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# IN DEFENSE OF GRADIENT THEORIES OF ILLUSORY LINE MOTION

by

**William C. Schmidt**

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy

at

Dalhousie University
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The undersigned hereby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled "In Defense of Gradient Theories of Illusory Line Motion"

by William Schmidt

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# TABLE OF CONTENTS

Page

## TABLE OF CONTENTS (continued)

## TABLE OF CONTENTS (continued)

## TABLE OF CONTENTS (continued)

CHAPTER 9

## LIST OF FIGURES

## LIST OF FIGURES (continued)

## LIST OF FIGURES (continued)

## LIST OF FIGURES (continued)

# LIST OF TABLES

# ABSTRACT

Several theories have been put forward to explain an illusory impression of motion within a figure that appears all at once (similar to the expansion of the figure over time). This illusion has recently been referred to as "Illusory Line Motion" (ILM) because it was found to strongly occur within a line probe presented beside a priming object. Gradient theories suggest that the source of the illusion is an asynchrony of signals arriving a motion detection system across space and time. On the gradient account, this asynchrony is introduced by a spatial gradient inherent in the visual system or created as the result of the visual system's response to prior stimulation.

Gradient theories have been challenged by low and high-level explanations of the phenomenon. High-level explanations of the illusion postulate that the motion is the result of transformational processes that attempt to link successive views of objects in the world and fill-in object transformations that were most likely to have occurred from one view to the next. Low-level explanations hypothesize that the illusion is an artifact of the neural machinery that is used to segment the visual scene.

This thesis examines the adequacy of alternative explanations through phenomenal demonstrations that have been put forward as counterexamples to the gradient hypothesis. In Experiments 1 and 2, contrary to claims of a high-level theory, it is demonstrated that ILM and classical apparent motion differ with respect to their spatial and temporal characteristics. In Experiments 3, 4 and 5 it is demonstrated that contrary to previous results, ILM is sensitive to, and can be influenced by, voluntary attention. This suggests that the representation underlying the illusion can be modulated by top-down visual processes, though it is found that such contributions are less than from stimulus-driven factors. In Experiment 6 the empirical examination of a high-level theory's claim that ILM occurs after amodal completion was not supported in a paradigm that had been reported to produce results incompatible with gradient theory predictions. In Experiment 7, a low-level neural model explanation that was incompatible with gradient theory predictions was shown to be incorrect when empirically tested. It was argued that the model has too many degrees of freedom to be a useful tool. In Experiment 8, a paradigm taken by others to demonstrate that the illusion is not produced by a gradient of signals arriving at a motion detection system, is shown not to warrant this conclusion because even real signals arriving over space and time were found to be masked in this paradigm. The results of Experiment 9 supported a motion system integration source for the effect derived in the aforementioned paradigm. To answer high-level theories that propose that ILM does not involve the motion processing system, Experiment 10 was used to reveal that ILM can be found to interact with the classic motion aftereffect, suggesting that both of these effects influence a common level of motion processing. A final experiment demonstrated that as a stimulus becomes more identifiable, processes other than the simple gradient dictate perception.

After a discussion of the arguments put forward by the various hypotheses in light of existing empirical evidence, it was concluded that none of the other theories are as easy to apply or as comprehensive in detailing the phenomenal effects of ILM as are gradient theories.

## LIST OF ABBREVIATIONS

| | |
|---|---|
| 2AFC | two-alternative forced-choice |
| ANOVA | analysis of variance |
| ARVO | Association for Research in Vision and Ophthalmology |
| BCS | boundary contour system |
| $cd/m^2$ | candle-metre squared (luminance) |
| F | F statistic |
| FCS | feature contour system |
| FIDO | filling-in domain |
| G-waves | a wave of neural activity |
| formotion | form motion |
| ISI | inter-stimulus interval |
| ILM | illusory line motion |
| msec | milliseconds |
| $MS_e$ | Mean-Squared Error |
| MT | medial temporal |
| p | probability of Type I Error |
| RT | response time |
| PSE | point of subjective equivalence |
| SOA | stimulus onset asynchrony |
| t | t statistic |
| $T_-$ | sum of negative ranks |
| TAM | transformational apparent motion |
| TMP | two motion percepts |
| TOJ | temporal order judgment |
| • | degrees of visual angle |
| % | percent |

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# CHAPTER 1: ILLUSORY LINE MOTION: THE PHENOMENOLOGY

If an object such as a dot (a primer) is presented in the visual field, and a short time later a line (a probe) appears with one end nearby the primer, motion away from the priming object's location is experienced *within* the line. This motion sensation is illusory because in reality the entire line is presented at once, though it is experienced as though it were being painted on over time. This effect has been referred to as illusory line motion (ILM; Hikosaka, Miyauchi, & Shimojo, 1991, 1993a, 1993b), motion induction (von Grünau & Faubert, 1994), apparent motion impletion (Downing & Treisman, 1997), formotion percepts (Baloch & Grossberg, 1997), morphing motion (Tse & Cavanagh, 1995), and transformational apparent motion (Tse, Cavanagh & Nakayama, 1998). In keeping with the terminology of its most vocal promoters, this class of illusion will be referred to as illusory line motion (ILM).

The illusion has been related historically to gamma movement (Kenkel, 1913; Harrower, 1929; Newman, 1934 cited in Kanizsa, 1979). Gamma movement is the label given by Gestalt psychology to the class of motion that is within an item, as opposed to motion of an item between two locations (beta movement) or formless motion (phi). Motion perceived within an instantaneously presented item, such as the expansion in the size of an item when it first appears, is gamma motion (von Grünau & Faubert, 1994).

