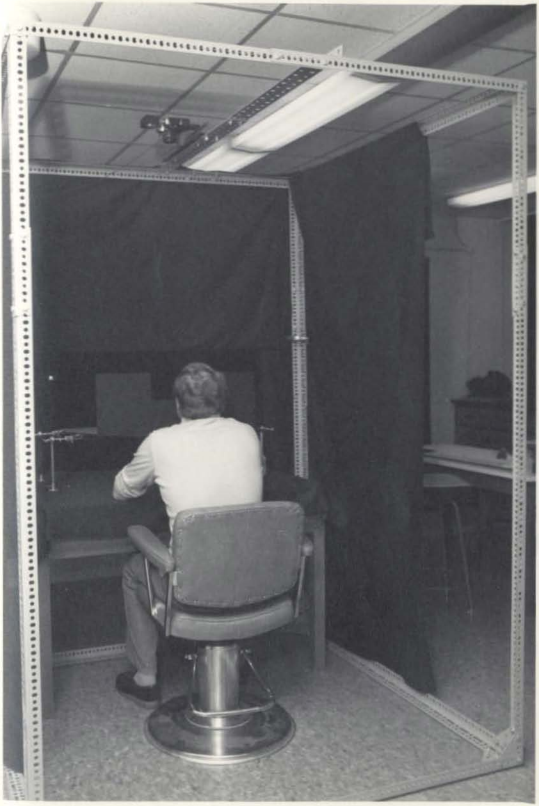

Figure 2. Steel frame structure.

apparatus was mounted. This platform was covered with black cloth. A piece of non-reflecting glass (76 cm x 61 cm x 2 mm) was positioned 23 cm above the surface of the platform and was held in place by rods and clamps located at the corners of the glass. On the top surface of the glass, a protractor was made in order to measure the subject's angular error in pointing to a visual target (see Figure 3). White drafting tape (1.5 mm) was affixed to the glass for each degree of angle from 40 degrees to the left and right of center, with the center line of the protractor (0 degrees) aligned with the target light. As can be seen from Figure 4, the origin was not located on the surface of the glass. Because the protractor was being used to measure pointing error in terms of visual angle, the origin was located in the vertical plane bisecting subject's eyes (at a point in space 25 cm from the edge nearest the subject).

In order to keep the subject's head in a fixed position throughout the experiment, a bite bar apparatus was used. The bite bar plate (coated with dental impression compound) was affixed to a 15 cm rod mounted in a transverse travel slide, which was in turn attached to a carrier on a 25 cm optical bench. The optical bench was bolted to the top surface of the platform in the subject's mid-sagittal plane. This arrangement allowed for fine adjustments of the bite bar forward and backward as well as up and down.

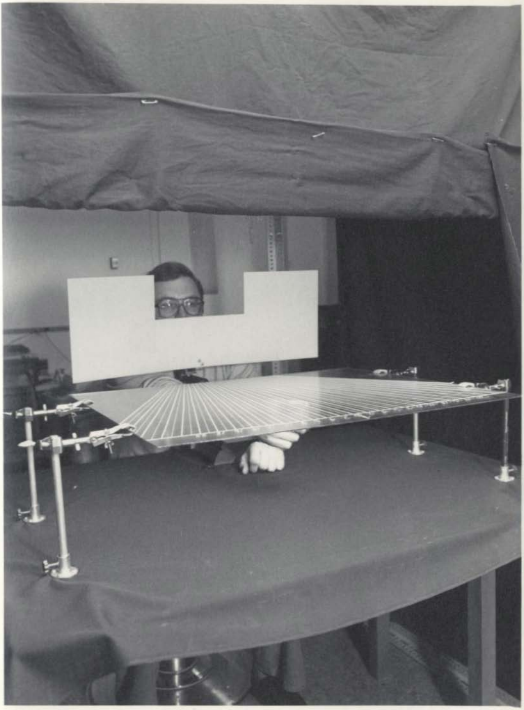

Figure 3. Glass protractor for measuring pointing error.

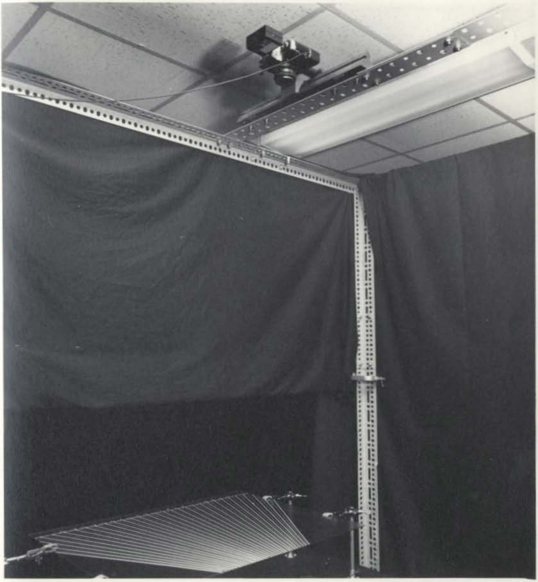

Figure 4. Glass protractor and camera mount.

A 71 cm x 25 cm x 1 mm black cardboard occluder with a 25 cm x 12 cm section cut from the middle of the top edge was attached to the bite bar rod and was positioned 14 cm from the subject's eyes. The occluder could be adjusted vertically so that the subject could not see any of the glass protractor in front of him. Thus, the subject viewed the stimuli by looking through an open area bounded on the top by a piece of black cloth and on the bottom and sides by the cardboard occluder.

The inducing stimulus was a 109 cm x 109 cm fluorescent orange frame made from four strips of 4 cm wide paper glued to a piece of black posterboard. This stimulus glowed orange under UV illumination. At the viewing distance used in this experiment (3.06 m), the frame subtended a visual angle of 40.7 degrees. (It should be mentioned that this is substantially larger than the visual frames usually used in studies of induced movement.) The frame was suspended from a 8.25 m curtain rail which ran the length of the wall in front of the subject. Two plexiglass mounting brackets connected by metal rods attached the frame to the curtain rail sliders and allowed for vertical adjustment (see Figure 5). The center of this stimulus was positioned 1.27 m from the floor. The frame could be moved to the left or right or stopped at any position along the length of curtain rail by means of a variable speed, 1/2 H.P. servo-motor attached to the curtain pull-cord.

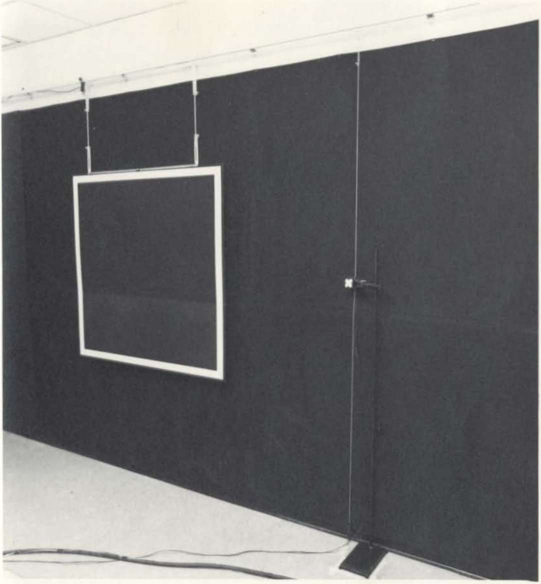

Figure 5. Target light and inducing frame.

The UV light source illuminating the frame was positioned immediately to the left of the steel frame structure and in line with its front edge (see Figure 6). It was adjusted to the same height as the center of the frame and thus illuminated it evenly. Since the UV lamp also emitted some visible light, it was necessary to reduce the amount of reflected light in the laboratory as much as possible. Black pieces of cardboard attached to the front of the UV light were used to direct illumination towards the frame. In addition, black cloth was stapled to the wall behind the frame and was also draped on the sides and front of the steel frame structure to further reduce the light level. The subject viewed the stimuli through ski goggles in which Kodak Wratten gelatin filters (No. 22) were fitted in front of the yellow plastic filters that had been supplied with the goggles. This effectively eliminated the extraneous light so that during the experiment, the subject could see nothing in the room other than the intended visual stimuli.

The target light was a 12 V, 12 W incandescent bulb (adjusted to 3.5 V with a D.C. power supply) mounted in a 3.5 cm diameter metal pipe 10 cm long. A translucent plexiglass disc was glued to the end of the pipe facing the subject and was painted black except for a 1 cm diagonal cross. The lamp was sealed at the back to prevent any extraneous light leakage. In order to eliminate the

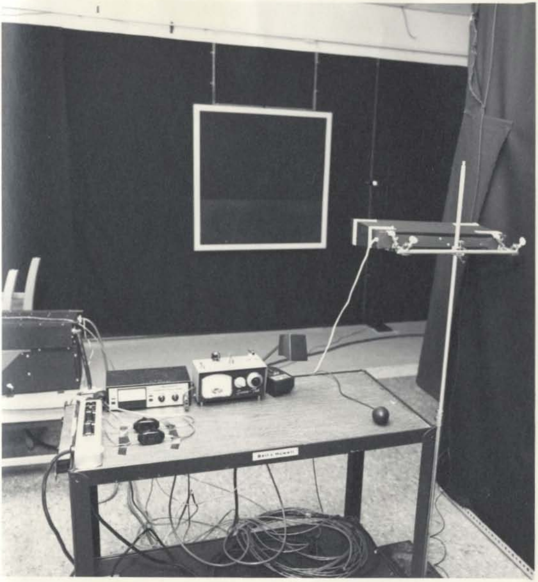

Figure 6. Ultraviolet light source and apparatus controls.

possibility of reflected light from the UV light the entire lamp assembly (except for the translucent disc) was painted black, as was the stand and clamp in which it was supported. The target light was adjusted so that the center of the diagonal cross was 1.27 m above the floor (the same height as the center of the frame). In this position it was 3.06 m from the subject in his mid-sagittal plane.

A 35 mm camera fitted with a wide angle lens, a flash unit, and an automatic winder was mounted on an optical bench at the top of the steel frame and was aimed down at the subject (see Figure 4). In this position, the camera lens was 1.53 m above the surface of the table. All of the protractor as well as the subject's arms and shoulders were visible through the viewfinder.

Procedure

Prior to the first experiment, a dental impression of the subject was made in the impression compound coating the bite bar. The bite bar was adjusted so that the midpoint between the subject's eyes at the corneal surface was 25 cm from the rear edge of the glass protractor. In this position, the origin of the protractor coincided with the theoretical "optical center" or "cyclopian eye" of the subject. The bite bar was then adjusted vertically so that the subject's eyes were at the same height as the target light (1.27 m). The subject's chair (which could be raised or lowered hydraulically) was set and locked at the height most comfortable for the subject when in position on the bite bar. The cardboard occluder was then adjusted so that the subject could see all of the frame but none of the glass protractor.

Subjects wore a sleeveless athletic shirt that left their shoulders visible. A cross was made with a felt-tip marker at the end of each shoulder (on the acromion process of the scapula). For the present purposes, the shoulder axis may be defined as the line passing through both of these crosses. Thus, the angle formed by the intersection of the shoulder axis and the axis of the pointing arm could be determined from the photographs.

Each experiment consisted of four blocks of trials run in an ABAB format. Blocks 1 and 3 were identical "control" conditions in which only the target light was illuminated. Blocks 2 and 4 were the "frame" blocks and were the same within a given experiment. In these two blocks, the fluorescent frame was visible and differed only in whether it was moving or stationary. Since the control blocks were exactly the same in all six experiments, the only difference was in what happened during the frame blocks of each experiment.

Each block of trials consisted of eight readings and the same format was followed for each block. During the experiment, the subject fixated the target light. For the first reading, the subject closed his eyes (after 30 seconds had elapsed as indicated by the experimenter) and set the right arm so that it felt to be 90 degrees to the shoulder axis when held out straight at shoulder height (see Figure 7). In this task, only kinesthetic cues could be used to make the judgement. The subject signalled that he had made his decision by tapping his left hand on the table top and a photograph was immediately taken with the overhead camera. The subject then opened his eyes and again fixated the target. On the next six readings, the subject pointed to the target light when instructed to do so by the experimenter (every 30 seconds). When pointing to the cross, the subject moved his unseen right index finger to the imaginary line between the midpoint of the two eyes and the center of the visual target. All pointings were done using binocular vision. The subject raised his outstretched arm in front of him until it touched the underside of the glass protractor. When he felt that his pointing was correct, he closed his eyes and tapped his left hand on the platform. The experimenter then took the photograph (see Figure 8). Between judgements the subject rested his arms on the platform with a slight bend at the elbows.

Figure 7. Subject setting arm to 90 degrees to shoulder axis.

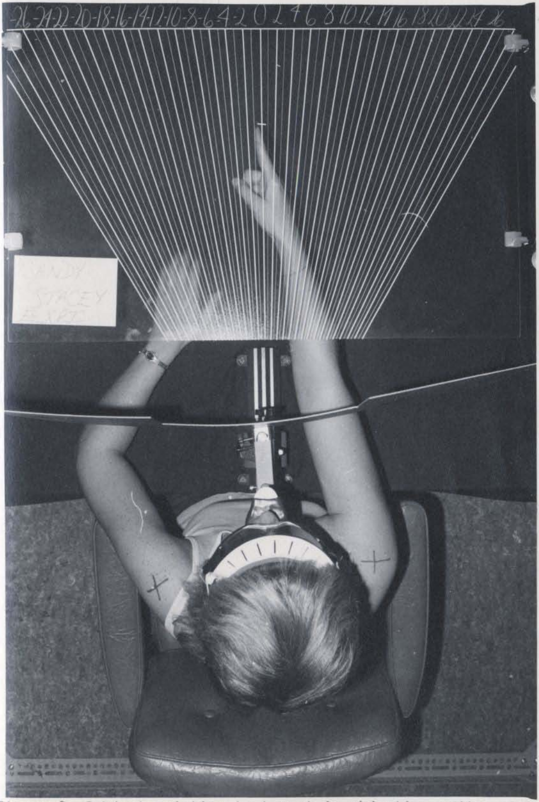

Figure 8. Subject pointing to target in objective median plane.

Having the subjects close their eyes just before the photograph was taken assured that they did not see any of the surroundings when the flash went off. It also eliminated the possibility of a bright afterimage which might adversely affect subsequent readings.

On the eighth and final reading of each block, the subject again set his arm to 90 degrees to his shoulder axis. The purpose of these readings at the beginning and end of each block was to determine if there were any changes either within or between blocks that might be due to postural aftereffects. Since these judgements were done on a strictly kinesthetic basis, they should be the same at the beginning and end of each block, irrespective of whether the intervening trials were control or frame blocks. If this proved to be the case, then any systematic shifts in the errors on pointing trials could only be attributed to changes within the visual rather than the kinesthetic system. However, if the subject's ability to perform a strictly kinesthetic task changed after exposure to the experimental condition, it would suggest that the pointing errors might be partially kinesthetic in nature, that is, arising from postural aftereffects.

The same sequence was followed for the frame blocks. On the arm-to-90-degree trials of these blocks, the frame was illuminated but stationary in the appropriate position for the start of the first pointing trial.

The experimental situation may be summarized as follows: the subject sat facing a target light and a large movable visual frame. Pointing to the target occurred both in the presence and absence of the frame. In two of the experiments, whenever the frame was present, it was stationary. In two other experiments, the frame moved while the target light was simultaneously illuminated. In the final two experiments, the target light did not appear until immediately after the moving frame was extinguished.

For ease of understanding, experiments are grouped according to similarity of design. Thus, the two experiments involving the Roelofs effect are presented first, followed by the two induced movement experiments, and finally the two experiments involving non-relative induced movement. Because this necessitated a change in the numbering of some experiments, this order of presentation does not represent the chronological order in which the experiments were conducted. However, all subjects were run through all six experiments in exactly the same sequence. For details on the exact order in which the experiments were conducted and the rationale for this choice of design, please refer to Appendix B - Experimental Order Aspects.

The Roelofs Effect

Experiment 1 - The Far Roelofs Effect

Experiment 1 examined the subject's errors in pointing to the spot when the stationary frame was located in the left visual field some distance from the spot. Because the frame was not immediately adjacent to the spot, this experiment was referred to as the Far Roelofs effect. Blocks 1 and 3 were "control" conditions and only the spot was illuminated. Blocks 2 and 4 were "frame" conditions and the frame was illuminated in addition to the spot. The center of the stationary frame was located 1.22 m to the left of the spot (43.8 degrees of visual angle) and the right edge of the frame was 61 cm to the left of the spot. This position will be referred to as "far left" to distinguish it from the "near left" position in which the right edge of the frame was only 5 cm to the left of the spot. The experimenter told the subject which task to perform either by saying "Set your arm 90 degrees to your shoulder axis" or "Point to the spot". Most subjects made their judgements within 5 seconds. Photographs were then taken of their arm position. A new trial began every 30 seconds.

Experiment 2 - The Near Roelofs Effect

Experiment 2 examined pointing errors when the stationary frame was immediately adjacent to the spot and is referred to as the Near Roelofs effect. It was identical to Experiment 1 except that the frame appeared in the near left rather than the far left position. Thus the center of the frame was 25.6 degrees of visual angle to the left of the spot as compared to 43.8 degrees in Experiment 1. Readings were taken every 30 seconds.

Induced Movement

Experiment 3 - Frame Moving Far Left to Near Left

Experiment 3 examined pointing errors when the spot was undergoing induced motion leftwards due to the rightward movement of the frame. Blocks 1 and 3, the control conditions, were again the same as in Experiments 1 and 2. However, in Blocks 2 and 4 of this experiment the frame moved from the far left to the near left position through a visual angle of 25.6 degrees. This movement of the frame took 30 seconds, at an angular velocity of .85 degrees of visual angle per second. When the frame had reached the near left position, the experimenter instructed the subject to point to the spot and a photograph was taken when the subject had made his judgement.

During pilot studies, it was noted that the spot appeared to be still moving while the subject was in the process of pointing. Because of this, the subject tended to take longer to make the judgement and was less certain of its accuracy due to the continuing "movement" of the spot. It was necessary for the subject's judgement to be made when the frame was close to the target light but before it came into contact with it as they were both located in the same plane. For this reason the experimenter instructed the subject to point to the perceived position of the light at the time the instruction "Point to the cross" was given, even though the light seemed to have moved still farther leftward while the subject was in the process of pointing. The frame was not stopped until after the photograph had been taken. The UV light was then extinguished so that the frame was no longer visible while being reset to the far left position. The reset time was 5 seconds.

A microswitch attached to the curtain rod automatically switched off the servo-motor when the frame had reached the correct starting position. The servo-motor was then turned on, starting the frame moving rightwards for the next trial. The UV light was illuminated making the frame once again visible to the subject and signalled the start of the next trial. Turning off the UV light just before resetting the frame and turning it on slightly after the servo-motor was started on the next trial ensured that the subject did not see the slightly uneven movement of the frame when the servo-motor started and stopped. This procedure was carried out in all experiments in which the frame was moved (Experiments 3, 4, 5, and 6) so that whenever the frame was in motion, it was seen to move smoothly.

Experiment 4 - Frame Moving Near Left to Far Left

Experiment 4 measured the errors in pointing when the frame moved leftwards away from the spot, in the opposite direction to Experiment 3. That is, the frame moved from the near left to the far left position, through a visual angle of 25.6 degrees leftwards. As in the previous experiment, the subject was asked to point to the perceived position of the spot at the time of the instruction, even though the spot might still appear to be moving. When the subject had made his decision and the photograph had been taken, the frame was extinguished and reset to the near left position for the next trial.

Non-Relative Induced Movement

Experiment 5 - Frame Moving Far Left to Near Left

Experiment 5 examined pointing errors in the absence of object-relative movement between the frame and the spot. This was done by moving the frame in the same manner as first IM condition (Experiment 3) except that the frame and the spot were not illuminated at the same time. This condition was therefore called "non-relative induced movement". The frame moved rightwards from the far left to the near left position. The UV light was then extinguished, making the frame invisible to the subject and the spot was immediately illuminated. The subject pointed to the spot as soon as it appeared and a photograph was taken when the subject signalled that he had made his judgement. The target light was then turned off and the non-illuminated frame was reset to the far left position for the next trial.

Due to the absence of a fixation point when the frame was present in this and the following experiment, subjects were not given specific intructions as to where to fixate. It had been noted during the pilot studies that subjects found it difficult to fixate the place where the non-illuminated light was thought to be because, in the absence of any other visual stimulus, the subject would invariably look at the frame. So subjects were simply asked to fixate the spot as soon as it appeared.

Experiment 6 - Frame Moving Near Left to Far Left

Experiment 6 measured the pointing errors of non-relative induced movement when the frame moved leftwards away from the spot. Thus the frame condition was the same as Experiment 5 except that the frame travelled in the opposite direction, moving from the near left to the far left position. The frame was then extinguished, followed immediately by the illumination of the spot. After the photograph had been taken of the subject's judgement, the target light was turned off and the non-illuminated frame was reset to the near left position for the next trial.

RESULTS

The results were based on the subject's error, measured in degrees of visual angle, in pointing to the target light on each trial. For each subject, the mean of the six pointing trials per block was calculated to give a single score for each block. Thus, in each experiment there were four scores per subject, one for each block. An overall mean for each block was then calculated from all subjects' scores on that experiment. All subsequent calculations were based on this score, which was the grand mean of each block.

Two planned orthogonal comparisons using the F ratio (Kirk, 1968) were calculated for each experiment (for more details see Appendix C - Rationale for the Choice of Statistical Analysis). This allowed for the comparison of the first control block (C1) to the first frame block (F1), and the second control block (C2) to the second frame block (F2).

The results are shown in Table 1 and Figures 9 to 15. Table 1 shows the calculated F values in Experiments 1 to 6 for the two planned comparisons and indicates whether or not these values reached statistical significance. Figure 9 shows the mean error of pointing on the first control block (C1) on all six experiments in the chronological order in which they were conducted. Figures 10 to 15 show the mean error in pointing to the target light on each of the four blocks of trials in Experiments 1 to 6. (It should be noted that due to the scale used for the Y-axis of Figures 9 to 15, points are plotted to the nearest .2 degree only. For more exact values of the pointing errors, please refer to Table 3.)

It is apparent from Figure 9 that in all experiments the mean error was always positive, that is, to the right of the true location of the target light (0 degrees). Although some negative scores (pointing to the left of the light) were recorded, such scores were infrequent. Subjects who recorded some negative scores tended to show the same behaviour in several experiments. In general, subjects tended to be consistent in their pointings within a given block.