Gamma movement has traditionally been produced by the manipulation of relative amounts of intensity in the presentation of a figure (Bartley, 1936; 1941; Bartley & Wilkinson, 1953). The perceived movement begins at the region of the visual field most intensely stimulated and proceeds to the less intensely stimulated parts of the field. This was explained by Bartley (1936) as a result of shorter latency in response to strong stimulation as compared with weak. Bartley also identified retinal eccentricity as another origin of the effect and hypothesized that gamma motion under circumstances where an object was presented bridging foveal and peripheral vision was due to a shorter latency in foveal signal transmission. Hence there are at least two presentation conditions under which gamma motion occurs without the prior presentation of a priming object.

With ILM, researchers have not been concerned with stimuli affecting their own immediate appearance, so much as with the way that prior stimulation affects the later appearance of objects. Furthermore, the stimuli used to elicit ILM are often of a constant luminance. In this respect, Kanizsa (1951, 1979) was the first to report ILM-like effects when he reported on the "polarization" of gamma movement. With polarized gamma movement, Kanizsa was interested in the effects of motion within objects (probes) that were presented or extinguished in the presence of more permanent display objects (the primers).

In this first chapter, an introductory summary of findings on ILM to date is presented, with very little theoretical interjection. These are some of the facts that any comprehensive theory of this phenomenon needs to explain. They will often be presented in an historical context regarding developments that have occurred since the illusion's popular reintroduction in 1991. In Chapter Two gradient theories are presented. This is the class of theory originally proposed by Bartley (1936) and reintroduced by Hikosaka, Miyauchi, and Shimojo (1991, 1993a, 1993b), which I will argue remains the most comprehensive and useful class of theory to date. More recently, several cognitive theories have been proposed to account for ILM effects, with some success. These theories will be introduced in Chapter Three, and motion level theories and frameworks for explaining the illusion are presented in Chapter Four. Beginning with Chapter Five, novel empirical work is presented, bearing on issues raised by the different theories. In many cases the experiments answer challenges to gradient theories, or present new discoveries based on gradient theory predictions. Evaluations of the adequacy of the various theoretical alternatives take place as they are introduced, and in Chapter 9 which serves as a summary and review chapter. The conclusion derived is that while no theory can comprehensively explain all of the phenomena that are grouped together as ILM-related, gradient theories provide more coverage of known effects and provide a framework in which it is easier to cast precise experimental predictions, than any of the alternatives.

## THE BASIC EFFECT

In his studies on polarized gamma movement, Kanizsa (1951, 1979) manipulated a number of factors in an experiment, including the distance between the primer and the probe, the length of, and the width of the probe relative to the primer. He found that motion was most frequent when the probe was spatially contiguous with the primer, when the height of the probe matched that of the primer, and with probe objects that were shorter than the primer. The frequency of the effect was found to decrease with distance between the primer and probe, as the side of the probe contiguous with the primer became longer than the primer, and as the probe's length increased.

At the 1991 annual meeting of the Association for Research in Vision and Ophthalmology (ARVO 91) Hikosaka, Miyauchi and Shimojo (1991) excited a number of groups in the vision research community with their report of what seemed to be a new illusion of motion. They reported that if one presents a dot followed shortly afterwards by a line, then motion is experienced within the line as if it were drawn on over time, in a direction away from the dot (see Figure 1 -- all figures are consolidated in Appendix P for easy reference). Hikosaka et al. (1991) had unknowingly, rediscovered Kanisza's (1951; 1979) polarized gamma movement illusion. Hikosaka et al. (1991) further reported that this illusion was sensitive to both voluntary and stimulus-induced attention.

The report that ILM was attention-sensitive was of widespread interest because if correct, then this illusion would present visual researchers with an easily-derived independent measure of the timecourse and allocation of visual attention throughout the visual field. Response time has certainly been an informative measure of processing throughout the history of psychology, but any science progresses through the use of converging operations. An added perceptual measure such as ILM affords, has the potential to bolster confidence in existing theories (Schmidt, Fisher & Pylyshyn, 1998) or support reformulations of such theories (Schmidt, 1996). The discovery of ILM opened the door to a series of questions pertaining to how the visual system organizes visual input, perceives motion and the role of top-down and bottom-up contributions to motion perception.

Hikosaka et al. (1993a) introduced the simple form of the illusion. In all of their experiments (Hikosaka et al., 1991, 1993a, 1993b, 1993c), the authors were the primary observers and a two-alternative forced-choice (2AFC) methodology selecting for the direction of motion within a probe line (leftwards or rightwards) was employed. In one experiment they presented a dot primer above and to either the left or right of a fixation cross and had subjects (the three authors and two naive participants) report the direction of motion experienced within the line. They examined the time course of the effect by manipulating the delay between the presentation of the primer (which remained present throughout the trial) and the appearance of the line probe (the stimulus-onset asynchrony or SOA) from 1 to 4800 msec. Illusory motion was reliably (over 90% of the time) reported away from the primer location from about 50 msec, and remained strong even after 4800 msec.

In a variation of the simple illusion, the primer was presented for a mere 2 msec (see Figure 2). This variation examined the effect of a long, blank interstimulus-interval (ISI) as opposed to leaving the primer on as in the above example. Here, the motion effect reached maximum (over 90% away from the location where the primer had appeared) after about 100 msec and remained strong until around an ISI of 1000 msec. Beyond a 1000 msec ISI, motion direction judgments in opposing motion directions were made equally often. Hence there was a strong effect of the primer up to a second after its disappearance.

In another experiment Hikosaka et al. (1993a) examined the effect of stimulus offsets on the illusion. Previous work using response time (RT) measures had demonstrated that transient attention is sensitive not only to the appearance, but also to the disappearance of visual stimulation (Miller, 1989; Theeuwes, 1991; Todd & van Gelder, 1979). To examine this issue, two primers were presented above and on either side of a fixation cross. One of the two primers was then extinguished and a short time later (between 1 and 4800 msec) a solid line probe was displayed at the location between where the original primers were presented (see Figure 3). By about 100 msec after the disappearance of the primer, motion was reliably (greater than 90% of the time) experienced away from the location of the extinguished primer toward the remaining primer. The perceived direction of motion turned around entirely between 200 and 400 msec, after which motion was experienced away from the remaining primer. It would seem that offsets are of interest to the visual system only briefly compared to onsets or other display elements. That is, there is a transient component to visual offsets, but no sustained component.

## STIMULUS-INDUCED AND VOLUNTARY ATTENTION

In a second paper on the basic phenomena, Hikosaka et al. (1993b) more directly addressed the attentional nature of the illusion. In one experiment they presented a square primer above and to the left and right of a fixation cross, and had subjects (the three authors and one naive participant) attend to either a primer which they then flashed briefly (17 msec), or to the other primer which underwent no change. The direction of motion perceived in a probe line was determined for SOAs between 0 and 2176 msec after the flash (see Figure 4). When observers were instructed to attend the flashed box, motion was perceived to be away from it after about 50 msec, and remained away from it for the duration of the examined time course. When observers were instructed to attend to the box that was not flashed, motion was perceived away from the flashed box from about 50 msec until 400 msec, after which it appeared away from the non-flashed box which they were presumably attending. These results were interpretted by Hikosaka et al. (1993b) as demonstrating that ILM is sensitive to stimulus-driven (exogenous) attention, as well as voluntary (endogenous) attention. It was argued that just as with more conventional measures of attention, exogenous cueing (the flash manipulation) had the effect of attracting the observer's attention even when they were consciously trying to attend elsewhere in the display. After the effect of the transient flash had passed, voluntary attention was demonstrated at the location of the primer that had not been flashed.

A second experiment more directly examined the ability of endogenous attention to cause the illusion. In this experiment primer boxes were again presented above and to the left and right of a fixation cross. The boxes were equiluminant red and green, and the participants were instructed to attend to the box of one or the other colour for an entire block of trials. After a variable SOA (0 to 2600 msec), a probe line appeared connecting the two colored primers and the observer's task was to indicate the side from which the line had appeared to be drawn (see Figure 5). Hikosaka et al. (1993b) found that after about a 400 msec SOA between the appearance of the colored boxes and the line, subjects frequently reported motion away from the colored box that they had been instructed to attend. Hence ILM appeared to be sensitive to endogenous attentional manipulations. In a variant of this task, exogenous and endogenous attention were once again put in conflict, this time through the presentation of a 17 msec flash at the unattended box 493 msec after the original two colored primers appeared. The result of this manipulation was that motion was first found to be away from the colored box that the observer was instructed to attend from 250 to 500 msec. At this point, the flash had the effect of pulling the observer's attention to the non-attended box, resulting in motion away from it for the next 400 msec, at which time volitional control of attention was regained and motion was once again experienced away from the colored box that the subject was willfully attending.

A final foundational experiment by Hikosaka et al. (1993b) regarding the role of attention in ILM suggested that when attention was endogenously bound to a tracked moving object (because observers were directed to track the item) then ILM occurred away from the tracked object more than similar untracked objects. In this experiment four spots appeared equally spaced on the circumference of an imaginary circle around a fixation point. After all of the objects began to move counterclockwise in synchrony, one of the spots was exogenously cued by changing colour for 765 msec, and the subject's task was to endogenously track this cued spot as the set rotated. A horizontal probe line was presented between the cued spot and the spot adjacent to it once the rotation had gone through 90, 180, 270 or 360 degrees (see Figure 6). Hikosaka et al. (1993b) found that motion was frequently (about 80% of the time) away from the tracked item. This finding led them to conclude once again that the illusion is sensitive to manipulations of endogenous visual attention.

Hikosaka et al. (1993a) have interpretted their time course data as demonstrating independent transient and sustained components of visual attention. Previous studies (Müller & Rabbit, 1989; Nakayama & Mackeben, 1989) have suggested that visual attention may demonstrate a time course such that stimulus-driven factors dominate within the first few hundred milliseconds after stimulus presentation, followed by later, slower arising but longer lasting sustained attention.

## NOVEL STIMULUS CONFIGURATIONS

The presentations and claims of Hikosaka et al. (1991) aroused the curiosities of several groups of researchers. The following few annual meetings of ARVO included several presentations of new findings related to ILM. Shimojo, Miyauchi and Hikosaka (1992, 1997) reported that auditory onsets at locations in space could prime motion within a probe bar presented visually. Later, tactile cueing was demonstrated as a sufficient primer for the illusion (Hikosaka, Miyauchi, Takeichi, & Shimojo, 1996; Shimojo, Tanaka, Hikosaka, & Miyauchi, 1996). The claim was that cross-modal attentional orienting was capable of priming the illusion as were remembered or imagined primer locations. Further work from this group came from Miyauchi, Hikosaka and Shimojo (1992) who presented a comprehensive set of experiments mapping out the visual field across space and time in response to various primer configurations (more on this study in Chapter 2).

In a series of experiments, von Grünau and Faubert (1992, 1994) factorially manipulated attributes (luminance, colour, stereo depth, motion in an object, and texture) composing the primer and the probe. When the primer and probe objects were drawn from the same attribute class (intraattribute conditions) motion was frequently experienced away from the primer. Luminance-defined and colour-defined intraattribute motion clearly produced the strongest illusory motion effects. For interattribute conditions the attribute of the probe was a more important determinant of motion strength than the attribute of the primer. Again, luminance and colour dominated the other attributes examined. The finding of interattribute motion suggested that signals are integrated centrally, and only slightly affected by the attributes defining the objects presented. Similar conclusions have been reached using simple two-frame apparent motion stimuli where the attributes composing the first and second appearing objects were factorially manipulated (Cavanagh, Arguin & von Grünau, 1989).

Some important findings were reported by von Grünau and Faubert (1992, 1994) who discovered that spreading motion effects occur using a wide variety of probe objects, and that line probes were not special. In this sense, they began relating the effect to gamma movement (Kenkel, 1913) and polarized gamma movement (Kanizsa, 1951, 1979). It was this observation that led them to begin referring to the illusion and the class of related effects as motion induction rather than ILM.