In addition to the rightward bias of the first control block, there was a slight but steady rightward increase in the mean error of the first block (with the exception of a small decrease in one experiment) over the course of the six experiments when considered in the chronological order in which they were conducted. The C1 means ranged from 2.8 to 4.5 degrees, with a mean of 3.6 degrees for all six experiments. These figures were somewhat high due to the disproportionate contribution to the mean by one particular subject. (A subject or data point that varies greatly from the rest of the sample is known in the statistics literature

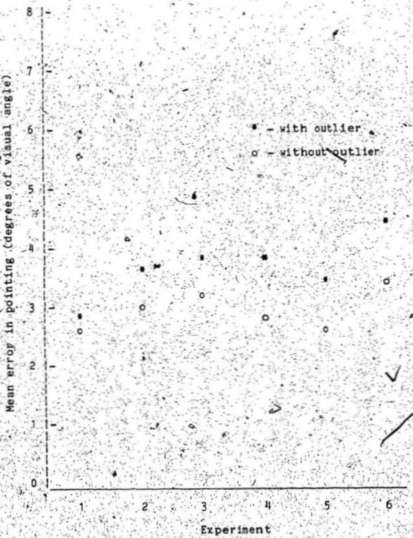

Figure 9. Mean error in pointing to target light on first control block of experiments in chronological order of running.

as an "outlier" or "wildshot".) This subject's scores were substantially higher (more rightward) than the rest and tended to increase over consecutive experiments. When the C1 means were calculated excluding the data from this subject, the range was from 2.7 degrees to 3.5 degrees with an overall mean of 2.9 degrees for all six experiments. Furthermore, the trend was no longer an increasing function. However, as Figure 9 shows, there was still a rightward increase in the C1 scores in the final experiment both with and without the outlier.

There are numerous ways of dealing with outliers in a set of data (Winer, 1962). In this experiment, the orthogonal contrasts were calculated both with and without the outlier to determine its effect on the statistical analysis. It can be seen by comparing Table 1 to 2 that the F values were changed somewhat but the inclusion of the outlier had no marked effect on the statistical significance of the results. Although this particular subject showed a greater error than the others, there was no indication that this individual had failed to understand the nature of the task but instead seemed to have a different "zero point" about which the pointing judgements were made. As there were no theoretical reasons for rejecting this subject's data, and since doing so without just cause would violate the assumptions of the normal distribution, the results presented here were calculated using all the data, including the outlier.

The results of the "arm straight out" measure at the beginning and end of each block indicated that there was no evidence for a postural aftereffect arising from the pointing measure itself. Thus any shifts in pointing between the control and experimental blocks were attributed to changes in the visual rather than the kinesthetic system.

Table 1

F Values for Planned Orthogonal Comparisons

in Experiments 1 to 6

Experiment	Orthogonal Comparison	
	C1-F1	C2-F2
1 - Far Roelofs	3.51 (p<.1)	8.48 (p<.01)
2 - Near Roelofs	.54 (n.s.)*	.54 (n.s.)
3 - Induced Movement (Frame FL - NL)**	.72 (n.s.)	.53 (n.s.)
4 - Induced Movement (Frame NL - FL)	20.11 (p<.001)	10.39 (p<.01)
5 - Non-Relative IM (Frame FL - NL)	9.10 (p<.01)	4.81 (p<.05)
6 - Non-Relative IM (Frame NL - FL)	10.44 (p<.01)	8.63 (p<.025)

* n.s. - non-significant

** FL - Far Left, NL - Near Left

Table 2

F Values for Planned Orthogonal Comparisons

Without Outlier in Experiments 1 to 6

	Orthogonal Comparison			
Experiment	C1-F1		C2-F2	
1 - Far Roelofs	3.42	(p<.1)	7.13	(p<.025)
2 - Near Roelofs	.84	(n.s.)	.21	(n.s.)
3 - Induced Movement (Frame FL - NL)	1.16	(n.s.)	.70	(n.s.)
4 - Induced Movement (Frame NL - FL)	27.32	(p<.001)	12.14	(p<.01)
5 - Non-Relative IM (Frame FL - NL)	9.50	(p<.01)	2.83	(p<.25)
6 - Non-Relative IM (Frame NL - FL)	9.10	(p<.01)	6.79	(p<.025)

Table 3

Pointing Errors on Control and Experimental Blocks

and Size of Shift

Experiment	C1	F1	SS*	C2	F2	SS
1 - Far Roelofs Effect	2.8	3.7	.9	3.0	4.4	1.4
2 - Near Roelofs Effect	3.8	4.1	.3	4.6	4.9	.3
3 - Induced Movement (Frame FL - NL)	3.8	3.1	.7	5.1	4.5	.6
4 - Induced Movement (Frame NL - FL)	4.5	7.7	3.2	6.2	8.5	2.3
5 - Non-Relative IM (Frame FL - NL)	3.6	4.7	1.1	5.8	6.6	.8
6 - Non-Relative IM (Frame NL - FL)	3.4	5.6	2.2	4.7	6.7	2.0

* SS - Size of Shift (Difference between Control and Experimental Blocks)

The Roelofs Effect

Experiment 1 - The Far Roelofs Effect

In Experiment 1, the Far Roelofs effect, the stationary frame was in the far left position so that its center was 1.22 m to the left of the target light. The results were in accordance with the experimental hypothesis. In the presence of the frame the pointing errors were more rightward than the control readings. From Table 1 and Figure 10 it can be seen that although the mean error in pointing to the target light was shifted to the right in the presence of the frame compared to the control score (C1 = 2.8 degrees and F1 = 3.7 degrees), the magnitude of this shift approached but did not reach statistical significance at the .05 level. However, it was significant at the .1 level, $F(1, 19) = 3.51$, $p < .1$. On the last two blocks, C2 and F2, the rightward shift was significant, $F(1, 19) = 8.48$, $p < 0.01$ (C2 = 3.0 degrees and F2 = 4.4 degrees).

Experiment 2 - The Near Roelofs Effect

In Experiment 2, the Near Roelofs effect, neither control-treatment pair was significantly different (see Table 1 and Figure 11). The presence of the frame had little effect on the subject's pointing to the target light,

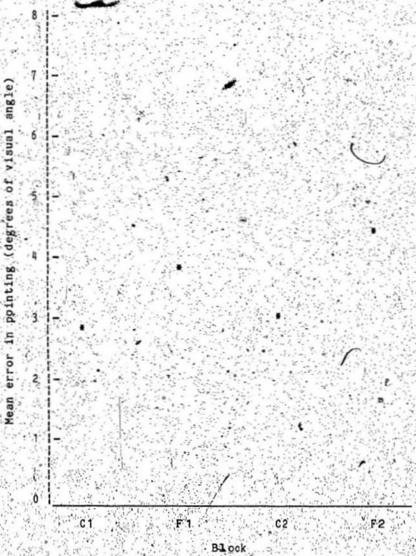

Figure 10. Experiment 1 - Far Roelofs effect - Mean error in pointing to target light on each block.

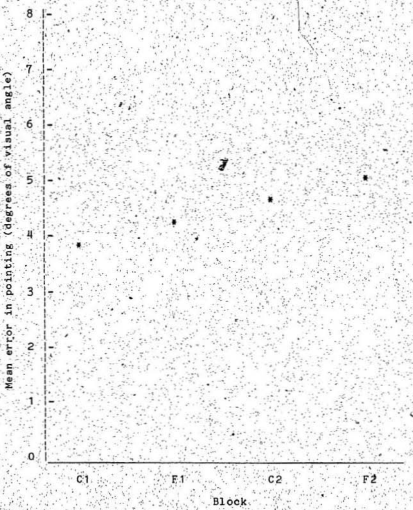

Figure 11. Experiment 2 - Near Roelofs effect - Mean error in pointing to target light on each block.

although there was a slight rightward shift in both cases (C1 = 3.8 and F1 = 4.1 degrees, C2 = 4.6 and F2 = 4.9 degrees). The largest shift occurred between F1 and C2 (.5 degrees). Figure 11 is essentially a straight line with a slight positive slope, with scores varying only 1.1 degrees over the four blocks.

When the two preceding experiments were compared with respect to the magnitude of the shift, the C1-F1 shift in the Far Roelofs effect was found to be three times larger than that in the Near Roelofs effect (.9 and .3 degrees, respectively). The C2-F2 shift resulted in nearly a five-fold increase (1.4 and .3 degrees, respectively).

Induced Movement

Experiment 3 - Frame Moving Far Left to Near Left

In this experiment, the frame moved rightwards from the far left to the near left position while the target light was illuminated, producing induced movement of the light leftwards. As predicted, the errors were in the direction of the perceived movement of the target light (see Figure 12). However, as shown in Table 1, the leftward shift from C1 to F1 was non-significant (C1 = 3.8 degrees and F1 = 3.1

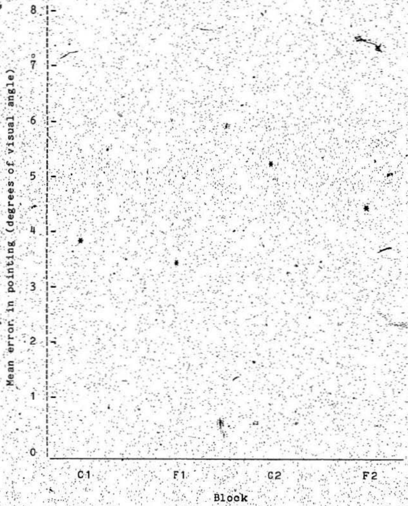

Figure 12. Experiment 3 - Induced movement (frame moving far left to near left) - Mean error in pointing to target light on each block.

degrees), as was the C2-F2 shift (C2 = 5.1 and F2 = 4.5 degrees). This was in spite of the fact that subjects reported strong IM.

In this experiment there was a different trend from the other experiments in which a clear treatment effect could be observed, namely Experiments 1, 4 and 6. In those experiments, after the first frame condition, the second control score returned toward, but did not quite reach, the same reading as in the first control score. That is, it was slightly biased in the direction of the first frame block. However, in Experiment 3, the C2 score not only returned to the C1 level but shifted even farther rightward. That is, there was a slight overshoot in the direction opposite to the treatment condition in this experiment.

Experiment 4 - Frame Moving Near Left to Far Left

In Experiment 4, the inverse of Experiment 3, the frame moved leftwards away from the target light while they were simultaneously illuminated, inducing rightward movement of the light. As expected, the pointing errors were in the direction of the perceived movement of the target light. As shown in Table 1 and Figure 13, this condition produced the largest effects of all six experiments (C1 = 4.5 and F1 = 7.7, C2 = 6.2 and F2 = 8.5 degrees). Both of these shifts were significant, F (1, 14) = 20.11, p < .001 and F (1, 14)

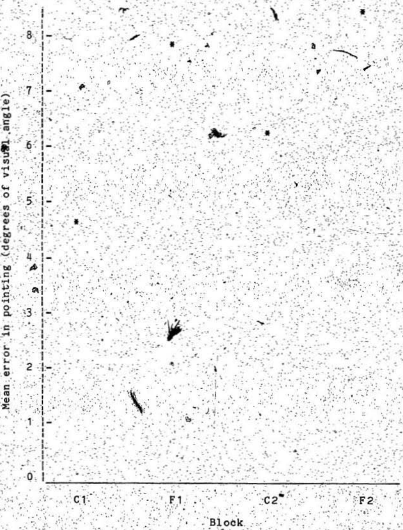

Figure 13. Experiment 4 - Induced movement (frame moving near left to far left) - Mean error in pointing to target light on each block.

= 10.39, $p < .01$, respectively. The C2 score approached but did not return to that of C1 after exposure to the first frame block and deviated in the direction of the F1 score (rightwards).