Importantly, von Grünau and Faubert (1992, 1994; Downing & Treisman, 1997; Kanizsa, 1951, 1979; Schmidt & Klein, 1997) reported that if one reverses the order of the primer and probe presentation, that is a line appears and is replaced by a dot at one end, then motion is experienced within the line's offset toward the priming dot (see Figure 7). Furthermore, Faubert and von Grünau (1992, 1995) found that in situations in which two primers oppose each other (what they referred to as double-primer conditions), motion was often experienced in a linking probe line away from both primers, colliding in the middle of the probe (an effect they referred to as split-priming - see Figure 8). This latter finding is significant because the work of Hikosaka et al. (1993b) used the double-primer paradigm, but always used 2AFC methodology, which left no room for the report of collisions. Even more important though, was that the commonly accepted view that attention can act at only a single display location (the so-called spotlight metaphor) was in conflict with Hikosaka et al.'s (1991, 1993a, 1993b) claim that the source of the illusion was attentional. This conflict caused many researchers to doubt an attentional basis of the effect.

Other interesting novel stimulus configurations were presented by Faubert and von Grünau (1992, 1995). They reported that the collision point of the probe line could be shifted by presenting one primer later in time than the other. To this end, they carried out an experiment where a primer was present above and to one side of a fixation cross. This primer was accompanied by a second primer above and on the opposite side of fixation after a variable SOA (see Figure 9). The probe line appeared 300 msec after the appearance of the second primer. At a zero msec SOA, motion in the probe collided centrally and the collision point shifted away from the later primer as the SOA between the primers increased. By about a 300 msec SOA motion was completely dominated by the most recently presented primer. Hence it appeared as though the delay between presenting the primers allowed the effects of the first presented primer to dissipate allowing the second primer's onset to dominate the percept.

In an interesting twist to split-priming, Faubert and von Grünau (1995) observed that if the colour of the primers and the probe were manipulated such that the probe was identical in colour to one or the other primer, then surprisingly, motion was always away from the same colored primer regardless of the delay between the primers' presentation (see Figure 10). This was not the case for the simple form of the illusion investigated by von Grünau and Faubert (1992, 1994). This result suggests that in the double-primer paradigm, intraattribute motion signal integration can occur earlier than interattribute motion signal integration.

Related to the finding of a motion collision in probes of double-primer displays, Faubert and von Grünau (1992, 1995; Downing & Treisman, 1997) reported that if a flanking probe bar is added off to one side of the display then no collision is perceived centrally, but instead motion is experienced in a single direction (see Figure 11). This report was the first case to violate the expected result of motion away from all sides of a priming stimulus. Adding two flanking bar probes, one off to either side of the double-primer display restored motion within the probes away from the primers (see Figure 12).

Steinman, Steinman and Lehmkuhle (1994) found that for small probe lines presented peripherally (approximately 4° of visual angle from the primer), the direction of motion was actually toward the primer, not away from it as is the normal case for ILM (see Figure 13). If the primer-probe separation is greater than about 4.5 degrees of visual angle, then the direction of motion within the probe reverses. By mapping out a space and time profile, these researchers were able to show that ILM demonstrates a center-surround organization. The property yielding this effect most likely belongs to the motion detection system itself which has independently been found to have such an organization (Loomis & Nakayama, 1973; Kim & Wilson, 1997; Murakami & Shimojo, 1995; Norman, Norman, Todd & Lindsey, 1996).

Further novel effects were discovered by Schmidt (Schmidt & Pylyshyn, 1994; Schmidt & Klein, 1997) who introduced a new illusion which was related to ILM. It was found that if a primer appears followed by the brief presentation of the probe, then motion is experienced within the probe first away from and then back toward the primer (see Figure 14). Similarly, if a primer dot is presented and is followed by the rapid presentation of a series of probe dots along a trajectory away from the primer, then motion is perceived away from and then back toward the primer (see Figure 15). The phenomenology of this illusion is of an expanding and then shrinking line. Curiously, if one rapidly presents the probe dots along a trajectory toward the primer, then the motion experience is similarly away from and then back toward the primer location and takes the form of an expanding and then shrinking line (see Figure 16). This illusion, which was dubbed the 'Two Motion Percepts' illusion (TMP) added a new group of phenomena that any comprehensive theory of ILM should strive to explain.

In 1995, Tse and Cavanagh (1995; Tse, Cavanagh & Nakayama, 1998) presented several very convincing demonstrations using double-primer displays that many ILM-related effects may require a high-level interpretive framework. These examples provide a rich set of important data. The remaining examples presented in this section are taken from Tse et al. (1998).

In Figure 17, each of the examples present the situation whereby the probe is spatially contiguous with one of the primers. As found by Kanizsa (1951; 1979) spatial contiguity is a strong determinant for predicting the direction of illusory motion. Tse et al. (1998) reported that in a competing cue or double-primer display in which the probe is spatially contiguous with just one of the primers, motion is away from the spatially contiguous primer, even if there is a match in color between the non-contiguous primer and probe (see Figure 17c). Figure 17b demonstrates that the removal of a primer-probe boundary on presentation of the probe is also sufficient to cause motion away from that primer.

In Figure 18 the role of smooth contours and concavities is demonstrated. Here it is found that motion is predominantly away from the primer that shares smooth contours with the probe (primers on the left). Similarly, deep concavities between a primer and a probe hinder the experience of motion away from the concave junctions. No systematic study of the relative strengths of the motion produced by these factors has been undertaken.