A comparison of the size of the experimental effects in the two induced movement studies indicated that the shifts in pointing were about four times larger when the frame was moving away from the light (Experiment 4 - C1-F1 shift = 3.2 and C2-F2 = 2.3 degrees) than when it was moving toward the light (Experiment 3 - C1-F1 shift = .7 and C2-F2 shift = .6 degrees).

In addition, the preceding four studies were compared for the size of the pointing shift when the frame and light were in the same relative position at the time the subject pointed at the target. This showed that the IM conditions produced larger shifts in pointing than did the Roelofs effect. That is, in both Experiment 1 and 4, the frame was in the far left position when the subject pointed, yet the shifts in pointing when the frame was moving were in the order of two to three times greater than when the frame was stationary. Similarly, in both Experiment 2 and 3, the frame was in the near left position when pointings were taken and the shifts produced in the IM condition were twice as large as in the matched Roelofs effect.

Non-Relative Induced Movement

Experiment 5 - Frame Moving Far Left to Near Left

In the frame blocks of Experiment 5, the target light was not illuminated when the frame moved from the far left to the near left position. The frame then disappeared and the target light was immediately illuminated. Table 1 and Figure 14 show that the rightward shift from the C1 to F1 block was significant, going from 3.6 to 4.7 degrees (F (1, 19) = 9.10, $p < 0.01$). The rightward shift from C2 to F2 was also significant, F (1, 19) = 4.81, $p < .05$ (C2 = 5.8 and F2 = 6.6).

It can be seen from Figure 14 that the trend in this experiment was different from the others (with the possible exception of the Near Roelofs effect where shifts in pointing were small) in that the C2 score did not return toward the C1 score at all after exposure to the first frame block. Following the C1-F1 shift of 1.1 degrees rightwards, the F1-C2 shift resulted in an additional 1.1 degrees rightwards, with another .8 degrees between C2 and F2. Thus the results indicate a linearly increasing function.

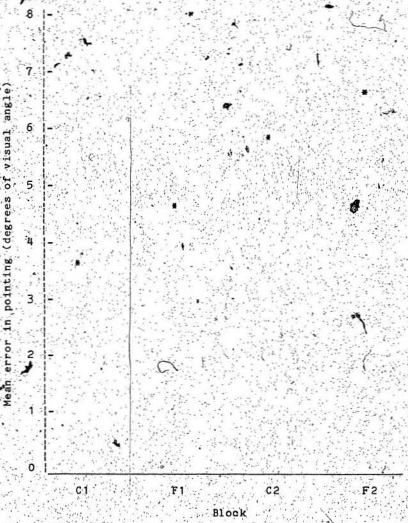

Figure 14. Experiment 5 - Non-relative induced movement (frame moving far left to near left) - Mean error in pointing to target light on each block.

Experiment 6 - Frame Moving Near Left to Far Left

Experiment 6 was the inverse of Experiment 5, that is, the frame moved leftwards from the near left to the far left position and was then extinguished, followed immediately by the onset of the target light. As shown in Table 1 and Figure 15, the mean pointing error shifted rightwards on the frame blocks relative to the control blocks (C1 = 3.4 and F1 = 5.6, C2 = 4.7 and F2 = 6.7 degrees). In both cases the shifts were significant, F (1, 14) = 10.44, $p < .01$ and F (1, 14) = 8.63, $p < .025$, respectively.

The comparison of the shifts in Experiment 5 and 6 showed a similar trend to that seen in the IM studies; greater shifts resulted when the frame moved away from the light. The shifts in Experiment 6 were twice as large as those in Experiment 5 (Experiment 5 - C1-F1 = 1.1 and C2-F2 = .8 degrees; Experiment 6 - C1-F1 = 2.2 and C2-F2 = 2.0 degrees).

When the non-relative induced movement conditions were compared to the appropriately matched Roelofs effect and IM condition (that is, when the frame and the light were in the same relative position at the time of pointing), it indicated that the size of the shift was in between these other conditions. Thus, IM produced the largest shifts, non-relative induced motion produced somewhat smaller

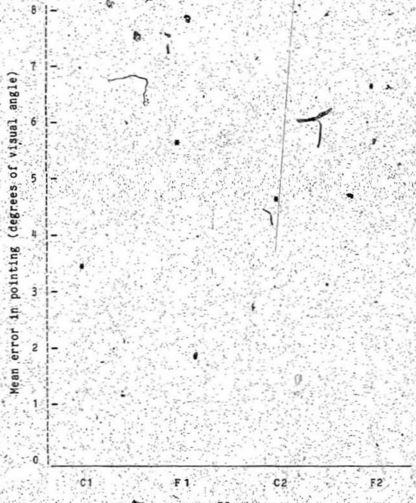

Figure 15. Experiment 6 - Non-relative induced movement (frame moving near left to far left) - Mean error in pointing to target light on each block.

shifts, and the Roelofs effect produced the smallest shifts of all.

Additional Analyses

In addition to the orthogonal comparisons calculated on the data with the outlier eliminated, a separate analysis was performed using only those subjects who participated in all six experiments. As previously mentioned, five of the initial twenty subjects were not available for three of the experiments. Therefore, those three experiments were re-analysed with a two-factor analysis of variance using only the data from those subjects who completed all six experiments and again with all 20 subjects. It can be seen from Table 4 that although the F values varied somewhat, the overall results remained the same whether 15 or 20 subjects were used in the analysis.

Because these experiments involved a visuo-spatial task, the data were also analysed for any differences in performance that might be attributable to sex, as it is well documented that sex differences exist in visuo-spatial abilities (see reviews in Maccoby and Jacklin, 1974). For this analysis, the outlier was eliminated and only the data from subjects who participated in all six experiments were used in the calculations, giving a sample of 14 subjects (seven males and seven females). An analysis of variance indicated that sex was not significant at the .05 level, nor were any interactions involving sex found to be significant.

Table 4

F Values for Analysis of Variance on Experiments 1, 3, and 5

	Number of Subjects in Analysis	
Experiment	n = 15	n = 20
1	8.05 (p<.025)	12.45 (p<.01)
3	.31 (n.s.)	1.24 (n.s.)
5	28.24 (p<.001)	12.87 (p<.01)

DISCUSSION

The scores on the first control blocks showed the same directional bias or constant error in pointing to a visual target (depending on which arm was used in the task) as that reported by Fitts and Crannell (1949), Sandstrom (1951), and Edgington (1953). In the present experiment, it was the change in accuracy, rather than absolute accuracy itself that was important. Any such changes could be assessed by the shift in pointing errors between the control and experimental conditions. Hence the actual size of the pointing error on the first control block was of itself irrelevant. However, it is reasonable to give it some consideration since any underlying mechanism may be involved in all parts of the experiment.

A possible explanation for this initial rightward bias may be that although the pre-experimental instructions specified that, when pointing to the target light, subjects should try to align their finger with the vertical plane bisecting the eyes, they may have unconsciously used a different system, for example, one based around the shoulder joint. If so, this may have been simply due to the physical nature of the pointing task. As mentioned in the Procedure, subjects were instructed to set their finger to the imaginary line running from the midpoint of the eyes to the target light. If one assumes this posture, it can be readily seen that the right arm makes an acute angle at the shoulder rather than being straight out from the shoulder as is the case in most instances of pointing. When one aligns the finger with the objective median plane in the prescribed manner, the tightening or binding felt in the shoulder gives the impression that one is pointing too far to the left. This was easily verified by sitting in position at the apparatus and setting the finger to the OMP (0 degrees) with the room lights on. Since subjects were deprived of visual cues which would normally override this misperception, this might explain the predominantly-rightward bias when using the right arm for pointing. That is, in this task the arm feels too far to the left when set to the OMP using a visually based origin and therefore the subjects may have adjusted by shifting to a kinesthetically defined shoulder origin which felt more correct.

Although this may account for the directional bias, the possibility of a postural aftereffect still exists. This simply refers to the tendency to deviate toward the side of previous exposure. As Edgington (1953) noted, the limb being swung stopped short of its goal, deviating toward the side of initial placement. The present study controlled for postural aftereffects as much as possible by having the subject rest his arm on the table so that it was roughly in the OMP between trials. However, since the right arm (which was always the one used to point) would be placed slightly to the right of center and for purely anatomical reasons, the possibility of a rightward postural aftereffect still exists for the first control block. However, any additional postural effects that might have arisen from the further rightward shift due to the experimental condition could be assessed by the "arm-to-90-degree" condition.

The tendency of the C1 scores to show a slight rightward increase over the course of the six experiments when considered in the chronological sequence in which they were conducted was not thought to have been due to carry-over effects. Because the sessions were conducted on different days, it is unlikely that any of the experimental conditions affected the first control scores of any of the subsequent experiments, although the possibility of contingent aftereffects cannot be ruled out. As shown in Figure 9, most of this increase resulted from the steadily increasing scores of one subject whose extreme rightward bias increased over the first four experiments. The C1 scores excluding this outlier showed a quite uniform error across the first five experiments. It is not clear why the additional rightward increase of about one degree, both with and without the outlier, occurred in the final experiment but it was probably not due to any systematic effect. In any case, the primary factor was not the initial control score itself but rather the change from control to experimental condition within each experiment. Since each subject served as his own control at the beginning of each experiment, carry-over effects were effectively controlled.

The Roelofs Effect

Experiment 1 - The Far Roelofs Effect

In Experiment 1, the Far Roelofs effect, it is clear that the presence of the frame in the far left position affected pointing. With the center of the frame 1.22 m to the left of the OMP, the F1 score was nearly one degree farther to the right of the C1 score (C1 = 2.8 and F1 = 3.7 degrees) while a comparison of the second pair of blocks showed a rightward shift of 1.4 degrees on the F2 block (C2 = 3.0 and F2 = 4.4 degrees). The fact that the orthogonal comparison of C1 and F1 did not reach statistical significance at the .05 level (it was significant at the .1 level) is mitigated by the C2-F2 shift which was significant at the .05 level, and suggests the real presence of an experimentally induced effect.

It is possible that the strength of the experimental effect, particularly in the first two blocks, may have been reduced somewhat due to the novelty of the experimental situation. It became apparent from post-experimental interviews that at least some of the subjects initially felt uncertain about the task because pointing to a visual target in the dark, particularly when they could not see their own hand, was a somewhat unusual situation. Their uncertainty disappeared as they became accustomed to the task. This factor might account for the failure of the first pair of blocks to reach significance. The first experiment was the only one in which the C1-F1 and C2-F2 blocks did not correspond; in all others, the orthogonal comparisons were either both significant or both non-significant. This provides some support for the notion that the novelty of the situation may have affected the first block of this experiment, although this remains somewhat speculative.

The results indicated that the presence of the frame to the left of the target light shifted the perceived location of the light to the right. This provides support for the hypothesis of Bruell (1958), Brosgole (1968), and others that the apparent straight ahead shifts in the direction of visual stimulation, which is leftwards in this case, and therefore the target light is perceived to be to the right of this newly-defined straight ahead.

Experiment 2 - The Near Roelofs Effect

In Experiment 2, the Near Roelofs effect, there was no clear shift in pointing on the frame blocks. Although both of the C1-F1 and C2-F2 shifts were in the predicted direction, neither reached statistical significance. As can be seen from Figure 9, the graph is essentially a straight line with a slight positive slope, with scores varying only 1.1 degrees over all four blocks. Thus there was no evidence that a shift in pointing occurred when the frame was in the near left position.

A comparison of the pointing errors in the above two experiments indicated that for the distances used, only the Far Roelofs effect was effective in shifting the apparent straight ahead. Two main factors might account for the observed differences between these experiments: (1) the lateral displacement of the frame and (2) the distance between the target light and the frame. In this study, these two factors could not be differentiated; since the light was always in the OMP, lateral displacement varied concurrently with the distance from the frame to the light. Because both factors were greater in the Far Roelofs effect, it cannot be determined from these experiments which is the more important variable.

There is also the possibility that the dependent variable, pointing to the visual target, may not have been a sufficiently sensitive means of detecting the relatively small differences in the perceived position of the light between the control and frame blocks on the Near Roelofs effect. That is, subjects may have actually perceived a greater change in the position of the target light between the control and frame blocks than suggested by the data, but the pointing technique may not have indicated those shifts behaviourally when the frame was immediately adjacent to the light. This point will be addressed in more detail in a later section.

Induced Movement

Experiment 3 - Frame Moving Far Left to Near Left

In Experiment 3, the frame moved rightward from its position 1.22 m to the left of the target light until its right edge was immediately adjacent to the light, thereby moving through 25.6 degrees of visual angle. The shifts in pointing were in the predicted direction. That is, the rightward movement of the frame produced leftward induced motion in the light. The leftward shifts in pointing reflect this perception, but neither of the frame-induced shifts was significant (.7 and .6 degrees leftwards, respectively).

Any of the factors mentioned regarding the Roelofs effect could also be involved here. In both the Near Roelofs effect and this IM study, pointings were made when the frame was in the same position with respect to the target light, that is, immediately adjacent to it. Decreasing the spatial separation between the frame and spot may reduce the perceived strength of the IM effect as well. Alternatively, this decrease in spatial separation may also make it more difficult for the pointing measure to accurately reflect the perceived amount of the shift. If the ASA was shifted by the frame as it moved from far left to near left, then the ASA would have become close to the OMP (the target light) when the subject pointed at the end of the trial. Thus, the smaller shifts between the control and frame blocks may simply reflect a reduction in the strength of the effect due to the relatively small angular difference between the ASA and the OMP in this condition.

An additional factor may also be involved in the somewhat small shifts between the control and frame blocks in Experiment 3. It will be recalled from the discussion about the first control block that there was a slight rightward bias in pointing to the target light before the subject was exposed to any of the frame conditions. That is, when pointing to the light in the OMP (0 degrees), subjects tended to point to the right of its true location. Thus, it seems that subjects were misperceiving the position of their arm. Part of this misperception may stem from the physical nature of the task; the tightening or binding felt around the shoulder joint when one assumes this position was suggested as a possible factor. If this is the case, it would be expected to have a greater effect when pointing with the right arm to a target perceived to be located to the left of the OMP than when pointing to a target perceived to the right of the OMP. As one moves the right arm more rightward, there is significantly less binding felt in the shoulder. During the frame blocks of Experiment 3, the target light was perceived to move even farther to the left of the OMP and thus perceptually present errors may have been "damped" by the binding of the shoulder joint. Therefore pointing scores may not reflect the perceived amount of induced movement of the target light.

The influence of shoulder feedback could be evaluated by either repeating Experiment 3 using the left hand for pointing or by conducting the mirror image of this experiment (the frame in the right visual field) with the subject continuing to point with the right arm. In either case, this binding in the shoulder would not be present because pointing would be in the opposite direction. Studies have since been conducted in this laboratory with a frame presented in the right visual field and moving towards and away from the target light (Warren and Coleridge, Note 2). The results of this work are presented in Appendices D and E (Induced Movement with the Frame in the Right Visual Field), and will be referred to after the discussion of Experiment 4.

Experiment 4 - Frame Moving Near Left to Far Left

In Experiment 4, the frame moved leftwards from the near left to the far left position while the light was simultaneously illuminated. The shifts were in the predicted direction, corresponding to the induced movement of the light rightward. These shifts were the largest observed in any of the experiments (3.2 and 2.3 degrees, respectively). For a more comprehensive interpretation of both these IM studies, it is helpful to refer to the results of the Warren and Coleridge experiment. The inclusion of their data provides valuable information on the pointing errors resulting from the mirror images of Experiments 3 and 4.

This set of four IM experiments provides support for the presence of two types of asymmetries, one visual and one kinesthetic. The visual asymmetry is important in that it bears directly on the differences between center-to-side versus side-to-center motion, as well as the issue of enclosure. It will be recalled from the Introduction that it has been commonly assumed that enclosure is an important parameter in IM and therefore enhances the perceived strength of the effect. Yet these present results indicate that a distant nonenclosing frame may actually increase the power of the illusion in some cases. Subjects in both the Warren and Coleridge study and the present experiment reported seeing stronger IM when the frame moved away from the target light. A common description by the subjects was that as the frame moved away from the light (which would be perceived as movement of the light itself), one became less aware of the presence of the frame as the light continued "moving" farther to the side. It is clear that as the frame gets farther away, it still exerts a strong influence on the perceived movement of the light or otherwise IM would deteriorate in such circumstances.

The results go beyond simply demonstrating that enclosure is not necessary for good induction effects. They strongly suggest that for a given size of frame, a nonenclosed spot may undergo even better IM than an enclosed one. Thus it seems that although the subject may become less aware of the presence of the frame in the visual field while "tracking" the spot in the opposite direction, the frame may actually cause greater induction effects as it moves farther into the periphery of the visual field. A possible explanation for this will be presented in the General Discussion.

The other asymmetry that occurred in this experiment was kinesthetic in nature and concerns the issue of whether the feedback from the shoulder might have had an effect on subjects' pointing. In referring once again to the results of Warren and Coleridge and the present experiment, it appears that the shifts in pointing to the target light did not always correspond with the perceived change in target position from the control to frame blocks. If one compares Experiment 3 and 4 of the present study, it is apparent that there was a greater shift in the latter case, as would be expected if the perceived strength of IM was greater when the frame moved away from the light. What is somewhat surprising, however, is that although the pointing errors in Experiment 3 were in the predicted direction, neither the C1-F1 nor the C2-F2 shift reached statistical significance despite subjects perceiving strong IM. These results do not by themselves indicate that binding in the shoulder reduced the size of the effect because it has already been mentioned that there is probably a smaller shift in the perceived location of the spot in the case where the frame moves toward it.

When the findings of Warren and Coleridge are taken into account, there is added support for the notion that binding in the shoulder probably influenced pointing errors to some extent. Their data showed that although better IM was perceived when the frame moved rightwards away from the light, the largest shifts in pointing occurred when the frame moved leftwards toward the light, that is, when the target was perceived to move rightward such that only obtuse angles were involved in pointing. In this latter case, pointing was in the opposite direction to that which would cause binding in the shoulder. The results of Experiment 1 and 2 of their study are shown in Appendix D and E, respectively.

In their first experiment, the frame in the right visual field moved leftwards toward the target light from the far right to the near right position, that is, it was the mirror image of Experiment 3 of the present study. The C1-F1 shift was significant, F (1, 9) = 11.66, $p < .01$, going from 1.2 on C1 to 3.7 degrees on F1. Although the C2-F2 shift was not significant at the .05 level, it was significant at the .25 level, going from 3.2 on C2 to 4.5 on F2.

In Experiment 2, the frame in the right visual field moved rightwards from the near right to the far right position (away from the target light) and was the mirror image of Experiment 4 of the present study. The shifts were again in the predicted direction but both planned orthogonal comparisons were non-significant. The C1-F1 scores went from 2.2 to 1.4 degrees while the C2-F2 scores went from 2.5 to 2.1. Thus in this case, the condition which produced better IM (Experiment 2) resulted in non-significant shifts.

Even the C2-F2 shift in Experiment 1 which was non-significant at the .05 level was almost twice the size as the largest shift in Experiment 2.

All of the results can be explained if feedback from the shoulder due to pointing with the right arm to a target perceived to be to the left of the OMP played a part in the reduction of experimental effect. It can be seen that in both cases in which the spot was perceived to move to the left of the OMP (Experiment 3 of the present and Experiment 2 in Warren and Coleridge) there was a non-significant shift between the control and treatment blocks despite subjects reporting strong IM. These results would be predicted if the pointing movement of the subject was damped because of binding in the shoulder with the associated misperception of arm position.

In contrast, in the studies in which the spot was perceived to move to the right of the OMP (Experiment 4 in the present study and Experiment 1 in Warren and Coleridge), significant shifts occurred between the control and treatment blocks. In both these cases, there would be no binding in the right shoulder as subjects would be pointing more rightward on the frame block.

It is perhaps worth noting that the foregoing discussion was not a post-hoc explanation presented to account for the data. The Warren and Coleridge study was conducted specifically for the purpose of testing the notion of shoulder binding during IM with the frame in the right visual field. Thus the obtained results were predicted prior to the running of the experiment.

Although the results of the other experiments must be interpreted somewhat more cautiously in light of these findings, it is not likely that this factor significantly affected any other study except Experiment 3 because it was the only study in which the perceived shift of the spot was leftward, the direction which would cause binding in the shoulder. Also, IM produces a more powerful shift in the perceived location of the spot than either the Roelofs effect or non-relative induced motion and thus any physical constraint affecting the behavioural measure would have had the greatest effect in the IM experiment. From both these perspectives, Experiment 3 would be the only condition likely to show a decrease in the treatment effect due to shoulder feedback.

Non-Relative Induced Movement

Experiment 5 - Frame Moving Far Left to Near Left

In Experiment 5, the frame moved rightwards from the far left to the near left position. The difference between this experiment and Experiment 3 (induced movement) was that the light did not come on until immediately after the frame was extinguished at the end of its transit. Since there was no relative movement between the frame and the light, induced motion in the usual sense could not occur. A somewhat unexpected finding of this experiment was that although the frame travelled at the same speed (.85 degrees of visual angle per second) and through the same distance as in the IM conditions, subjects could not detect any motion whatsoever. Obviously, frame motion in the typical IM condition was not detected directly because the object-relative movement between the frame and the spot was attributed entirely to the spot. However, it is noteworthy that no frame motion was detected when it was presented by itself in the non-relative IM condition because it was moving more than four times faster than the speed often cited as the subject-relative motion threshold (.2 degrees of visual angle per second).

Experiment 5 clearly indicates that object-relative motion between the two stimuli is not necessary in order to produce statistically significant shifts in pointing on the frame blocks. The results are in accordance with Brosgole's notion that the apparent straight ahead is on the same side as, and moves along with, the inducing frame. It appears that the frame was producing a shift in the egocenter of the subject because motion of the frame was not detected either directly (as a result of being above the subject-relative threshold) or indirectly (motion perceived as a change in position over time).

The overall effect of non-relative IM was similar to typical IM because the motion of the frame was undetected and when the light was illuminated, the subject indicated by his pointing error that the perceived location of the light has been altered with respect to the frame. In Experiment 5 it was predicted that the light would be perceived to be more to the right on the frame trials because even as the ASA was moving toward the OMP, the light, when illuminated, would always be located farther to the right of ASA. However, the continued rightward shift between the F1 and C2 blocks is more difficult to explain. This shift was the same size as that seen on the C1-F1 shift (1.1 degrees). Since this was the only experiment in the series in which the C2 score did not return in the direction of the C1 score (apart from the Near Roelofs effect where there was little change in pointing), this deserves some comment.