In Figure 19 motion is reportedly experienced only when the probe could possibly be an extension of the primer on the right (Figure 19b). In Figure 19a the probe is taken to be occluding the primers and is therefore not a part of the priming objects, and does not produce an illusory motion experience. These results are interpretted as suggesting that the illusion is figure centered (Tse et al, 1998). Further work involving the role of occlusion and the experience of illusory motion is presented in Figure 20. Here Tse et al. (1998) report that motion is experienced within the entire length of the probe bar when it is experienced as continuing behind the occluding rectangular object (Figure 20a). When the probe bar is not continuous and is not completed behind the rectangle, it is claimed that no motion is experienced in the portion of the bar that is not experienced as being spatially contiguous with the primer.

A final interesting stimulus configuration presented by Tse et al. (1998) is presented in Figure 21. These odd shaped objects again demonstrate motion is away from the primer that forms a smooth contour with the probe (the primer on the right).

## ILM AT MULTIPLE LOCATIONS

Schmidt, Fisher and Pylyshyn (1998; Fisher, Schmidt & Pylyshyn, 1993) expanded on the finding that ILM can occur away from two locations and sought to determine whether there was a limit on the number of locations at which motion could simultaneously be assessed. According to Pylyshyn's (1989) visual indexing hypothesis there should be a capacity limit on the number of spatial locations that can be individuated and interrogated for information. Schmidt et al. (1998) presented 8 to 12 evenly spaced priming dots around the circumference of an imaginary circle and then randomly probed one of the locations, or the point between two adjacent primer locations with a probe line that bridged the radius of the circle (see Figure 22). The illusion frequently was experienced away from primer locations, but not when the probe line appeared between adjacent primers. This suggested that facilitative effects were confined to multiple spatial locations surrounding display stimuli. Mathematical modeling of the performance data revealed that the illusion did not behave entirely as though it were simply a bottom-up process: A capacity limitation in terms of the number of locations that could simultaneously be individuated was found to be between five and seven items. This finding underlies

Schmidt et al.'s (1998) contention that ILM taps a distributed, spatially-parallel form of attention prior to focussed serial attention.

Kawahara, Yokosawa, Nishida and Sato (1995; 1996) also reported on ILM at multiple locations. They had subjects search for an ILM directional singleton (an item that is unique from all other items in the display on at least one attribute dimension) while ILM was presented at several other locations in an array simultaneously. Using display sizes with up to eight items they found only a slight reduction in observers' ability to detect the presence of an illusory motion direction singleton.

Further work with ILM at multiple display locations was carried out by Faubert (1996). It was demonstrated that by repeatedly presenting a large number of priming dots randomly distributed in a display, followed by a large number of lines after a brief SOA, that one could induce the perception of global motion (see Figure 23). Such displays use multiple instances of ILM on a small scale to cause the global sensation of motion in the direction of the illusion on a large scale. This finding demonstrates that there is an integration of motion signals arising from many spatially distributed instances of the illusion.

The finding that global motion can be induced from the simultaneous presentation of the illusion at multiple locations is not in conflict with the finding of a capacity limit in determining the direction of ILM (Schmidt et al., 1998). The latter task requires that observers individuate the visual items about which they are reporting, whereas the former task allows integration across space to guide the overall percept without the selection of specific items. If the observer's task in the former case were to report on the phenomenology of the individual illusions, then a capacity limit would once again be expected to be detected.

## NEURAL ORIGINS OF THE EFFECT

Several researchers have attempted to narrow down where in the visual system the illusory motion may be taking place. Hikosaka et al. (1993a) examined whether the illusion might occur before binocular integration. To this end, they presented the primer to one eye and the probe line to the other to determine whether an early locus to the effect would be discovered. No difference was observed in the time course of the effect whether the primer and probe were presented dichoptically or monoptically, leading them to conclude that the likely source for the illusion was V1 (the earliest place in the occipital stream at which information from both eyes is integrated) or beyond. Alternatively, they reasoned, extrageniculate subcortical areas could be the source of the illusion, indirectly involving retinal projections to the superior colliculus which transits to the pulvinar and finally reaches motion processing mechanisms in medial temporal (MT) cortex.

Faubert and von Grünau (1992, 1995) examined the double-primer paradigm (see Figure 9) in the context of dichoptic stimulus presentation, and came to rather different conclusions. When they presented one primer to one eye, and the second primer and the probe bar to the other eye, motion was experienced almost exclusively away from the later appearing primer. Note that this is a slightly different result than would be expected under binocular conditions, where motion was inwards from both primers colliding at a point closer to the first appearing primer as SOA increased (see Figure 9). This effect of the eye of origin of the primers was most pronounced at short SOAs between the primers -- the influence of the first appearing primer was negligible in counteracting the effects of the later primer.

When Faubert and von Grünau (1992, 1995) presented the first primer and the bar probe to the same eye, then there was an effect of the eye of origin at short SOAs between primers -- motion was almost completely away from the first primer, not colliding centrally or closer to the first primer as is the case under binocular vision. After about 300 msec, collisions began to occur, and the direction of motion began to be primarily away from the second primer (the collision point moved toward the first-appearing primer with increasing SOA as was the case in the binocular condition). It was concluded that early on in the time course monocular processes were likely to dominate the effect, while later in the time course, higher level processes determined the perceived motion direction.

While the conclusions of Faubert and von Grünau (1992, 1995) differ from those of Hikosaka et al. (1993a), the two sets of data are not necessarily in conflict. The earlier finding of no difference between binocular and monocular presentations is consistent with a late signal integration point prior to motion detection, but this does not rule out the possibility of an early integration point existing as well. The Faubert and von Grünau (1992, 1995) data show that early and late integration points exist. As suggested by the strength of intraattribute versions of the illusion (von Grünau & Faubert, 1992, 1994), there may well be several sites at which signals are integrated, and several sites where motion is detected.