The linear rightward increase in pointing error over the four consecutive blocks may have been related to a striking spatial distortion which was noted by chance. It became apparent in a post-experimental interview with one of the first subjects run in this condition that his impression of the distance between the target light and the right edge of the frame at the end of its transit was greatly in error. When the frame moved from the far left to the near left position, its right edge was immediately adjacent to the light. Because there was only a delay of about one second between the frame's disappearance and the time the light was illuminated, it was thought that subjects would be aware that the frame and light were separated by a very small distance. When it was discovered that this was not what subjects were experiencing, an informal additional trial at the end of this experiment was used to determine what they thought to be the relative positions of the frame and the light. No pointings were taken on this trial but subjects were asked to give a verbal estimate of the distance between the right edge of the frame and the light. Virtually all subjects thought the distance to be <u>several feet</u> as opposed to the actual distance of 2 inches (5 cm).

After these verbal estimates had been made, the frame and the light were illuminated simultaneously and the experimenter moved the frame leftwards until the subject reported that it matched the previously judged distance from the light. Most subjects' verbal and visual judgements placed the frame near or at the far left position, that is, the place from which the frame started at the beginning of the trial, a spatial separation of 61 cm between the right edge of the frame and the light. In other words, although at the time of pointing the light and frame were in the same position as in the Near Roelofs effect, the subject's impression was that the distance was similar to that used in the Far Roelofs effect.

A possible explanation for the finding runs as follows. In the absence of the target light in the OMP, subjects no doubt tracked the frame as it moved from the far left to near left position. These tracking eye movements were not being registered or monitored by the subject because, as mentioned earlier, the frame was neither seen to move nor change its position. At the time the frame disappeared, the subject, lacking firm evidence about eye/head position, thought he was gazing straight ahead despite actually looking to the left of the OMP. In order to fixate the target light in the OMP when it was turned on, the subject had to shift his eyes to the right of their previous position. Since he previously thought he was looking straight ahead, any additional rightward shift in fixation would be interpreted as fixation to the right of straight ahead.

It is probable that there would have been sufficient opportunity for an aftereffect to build up in the visual system because on the F1 block, subjects had six consecutive 30-second exposures to the moving frame. If any aftereffect resulted from this exposure, it would very likely carry over into the C2 block in some form, such as the increased rightward shift in the perceived position of the light.

The fairly steep linear slope in Experiment 5 suggests that whatever disturbance may have been present in the visual system was increasing over each successive block (because the C2 scores did not shift back toward the C1 score). However, it is probably best to limit the main comparisons to those within the control-treatment pairs because although the F1-C2 shift may or may not be repeatable, it is safe to conclude that within each control-treatment pair, the target light was perceived to be more to the right on the frame block.

Experiment 6 - Frame Moving Near Left to Far Left

In Experiment 6, the frame moved leftwards from the near left to the far left position prior to the onset of the light. Thus, it was similar to Experiment 5 except that the frame moved in the opposite direction. As in Experiment 5, subjects could not tell that the frame was moving and again significant rightward shifts were produced in the absence of any object-relative movement between the spot and frame. Not surprisingly, these shifts were larger than those in the previous experiment, probably because after tracking the frame from the near left to the far left position, the eyes had to saccade farther rightward in order to fixate the light when it was illuminated in the OMP. Consequently, it would be perceived to be even farther to the right of straight ahead than in the other non-relative IM condition.

There was no evidence of spatial distortion in this experiment; the subjects' estimations of the separation between the right edge of the frame and the light approximated the actual distance. This could mean that the distortion might only occur under very specific conditions such as those in Experiment 5, or that it was actually present in Experiment 6 but reduced to such a degree by the substantially greater distance between the frame and spot that it could not be detected by the subjects. Since the judgement of this distance required remembering the position of the frame before it disappeared, it may be that the effect can only be reliably observed when there is a great discrepancy between what is perceived and the veridical situation. Such a large discrepancy would exist when the real distance of 2 inches appeared to be 2 feet. However, when the frame moved in the opposite direction so that the actual separation was 2 feet, the effect may be reduced or perhaps completely eliminated.

If tracking eye movements played any role in the spatial distortion, there was another difference between the two non-relative IM experiments which might account for its apparent absence in the latter case. In Experiment 5, tracking movements would have been from left to right with a small saccade in the same direction when the light was fixated. In Experiment 6, the tracking movements would have been from <u>right to left</u> with a <u>large</u> saccade in the <u>opposite</u> direction when the light was fixated. This might have resulted in the reduction or complete cancellation of the effect. This is speculation however.

A further difference may involve some type of visual directional anisotropy arising from center-to-side as opposed to side-to-center motion. It is possible that shifts in the ASA occur more readily with one kind of motion than the other.

The comparison of Experiment 6 and 1 (the Far Roelofs effect) is of interest because at the time of pointing, the frame and the light were in exactly the same positions. Experiment 6 showed an increased rightward shift by a factor of two on the first pair of blocks and by about 1.5 on the second pair of blocks. This suggests that there is something more powerful about movement per se, even if this movement goes undetected by the subject. Furthermore, a comparison between Experiment 4 and 6, which were identical except that the light was not lit until the frame disappeared in Experiment 6, suggests the increased potency of object-relative motion in the IM paradigm. Although the overall trends in both experiments were the same, the induced movement in Experiment 4 produced greater rightward shifts in the perceived location of the target light.

General Discussion

Several conclusions can be drawn from the results of the present experiments. Firstly, the presence of the frame in the peripheral visual field clearly affected subjects' accuracy in pointing to a stationary visual target in the objective median plane. Secondly, movement of the frame either towards or away from the position of an unseen visual target produced similar, but still greater errors in subsequent pointing to the target than did the static case. This was in the absence of any object-relative motion between the target and frame and although the motion was not detected by the subject. Thirdly, object-relative movement between the frame and the target light, which gave rise to induced movement of the light, caused errors in pointing greater than both the stationary condition (Roelofs effect) and the case in which there was the same amount of motion between the frame and the visual target but of a non-relative nature. In light of these findings, the two major theories of IM will now be examined.

Evaluation of Theories of Induced Movement

The Subject-Relative Theory. Despite some shortcomings, Brosgole's (1968) research is noteworthy not only for its value in presenting an alternative theory of induced motion but also for its demonstration of egocentric shifts in both the Roelofs effect and induced movement. He showed that IM cannot be explained solely by object-relative movement and concluded that "the perception of object motion is based upon changes in the egocentrically determined location of that object in phenomenally structured space" (P. 15). We have already seen that visual stimuli in the peripheral visual field can alter egocentric localization in the static case (Roelofs effect). It is reasonable to conclude, as Brosgole did, that the egocentric shift induced by visual frames plays some role in IM. Unfortunately, he attempted to explain induced movement (and some other forms of motion perception) strictly in terms of egocentric shifts. In view of the present findings and the research of others, to conclude that egocentric shifts are the sole determinant of induced movement is clearly an oversimplification.

Brosgole argued that the presence of the frame in the IM paradigm shifted the apparent straight ahead toward the center of the frame and "pulled" the straight ahead along with it as it moved. Relative to this newly defined and changing straight ahead (although this change is not detected by the subject) the spot is seen to move in the opposite direction with respect to the frame. However, if an egocentric shift was the main determinant of IM and object-relative motion played no part, the perception of IM should break down as soon as the subject-relative threshold is exceeded. That is, the movement of the frame should be detected and hence it should be correctly identified as the object in motion. This is not what is perceived. Rock, Auster, Schiffman, and Wheeler (1980) reported that IM occurred even when the frame was moving at above threshold speeds and that the objective motion of the inducing stimulus was totally transferred to the induced stimulus.

There are other problems with the subject-relative theory. By attempting to interpret the location of objects strictly in terms of the location of each individual object with respect to the observer (egocentric localization), Brosgole has seemingly eliminated the concept of object-relative location (and object-relative movement in the case of motion between the objects). However, there can be no strictly egocentric judgement when two or more objects are present in the visual field because the location of one must always be seen relative to the other. Even if their relative positions are mediated through the egocentre, at some level their positions relative to one another must be taken into account.

The results of the present experiments do not support Brosgole's notion that IM is simply a dynamic form of the Roelofs effect. Not only were the pointing errors substantially larger in the IM experiments than those produced by the corresponding Roelofs effect but the errors in one IM experiment (Experiment 3) were in the opposite direction to those in the Roelofs effect (Experiments 1 and 2). This evidence indicates that there are some important differences between these phenomena.

It is likely that the present design with the nonenclosed spot made it possible to produce more extreme errors due to the greater separation between the frame and the spot, rendering any differences between the Roelofs effect and IM more discriminable. The use of an enclosed spot array would make it more difficult to demonstrate real differences between the two paradigms due to the proximity of the two stimuli.

<u>The Object-Relative Theory</u>. To attempt to ignore all object-relative factors, as Brosgole does, is to ignore a very important cue to motion perception. Most responses to moving objects in the visual field are really responses to the relative motion between the object and its frame of reference or to other objects (Gibson, 1966). Physiological evidence shows that there are cells in the mammalian system that, although not sensitive to motion in general, respond to relative motion (Bridgeman, 1972; Burns, Gassanov, and Webb, 1972; Phelps, 1974; Mandl, 1974). Numerous studies have shown that the speed of a visual stimulus traversing a uniform, contourless field seems slower than when moving through a field of stationary dots or lines (Teuber,

1960; Mandl, 1974).

In the case of the present study, object-relative movement clearly changed the subject's <u>perception</u> of the display. Specifically, when the frame was moving in the absence of any other visual stimuli, it was seen to be stationary. However, when the frame moved at the same speed in the presence of the target light, the subject then saw the light undergoing IM. Thus, the presence of other stimuli in the visual field not only affected the perceived speed of the moving object, but also influenced which object was perceived to be moving.

Sensitivity to object-relative motion is vital for proper visual perception. Because of both voluntary eye movements and the involuntary optical nystagmus, the retinal image is constantly in motion. Thus motion detectors are always stimulated even when there is no movement in the outside world. In order to detect true external movement, it is necessary for any relative motion in a part of the retinal image to be a powerful cue to movement.

Further support for the special potency of relative motion or object-relative displacement was demonstrated by Johansson (1964). He found that when two spots moved perpendicularly to one another at well above their subject-relative threshold, subjects perceived them to be approaching and receding from one another along an oblique path. The horizontal and vertical components of the motion were usually noted only if subjects were prompted. Thus when subject-relative and object-relative displacements come into conflict, the latter cue can predominate. Under most conditions, these cues do not conflict with one another but contribute to the same perception. However, when the subject is deprived of a normal frame of reference, such as in the conditions conducive to the demonstration of IM, a conflict arises because what the frame and spot are doing in relation to the observer is not the same as what they seem to be doing in relation to each other. In this instance, the object-relative motion is the dominant perception and all motion is attributed to the spot.

Despite the importance of object-relative motion, a strictly object-relative interpretation cannot account for all the known factors regarding IM. With reference to the present findings, the results of Experiments 5 and 6 clearly showed that although there was no object-relative displacement between the frame and the light (as they were not illuminated at the same time), the perceived location of the light was definitely shifted. Even though it could be argued that this was not IM in the typical sense, it indicates that object-relative motion is not a necessary condition for a change in the perceived location of the spot.

The results of numerous other studies indicate other shortcomings of the object-relative theory. Brosgole (1968) conducted an experiment in which he used two frames which differed only in height. The taller frame produced significantly more IM than the smaller frame and yet the amount of object-relative movement between the frame and the spot was the same in both cases.

It has also been frequently observed that IM occurs more often when the speed of the inducing object is slow rather than fast (Duncker, 1929; Brosgole, 1968; Rock, Auster, Schiffman, and Wheeler, 1980) yet the amount of object-relative movement is the same regardless of frame velocity.