Further support for a V1 locus of ILM comes from the finding that both ILM (von Grünau, Dubé & Kwas, 1994, 1996; McColl & Schmidt, 1995; Schmidt, 1994) and visual motion detection systems are sensitive to singleton stimuli. Recent work investigating properties of cells in cat striate visual cortex has demonstrated that motion sensitive cells, even at this early level respond to feature contrasts and precise forms that are separated by distances greater than their receptive fields (Levitt & Lund, 1997). Such mechanisms have been argued to implement pop-out or feature contrast detectors even at this early stage of processing (Kastner, Northdurft & Pigarev, 1997). The coincidence of ILM sensitivity to these sorts of stimulus configurations makes this locus a strong candidate for the illusion's neural origins.

## BOTTOM-UP AND TOP-DOWN CONTRIBUTIONS

Several groups of researchers have reported the ability to detect both low-level and high-level contributions to the illusion. As discussed earlier, ILM can occur simultaneously at more than one display location which led Schmidt et al. (1998) to conclude that the illusion occurred from a spatially parallel form of facilitation which could be modulated in a top-down fashion by focal attention. Kawahara et al. (1995, 1996) concluded that, because ILM can occur at multiple locations with only a minor decrease in detectability it must share preattentive mechanisms with apparent motion and be modulated in some other fashion by attention. Downing and Treisman (1995, 1997) reached similar conclusions, arguing that ILM is classical apparent motion augmented with a cognitive inferencing process, which can be biased by attention. Hecht (1995) similarly concluded that there were both high and low-level contributions to the illusion, including contributions from irrelevant objects in the displays he used as well as those to which his subjects directed their attention.

Perhaps the strongest evidence for bottom-up and top-down contributions to the illusion comes from the work of von Grünau, Dubé and Kwas (1994, 1996). Using a visual search pop-out display with an orientation singleton embedded within a rectangular array of distractor items, they had participants rate the direction of motion within a line that was presented between two display items. When the line appeared between two distractors, motion direction was at about chance regardless of whether a pop-out orientation singleton was in the display or not. When the line abutted the pop-out target, motion was away from that item. The claim was that ILM has automatic components that arise from simple aspects of the display and that attention can modulate these bottom-up effects in a top-down fashion. Similar work was carried out by Schmidt (1994) and McColl and Schmidt (1995). Schmidt examined stimulus-driven attentional capture using ILM, and found that the illusion was sensitive to several types of singletons, but in homogenous displays with small numbers of primers, motion could often be detected away from the primers.

## SUMMARY

As this chapter demonstrates, the phenomenology of ILM is rather diverse and detailed. This situation will only deepen as more detailed examples are added in later chapters. Nonetheless, these are the findings that must be accounted for by any aspiring model. The next chapter outlines the class of model (gradient models) that was originally put forward to explain the illusion, and follows its development to date. Subsequent chapters describe proposed alternative models and views put forward by other researchers claiming to invalidate gradient accounts. Empirical work thereafter will examine several challenges to gradient models and will further develop the account.

# CHAPTER 2: GRADIENT MODELS OF ILLUSORY LINE MOTION

The idea that a gradient plays a role in producing motion that is experienced within objects is not new. Bartley (1936; 1941; Bartley & Wilkinson, 1953) explained gamma motion by positing that a gradient or 'taper' was responsible for the effect. This earlier research revealed gamma motion from brighter to dimmer stimuli that were presented simultaneously. Gamma motion could also be experienced when a large object was presented subtending foveal and peripheral vision. In the former case Bartley (1936; Bartley & Wilkinson, 1953) hypothesized that brighter stimuli were transmitted faster than dimmer stimuli, resulting in motion toward the less intense item. In the latter case Bartley (1941; Bartley & Wilkinson, 1953) hypothesized that a temporal asynchrony was introduced by faster transmission of signals foveally as opposed to peripherally.

As discussed in Chapter 1, Hikosaka, Miyauchi, & Shimojo (1991, 1993a, 1993b, 1993c) reported that if an object (a primer) is presented in the visual field, and a short time later a line appears with one end nearby the primer, motion away from the priming object's location occurs *within* the line (see Figure 1). They explained this illusory line-motion (ILM) by positing that attention is summoned to the location of the primer and this causes the transmission and reception of signals arising at, and nearby, the primer location to be speeded. Because the degree of signal acceleration by attention is purported to drop off as the distance from its focus increases (Downing, 1988; Erikson, Pan, & Botella, 1993; Kröse & Julesz, 1989; LaBerge & Brown, 1989; Mangun & Hillyard, 1988; McCormick & Klein, 1990; Sagi & Julesz, 1986; Shaw, 1978; Shulman, James, & Sheehy, 1985), it was hypothesized that a temporal asynchrony in neural responses is relayed to a motion detection system, causing motion away from the primer to be experienced (see Figure 24).

The fact that gamma motion can occur within the presentation of a single object (Bartley, 1936) even when it is presented with a constant luminance demonstrates that attention cannot be the sole source of the effect because attention takes time to become activated. Having said this, there is ample evidence using RT measures that attention can modulate perception in order to speed the transmission of signals at attended locations relative to unattended locations. This principle formed the basis of Titchener's (1908) prior entry hypothesis. A similar mechanism underlying certain types of motion phenomena has been proposed by Stelmach, Herdman and MacNeil (1994).

This chapter provides a sketch of gradient theory, presents several ways in which models based on such a theory might vary, and clarifies the definition of the gradient theory under test. Existing empirical support for gradient mechanisms is summarized.

## WHAT IS A GRADIENT THEORY?

All gradient theories share at least two things in common. First, all gradient theories assume that illusory motion is produced by differing arrival times of signals at a motion detection system. Hence they inherit properties common to motion detection systems. Second, all gradient theories assume that there is a modulatory effect of a spatial gradient on incoming visual signals prior to their arrival at a motion detection system. Gradient theories may differ on the specific implementation of the motion detection system, or they may differ on what sorts of processes they postulate are involved in the modulation of visual signals.

When a real stimulus moves across the retina it causes signals to arise over time, from different spatial locations in the world. These signals are transmitted to a motion detection system over time and through different represented locations. Gradient theories of ILM assume that the same motion detectors receive signals and indicate the perception of motion in both real movement and illusory movement cases. The difference is that in the illusory motion case, it is a property of the visual system itself which introduces a modulation of the temporal aspects of the represented stimulus producing a temporal asynchrony of signals arriving at the motion detection system when in fact those signals entered the visual system at the same time. Temporal modulation of signals from real moving items may also exist, although because their order of arrival at the motion detection system is not necessarily distorted, direction of motion is often perceived veridically.

The property of the visual system postulated to be responsible for this modulation is proposed to be a spatial gradient. The precise definition of a spatial gradient is rather vague, because the term both denotes the consequence of such modulation and a mechanism that introduces the modulation. One need not have a gradient to transform a spatially distributed linear series of signals into a spatially graded series with modulatory properties such as accelerating and temporally extending transmitted signals. Hence, there are strong and weak versions of gradient theories. Strong versions assume that there is a mechanism which both acts like a spatial gradient and modulates signals. Weak versions simply assume that some sort of mechanism exists that introduces a spatial and temporal grade of signals. On weak interpretations, gradients simply refer to the pattern of signals arriving at motion detectors. However, on the strong interpretation, gradients actually exist as an intermediate representation independent of their modulated signals.

At the level of input to motion detectors, one notable difference exists between the stimulation that would be produced by a real moving object and that which is produced by the illusion. While in the former case object motion is often generated through spatial displacement of the moving item, with simple ILM (see Figure 1) the motion is produced only by signals from the leading edge of the probe item. Because signals from the probe item remain on after their initial entry, there is no offset signal that would normally be associated with spatial displacement. This situation can occur in the real world as well, as in the situation whereby only an object's leading edge moves into one's peripheral vision. The percept of such motion is more of a growth or expansion than of spatial displacement associated with a moving object.

## EMPIRICAL SUPPORT FOR GRADIENT THEORIES

Both of the major assumptions of spatial gradient theories have been supported by previous research. First, research from the much studied phi phenomenon has demonstrated that the presentation of signals across space and time is sufficient to cause the sensation of motion. The second major assumption of gradient theories, that there is a modulatory effect of the visual system, implicit or explicit, on the transmission of signals is supported by the finding that a motion sensation can be brought about even in a stationary stimulus. As reported above, Bartley (1936) notes that gamma movement can occur for objects bridging foveal and peripheral vision, likely as a result of the difference in processing time introduced in cone versus rod receptor systems. This is a clear example that the visual system can introduce processing artifacts that modulate signal transmission in order to cause the smooth sensation of motion.

Additional research on the transmission of luminance signals in the visual system has revealed that brighter signals are transmitted within the visual system more quickly than dimmer signals (Bartley, 1936; Roufs, 1963, 1974; Wilson & Anstis, 1969). Presenting a simple luminance gradient that is tapered from bright to dim across space causes observers to experience motion within the gradient from the bright location toward the dim location (Bartley, 1941; von Grünau, Saikali & Faubert, 1995). This demonstrates that a temporal asynchrony between visual signals presented across a spatial area is sufficient to trigger motion detectors. It further demonstrates that delays introduced by the construction of the visual system are capable of causing illusory motion in a situation that is directly comparable to ILM.

Further support for the notion that the visual system can introduce a temporal asynchrony between the signals that it transmits comes from the domain of temporal order judgments (TOJs). In TOJ tasks observers are presented with a pair of brief stimuli and asked to report which occurred first in time. Sternberg and Knoll (1973) summarized the results of several studies suggesting that focal attention can create an illusory temporal asynchrony such that an attended stimulus is perceived prior to a non-attended visual stimulus. Titchener (1908) is credited with this discovery which formed his law of prior entry: "The stimulus for which we are predisposed requires less time than a like stimulus, for which we are unprepared, to produce its full conscious effect" (p. 251).

Maylor (1985) examined the effects of an exogenous attentional cue on TOJs and found that cueing acted to speed the arrival of subsequent stimuli presented at the cued location relative to an uncued location. Stelmach and Herdman (1991) expanded on this work within the visual domain by clearly demonstrating such an effect using a mixture of endogenous and exogenous attention as well as purely endogenously directed attention (Stelmach, Herdman & MacNeil, 1994). Their later work had observers judge motion direction rather than temporal order.

Hikosaka et al. (1993a) began their study of ILM by examining the effects of exogenous attention (as summoned by the abrupt appearance of a dot) on TOJs. Hikosaka et al.'s investigations of the time course of TOJs using exogenous attentional cueing revealed that when one of two briefly presented vertical bars was preceded by the appearance of an exogenous cue (the presentation of a dot at one of the vertical bar locations between 50 and 1600 msec prior to the appearance of the vertical bars), then the bar at the cued location was more often judged to have been presented first. This bias for the cued location began as early as 50 msec after the cue appeared, reached a maximum around 150 msec, and continued to have a biasing effect throughout the 1600 msec time course they examined. Calculated points of subjective equality (PSE - the temporal difference in the presentation of the vertical bars such that subjects were at chance reporting which stimulus was presented first) revealed that differences of 30-70 msec between the presentation of the vertical bars were required for observers to begin to overcome the biasing effects of the exogenous cue.

To answer any potential concerns about the possibility of temporal summation between the cue and one of the vertical bars being responsible for the facilitative effect of the cue, Hikosaka et al. (1993) examined the effect of a cue offset prior to the bars' presentation. Previous work (Miller, 1989; Theeuwes, 1991; Todd & van Gelder, 1979) had found that stimulus offsets produce an early facilitatory effect like stimulus onsets. Hikosaka et al. (1993a) found a similar facilitatory effect for turning off the cue. In this paradigm, two dots were presented, one was extinguished and then the vertical bars appeared in the original dot locations. The time course of this offset effect was slower to develop than for the onset case, reached a maximum around 150 msec after the disappearance of the cue (PSE of about 50 msec), and decayed substantially by 400 msec (33 msec PSE). Motion was entirely away from the remaining primer stimulus by 1600 msec (PSEs were now negative).