The object-relative theory also fails to provide any explanation for the observation of numerous researchers that visual space is anisotropic (as opposed to Euclidean in nature) such that the strength of IM varies depending on the location and direction of the frame relative to the observer. Day, Dickinson, and Forster (1976) found that center-to-side motion of the frame produced stronger IM than side-to-center motion. This was also true in the present study. Brosgole (1968) noted anisotropies in several of his experiments such that when the frame was located in the right visual field, the amount of IM was greater than when the frame was in the left field. A theory based strictly on object-relative displacements does not explain these effects.

Experiments relevant to the adjacency principle also present further problems for the object-relative theory. They have shown that there are some differences in the strength of IM when the frame and the spot are at different positions in the third dimension, even when the amount of object-relative movement between the two stimuli is controlled. This suggests that a comprehensive theory of IM must take into account the active involvement of the observer rather than viewing the effect as arising from the passive response of the observer to a given amount of object-relative movement in the stimulus array. A theory involving the observer as an integral part of the perceptual process also makes it easier to account for very different responses to the same amount of object-relative displacement, both between different subjects and within the same subject on different occasions. That such marked individual differences exist is clear from the results of many IM studies.

With respect to a stationary observer, all motion involves a subject-relative component whether or not there is any object-relative movement in the visual field, so it is an oversimplification to ignore this element, as the object-relative theory does. Finally, since the presence of a stationary frame can alter the perceived location of another object in the visual field, it would be unreasonable to assume that the same frame exerts no such influence when it is in motion.

Toward a Combined Theory of Induced Movement

The problem of definition regarding the exact meaning of the term induced movement has already been discussed in the Introduction. A somewhat related difficulty pertaining to IM and its relationship to motion perception in general may stem from the fact that IM does not fall distinctly into either category of real or apparent movement, which are the two main categories of motion. Instead, it has certain properties of each. It resembles apparent movement in that a truly stationary visual target appears to be in motion. However, in a "pure" apparent motion paradigm, there is no actual motion involved whatsoever. In contrast, the IM stimulus array involves real movement of the frame. Thus, the induction effect results from the perceived movement being attributed to the stationary stimulus. This difficulty of classification may in part explain why induced movement has frequently been discussed as if it was an isolated phenomenon and why it has not been fitted into the general framework of visual spatial orientation. Unlike some other theories describing various types of motion perception, neither the subject-relative nor object-relative theory addresses the question of what physiological mechanisms might underlie the effect. This will be the purpose of the final part of this thesis.

The Eye/Head System

In light of the present findings, let us re-examine the role of the eye/head system in the perception of IM. It was mentioned in the Introduction that undetected eye movements could not account for IM. However, this does not mean that the eye/head system is totally uninvolved in the process. In fact, the eye/head system apparently contributes to the perception of IM in such a way as to reinforce the illusory nature of the effect. Subjects in this experiment were convinced that they were actually visually tracking a moving target while fixating the stationary light in the presence of the moving frame. This has also been reported in other studies (Duncker, 1929; Brosgole, 1968) and under the conditions used in the present experiment, the effect was extremely compelling.

Obviously, under some circumstances, there can be a substantial error in where we think our eyes are looking in relation to our head. A similar example of illusory eye tracking movements also occurs in a phenomenon known as the autokinetic effect in which a small stationary spot of light (in an otherwise dark room) appears to move about in a rather erratic manner (Gregory and Zangwill, 1963). Perhaps the most striking aspect of this illusion is that it also feels as if one's eyes are actively tracking the veridically stationary light.

In both induced motion and autokinesis, the erroneous impression of eye movement occurs in the absence of a sustained outflow signal from the brain instructing the eyes to move and despite the fact that there could be no changing inflow signal originating from the ocular muscles simply because the eyes are fixating a stationary object.

These errors in the eye/head system were not limited to the IM paradigm but also occurred in the Roelofs effect. When fixating the target light located in their objective median plane, subjects often felt as if their eyes were looking to the right of center when the frame to the left of the light was illuminated. This corresponded directly with their behavioural response; they pointed farther to the right when attempting to indicate the position of the light in the presence of the frame.

The preceding cases show that tracking eye movements (or lateral deviation of the eyes in the Roelofs effect) can be perceived even when the eyes are stationary and fixating an object located in the OMP. Also, the converse of this was demonstrated in the non-relative induced movement studies; in this instance, subjects were no doubt tracking the moving frame with their eyes, and yet they were totally unaware that the frame was in motion. There are two possible explanations suggested by this. Firstly, even an outflow signal from the brain instructing the eyes to track may not always be sufficient for the perception of eye movements. The second possibility is that the outflow signal was an instruction for the eyes to fixate rather than to track, even though tracking movements had to be initiated in order to maintain fixation. As Gregory (1966) has said, the eye/head system does not work by actual movement of the eyes, but by commands to move them (or not move them in the case of fixation).

Thus the eye/head system can reinforce the erroneous perception of both a lateral deviation and tracking movements when the eyes are in fact looking straight ahead. Conversely, true tracking movements can go completely undetected in the absence of other corresponding information indicating that object motion has occurred in the visual field. Although the eye/head system contributes to the impression of motion in induced movement, it is apparent that the eye/head system must be largely influenced by the image/retina system. With this in mind, we will now examine how various retinal events might lead to the perception of the Roelofs effect and induced movement.

The Image/Retina System

It is well known that all sensory systems can adapt and therefore must be calibrated in some meaningful way with respect to the external world in order for the organism to function appropriately. Under normal conditions, the entire visual field is stimulated, and therefore provides a solid frame of reference from which we can judge the position and motion of objects within that field. Thus, the "straight ahead" could be determined most easily and automatically as the midpoint between the most peripheral points of visual stimulation. Normally, this would result in an accurate perception of straight ahead, but with asymmetrical visual stimulation, such a mechanism would lead to precisely the type of shifts in the apparent straight ahead demonstrated in this and other studies of the Roelofs effect. Since the subject is deprived of almost all visual cues in the Roelofs situation, his only frame of reference is the offset luminous frame which produces a shift in perceived straight ahead in the direction of the visual stimulation.

The differences in the magnitude of the effects in the three experimental conditions (Roelofs effect, non-relative induced movement, and induced movement) suggest an increasingly complex type of visual analysis depending on the amount of visual information available to the system. The smallest shifts occurred in the Roelofs effect and seem to result from a recalibration of the ASA due to stationary subject-relative (egocentric) changes under deprived visual conditions. The non-relative induced movement experiments resulted in still larger shifts because of moving subject-relative cues. That is, the larger pointing errors may have resulted from the additional effect arising from exposure to movement superimposed upon those errors introduced by the Roelofs effect. Finally, the largest shifts occurred in the IM condition, which by virtue of the direction specificity of induced movement with respect to the direction of frame motion, emphasizes the special potency of object-relative movement as an important cue to motion perception.

The results of the non-relative induced movement conditions were of particular interest because of the finding that subjects were unable to detect that the frame was in motion. It was thought that the frame speed chosen was fast enough to be seen as moving during the frame blocks and therefore direct comparisons between the non-relative induced movement and typical IM conditions could be made. That is, it was anticipated that subjects would detect motion in both cases, with one being only subject-relative (non-relative IM) and the other involving an object-relative component.

The fact that subjects did not detect frame motion in the non-relative IM conditions was especially surprising since it was travelling at more than four times the subject-relative threshold. Since subjects thought they were looking at a stationary frame, it was analogous to the the Roelofs effect except that the frame and light were illuminated simultaneously in the Roelofs effect. Yet despite the perceived similarity of these experiments, the errors in pointing were considerably larger in the non-relative IM experiments. It seems that exposure to motion, even that which has not been detected by the observer, has a greater power than static cues in altering the egocentric coordinates of the observer. Since subjects saw the frame as being straight ahead and neither moving nor changing position, it seems reasonable to conclude that the ASA was being "carried along" by the moving frame.

It was suggested in the Introduction that stimulus (frame) size might quite likely be an important parameter in the perception of IM. It is worth returning to this point in light of the present findings. Brosgole (1968) reported that frame motion was detected much less often when the stimulus was large than when it was small, even though the amount of object-relative movement between the spot and frame was the same. This raises some doubts about the notion of a well-defined object-relative motion threshold above which movement between two stimuli is perceived and below which it is not. Brosgole's observations would seem to indicate that there may be different thresholds for detecting frame motion in the case of object-relative movement, depending on the size of the frame.

The same might also apply to subject-relative thresholds. The accepted value of this threshold was determined with small spots of light, yet the frame in the non-relative IM conditions was moving at more than four times this speed and was still thought to be stationary. Thus, motion thresholds may be dependent not only on the presence or absence of other reference points in the visual field but also upon the size of the stimuli in question. Informal observations in this laboratory lend some support to this notion. A small piece of luminous tape attached to the non-illuminated frame was more readily detected in motion than the illuminated frame moving at the same speed. Furthermore, the motion of the luminous tape seemed to stop when the frame was then illuminated, as if the presence of the frame somehow "stabilized" the visual display. If stimulus size is, in fact, a parameter in motion thresholds, it may have been more apparent in the present experiment as a result of using a considerably larger frame than other IM studies.

Although no reference to stimulus size was found in the motion threshold literature, the physiology of the retina makes it very likely that size would have some effect on the ability to detect motion. As mentioned in the Introduction, movement sensitivity varies for different retinal locations and our ability to detect slow target movements decreases with increasing distance from the fovea (Lichtenstein, 1963; McColgin, 1960). For higher target velocities, this relationship is reversed. This evidence indicates that stimulus size must be related to motion thresholds, for a large stimulus falls on a more peripheral part of the retina than a small stimulus.

If thresholds vary depending upon the size and retinal location of the stimulus, this provides a simplified explanation for the perception of IM; that is, IM may result from the varying sensitivity of different retinal locations to movement. Because the frame is always larger than the spot, it would fall on a more peripheral part of the retina. At the frame speeds typically used in IM studies, the peripheral retina would be less sensitive to motion than the fovea. Since there is a substantially lower threshold for object-relative motion than for subject-relative motion, the overall perception would be that of object-relative motion; as Johannson (1964) has indicated, when subject-relative and object-relative motion occur simultaneously, object-relative cues predominate. The perceived displacement between the two stimuli would likely be attributed entirely to the target light because when in doubt about what is moving, the brain is likely to accept that movement is due to smaller rather than larger objects. Under normal circumstances, the attribution of motion to smaller objects would tend to lead to the correct perception most of the time. But when limited visual cues are available, as in the case of induced movement, this results in the illusory motion of the stationary object.

If IM is looked upon as arising from differential retinal sensitivity, reference to subject-relative and object-relative factors becomes unnecessary because this factor can encompass both. The subject-relative or egocentric location of an object is accounted for by the retinal position on which the image falls since any change in the egocentric location of a visual stimulus corresponds directly with a change in retinal position. Also, the eye's response to object-relative movement would depend upon an interaction between the size of the stimuli in question and the relative sensitivity to motion of retinal area on which the stimuli fall.

From this perspective, it is readily apparent why a larger frame produces a more powerful induction effect. A stimulus subtending a greater visual angle falls on a more peripheral part of the retina and hence is less likely to be detected in motion than a smaller stimulus. The operation of such a mechanism would indicate Ebenholtz's (1977) finding that retinal size is the main determinant in the rod-and-frame effect is equally applicable to IM.

This could also account for the results of Rock, Auster, Schiffman, and Wheeler (1980), who showed that IM can be demonstrated even when the frame is moving well above its subject-relative threshold. Within a certain range of frame speeds, the periphery would always be less sensitive to motion than the fovea and therefore any detected object-relative displacement would be attributed to movement of the spot. Moreover, the same mechanism could also explain the breakdown of IM at higher speeds. As noted, the sensitivity to movement reverses with increasing speeds such that the peripheral retina becomes more sensitive to motion than the fovea. At higher speeds, the frame would be correctly identified as the object in motion.

The notion of varying retinal sensitivity might also explain some of the anisotropies of visual movement (Brosgole, 1968; Day, Dickinson, and Forster, 1976). A variation in sensitivity to movement would result in the response pattern of the receptor cells to image motion in one direction (for example, center-to-side) differing from that produced by motion in the opposite direction (side-to-center).

SUMMARY AND CONCLUSIONS

The results of this series of experiments demonstrate that both stationary and moving frames of reference can alter the perceived location of another object present in the visual field. Brosgole's suggestion that induced movement is essentially a dynamic form of the Roelofs effect was tested but was not supported by the results. Although the Roelofs effect and induced movement have some properties in common, the perception of IM involves object-relative motion in addition to subject-relative (egocentric) shifts.

It was found that neither of the two major theories of induced movement could fully account for the results of the present experiments nor could they adequately deal with some of the other results in the IM literature. Furthermore, these theories do not postulate any probable mechanism, physiological or otherwise, to explain how the analysis of IM might possibly be carried out by the visual system.

An alternative interpretation has been proposed which (1) attempts to combine the subject-relative and object-relative theories of induced movement by demonstrating the contribution of both (2) provides a possible means of dealing with those findings which are not addressed by either theory, and (3) suggests a mechanism, based on documented physiological evidence, by which the analysis of induced movement and the Roelofs effect might be performed by the visual system. Finally, an argument has been made for the importance of stimulus size as parameter, not only in induced movement and the Roelofs effect, but also with respect to motion thresholds in general.

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APPENDIX A

Considerations on the Choice of Experimental Design

A within-subject design was chosen for both practical and theoretical reasons. The advantages of this design from a theoretical standpoint were numerous. It served to reduce the error variance and also allowed for the comparison of the subject's pointing errors over the entire series of experiments. It could be argued that carry-over effects might be a problem in such a design. However this possibility was controlled for in several ways. First of all, there were two control blocks per experiment, the first of which was prior to exposure to the frame. Thus, any experimental effects were relative to this first control reading, irrespective of how that subject might have responded in other experiments. That is, it was the pattern of responding within rather than between experiments that was of primary importance. Secondly, any trends that might occur between experiments could be easily determined by looking at the mean readings of the first control block over the course of the six experiments. Finally, the two major disadvantages of a repeated measures design, practice and fatigue, were not thought to be problematic in this experiment. Subjects could not derive any benefit from practice because their judgements were done on a purely kinesthetic basis; that is, they could not see their own hand during the task and therefore received no feedback regarding their accuracy. The second factor, fatigue, was controlled by making the sessions long enough to obtain a sufficient number of readings but not so long that the subject's attention or performance decreased.

Although many studies control for the effects of practice and fatigue in repeated measures designs by counterbalancing the order of experiments, this was not done in the present study. As noted above, these two factors did not seem to pose design problems in this experiment. Additional reasons for not employing a counterbalancing technique are discussed in Appendix B - Experimental Order Aspects.

On the practical side, it should be noted that the experiment imposed numerous physical constraints upon the subject. First of all, because of the need to control the exact eye position in both the vertical and horizontal planes, a bite bar with each subject's dental impression was made prior to the first experiment. There were obvious advantages to performing this procedure only once and using the same subject in several experiments. Secondly, due to the exacting nature of the apparatus adjustments, the experiment required that the subject remain on the bite bar for approximately 15 minutes, fixating the target light all the time, and that he make pointing judgements every 30 seconds as indicated by the experimenter. Although this may not seem to be a physically demanding task, most subjects found that it required a fair degree of concentration and patience. Thirdly, the instructions given prior to the experiment were quite detailed and the experimenter had to be certain that the subject knew exactly what to do at all times. It was often necessary to repeat these instructions as some parts of the experiment required subtle but important differences in the subject's response.

The subject's familiarity with all of the foregoing factors greatly increased the ease with which the subsequent experiments could be conducted. Not only did it eliminate any uncertainty that may have been present during the first block or two of the first experiment, but the instructions for all the following experiments contained only minor changes and could be given quickly with the knowledge that the subject was familiar with the task. Finally, after participating in the first experiment, the subject was also familiar with the pre-experimental adjustments (which were considerable both in number and in the required degree of accuracy) and this greatly facilitated the procedure.

For all the foregoing reasons it was decided to use a repeated measures design on a small group of subjects who could be depended upon to bear with the physical constraints of the experiment, to concentrate on the task, and to return on subsequent days until the completion of all experiments.

APPENDIX B

Experimental Order Aspects

As mentioned in the Procedure, the experiments were numbered according to similarity of design, rather than in the chronological order in which they were conducted, in order to facilitate comparisons between experiments. That is, the two studies of the Roelofs effect were presented first, followed by the induced movement studies, and finally the non-relative induced movement studies. There were several reasons that the experiments were not conducted in this order. Firstly, the original intention was to conduct only three experiments in the following sequence: the Far Roelofs effect, non-relative induced movement with the frame moving from the far left to the near left position, and induced movement with the frame again moving from far left to near left. Since the Roelofs effect involved no movement of the frame, it served as a good baseline against which the subsequent experiments, which involved exposure to the moving frame, could be compared. Even though each experiment had its own control condition, running the Roelofs effect first served as an additional control in the event that there was any evidence to suggest that exposure to the moving frame led to carry-over effects in the subsequent experiments.

The non-relative induced movement was placed second because it involved the transition between the Roelofs effect and induced movement. Thus, there was movement of the frame but no relative movement between the stimuli because the target light was not illuminated in the presence of the frame. The final experiment in the sequence was, of course, induced movement.

It was subsequently decided that a fourth experiment, the Near Roelofs effect, was needed because there was a possible confounding variable in the first three studies. Although in both the non-relative induced movement and induced movement experiments the frame started from the same position as the non-moving frame in the Far Roelofs effect, at the time that the subject pointed at the target light, the right edge of the frame was about 5 cm from the light as opposed to 66 cm in the Far Roelofs effect. This obviously made comparisons between these conditions somewhat tenuous. Adding the Near Roelofs effect made the appropriate comparisons possible because at the time the subject pointed, the frame and the light were in the same relative positions as they were in the non-relative induced movement and induced movement experiments. This provided data for both ends of the distance through which the frame moved. It also enabled the comparison of the Far and Near Roelofs effects in order to determine if the magnitude of error in pointing to the target light changed with an increasing amount of frame displacement across the visual field.

The inclusion of the final two experiments, non-relative induced movement and induced movement with the frame moving from the near left to the far left position in both cases, provided information on the possible effects of visual anisotropies (in this instance, differential effects of side-to-center versus center-to-side movement). In addition, these last two experiments served as another control for the two asymmetries present in all these experiments: (1) all pointing was done with the right arm, and (2) the frame was always to the left of the light, differing only in the amount of lateral displacement and whether or not it was moving. Since the first two experiments involved movement from the far left to near left, it was advantageous to have the near left to far left counterpart in order to compare both the direction and magnitude of the effects. Also, these last experiments allowed for the comparison with the Far Roelofs effect as the frame was at the same position relative to the light at the time the subject pointed.

To summarize, the six experimental conditions are listed below with both the sequence in which subjects were run (all subjects were run in the same order) and the order in which experiments were presented in the text.

Table 5

Chronological Order in which Experiments were Conducted and Order as Numbered in Text

Experiment	Order of Running	Order in Text
Far Roelofs effect	1	1
Non-relative induced movement (frame moving far left to near left)	2	5
Induced movement (frame moving far left to near left)	3	3
Near Roelofs effect	4	2
Non-relative induced movement (frame moving near left to far left)	5	6
Induced movement (frame moving near left to far left)	6	4

APPENDIX C

Rationale for the Choice of Statistical Analysis

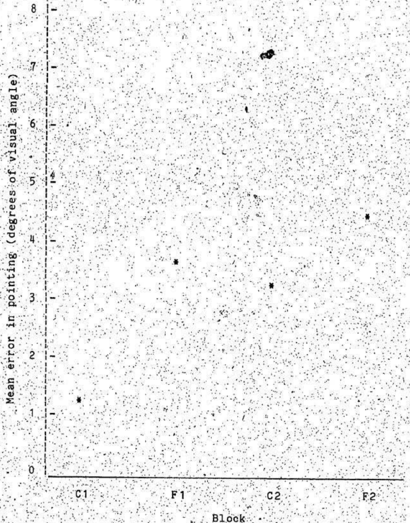
The most common use of analysis of variance in the behavioural sciences is in testing the hypothesis that three or more population means are equal. The F ratio may be viewed as a simultaneous test of the hypothesis that all possible comparisons between pairs of treatment means are zero. For this reason, the F ratio is sometimes known as the "omnibus" or "overall" F test. Although a significant F ratio indicates that there are statistical differences among the treatment means, it does not locate the source of the difference. An appropriate multiple comparison test is needed to isolate which group or groups are significantly different and the more comparisons that are conducted, the greater is the probability of incurring a type I error. Individual post hoc techniques statistically control for this factor in different ways, resulting in these tests varying in their statistical power.

An alternative approach is to use planned (a priori) comparisons instead of the overall F test. In this case, the experimenter is not interested in the simultaneous test of all possible pairs of means but rather only those that have experimental relevance. The comparisons of interest are known before the experiment is conducted.

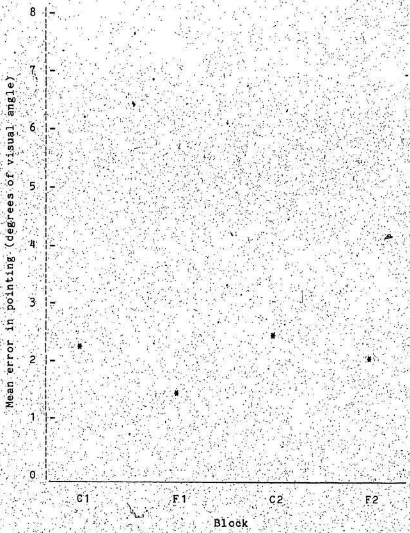
These comparisons or contrasts are classified as either orthogonal or nonorthogonal. Orthogonal comparisons are those that use nonoverlapping or independent pieces of information from the data. There is some debate as to the permissible type and number of comparisons that can be used in the analysis. Hays (1963) has argued that the only valid comparisons are those that are orthogonal. Kirk (1968) has taken a somewhat more moderate approach by suggesting that a distinction should be made between orthogonal and nonorthogonal comparisons and that the latter should be placed in the some category as post hoc comparisons. Winer (1962) maintains that for all practical purposes, whether the comparisons are independent or not makes little or no difference.

Although both the overall _F_ test and planned comparisons are based on the _F_ ratio, the latter has the advantage of being more powerful statistically than both nonorthogonal and post hoc comparisons and is therefore more likely to detect real differences amoung means (Kirk, 1968).

In the present experiment, there were only two relevant pairwise comparisons to be made (C1 to F1 and C2 to F2). This factor in combination with the greater statistical power of planned comparisons made it an appropriate statistical technique.



APPENDIX D - Experiment 1 - Induced movement with frame in right visual field (frame moving far right to near right) - Mean error in pointing to target light on each block.



APPENDIX E - Experiment 2 - Induced movement with frame in right visual field (frame moving near right to far right) - Mean error in pointing to target light on each block.