Hikosaka et al.'s (1993a) next step was to revert to the simple exogenous cueing situation, and to draw a series of vertical bars from the uncued side toward the cued side. They reasoned that if they reduced the spacing between the display items that they might tap into short-range motion processes (thought to be active at inter-stimulus distances below 15 minutes of arc, Braddick, 1974) thereby yielding a motion percept across several stimuli rather than simply a judgment of two independent events. As in their earlier experiments, a time course for the effect was examined. On a subject by subject basis, they increased the time interval required between the presentation of each of four vertical bars until all four appeared to come on at once. The cue led the presentation of the first bar by between 50 and 2000 msec. As in the simpler case when only two vertical stimuli were judged (see the first experiment described in this section), the point was determined at which observers were at chance level in judging the direction of drawing (the PSE). PSE values were found to be greatest (about 25 msec) at short cue lead times, decreased until about 400 msec cue lead time, and remained positive (about 18 msec) even up to 2000 msec.

The work of Hikosaka et al. (1993a) draws a strong parallel between the behavior of TOJs and ILM suggesting that the two tasks may share mechanisms. Furthermore, it ties

ILM to a larger body of TOJ research making it such that any account of ILM-related phenomena should also be able to explain TOJ phenomena.

A series of experiments by von Grünau's group (von Grünau, Racette & Kwas, 1996; von Grünau, Saikali & Faubert, 1995) used the fact that the simple presentation of a bar composed of a luminance gradient is sufficient to cause motion within the bar to determine whether such a physical gradient would counteract the illusion (von Grünau et al., 1995). If ILM is caused by the temporal asynchrony of signals arriving at a motion detector, then directly counteracting this with a stimulus that performs this function should affect ILM. Using the simple form of the illusion (see Figure 1), a primer was presented followed by a luminance gradient probe with either its brightest or dimmest end abutting the primer. The primer's luminance was approximately the mean luminance of the probe bar, and primer-probe SOA was manipulated. When the luminance gradient was compatible with the hypothetical gradient caused by the primer, motion was frequently away from the primer even at a 0 msec SOA and throughout the 300 msec time course examined. When the luminance gradient was brightest on the end of the probe opposite the primer (i.e., the luminance gradient was in conflict with the effect of the primer), the frequency of motion away from the primer increased with increasing SOA. At short SOAs the illusion was reported significantly less often when the primer and gradient were in conflict up to about a 90 msec SOA, after which the influence of the primer dominated. Cancellation results demonstrate, as one would expect from the gradient account, that a perceptual gradient of arrival times caused by differing luminance is capable of counteracting the hypothetical gradient of arrival times that result from the presentation of a priming stimulus.

In a second experiment, von Grünau et al. (1995) examined the double-primer paradigm (see Figure 9) to determine whether, when two primers set up gradients counteracting one another, the effects of a luminance gradient on signal arrival times would be more pronounced. Recall that normally in this paradigm two primers are presented with some time delay between them and they are followed by the presentation of a probe bar.

There is generally motion toward the probe's center, colliding centrally at short SOAs and with motion away from the later-appearing primer at longer primer-probe SOAs. Hence the second spot generally determines the direction of motion in the paradigm (Faubert et al., 1995). Observers reported the dominant motion direction present on each trial. When a luminance gradient probe was used and the brightest end of the gradient was presented abutting the second primer, motion was always away from it. When the bright end of the luminance gradient was presented abutting the first primer, motion was away from the first primer at all SOAs (0-3000 msec) indicating that the luminance gradient overrode the effects of the second primer. Hence the introduction of a physical temporal asynchrony of signal arrival completely overrode the effects of the later primer when it was in opposition, and added to that effect when it was compatible.

In further work, von Grünau et al. (1996) used luminance gradients to derive an estimate of the temporal change in processing that the primer had on subsequent signal arrival in a double-primer paradigm. For several observers, they first determined the SOA between primers that was required so that a collision was experienced close to the first-appearing primer. They then examined the effects on the collision point, of ten luminance gradients (all with a mean of 41.2 cd/m$^2$ and ranges of 8 to 80 cd/m$^2$) presented at the determined observer-specific primer-probe delay. The goal was to find a luminance gradient that when presented in opposition to the second primer would drive the collision point back to the bar's center. Determining the change in time introduced by the luminance gradient that just counteracted the gradient introduced by the second primer at an SOA where the second primer was dominant, would yield an estimate of the influence of the second primer on processing speed. Having found such a stimulus configuration for four of five observers, a third experiment, using detection RT as a dependent measure, determined on a subject by subject basis the difference in processing time that was expected for each observer's luminance gradient as a function of luminance. Knowing this, the expected change in processing introduced by the gradient was calculated and found to be 14, 17, 17 and 19 msec for the four observers.

In a final set of experiments, von Grünau et al. (1996) repeated the above procedures for bars of varying lengths, with the prediction that if the gradient drops off with distance, and if the motion is determined by the differential amount of priming at the ends of the bar, then shorter probes should be able to tap only part of the priming effect while longer bars would have more of their signals modulated. It was found that the longer the probe bar was, the greater a change in processing time was required to counteract the second primer. Hence a stronger priming effect is obtained with longer probes which presumably tapped a greater spatial area of the gradient. A plot of the derived change in processing values as a function of distance revealed that the profile that best seems to fit is one of a negatively decaying exponential function. Inhibitory surrounds were found ranging from between 1 and 5 degrees of visual angle from the primer, consistent with several reports of center-surround motion detector properties (Loomis & Nakayama, 1973; Kim & Wilson, 1997; Murakami & Shimojo, 1995; Norman et al., 1996) and other ILM results (Steinman et al., 1995).

A final set of experiments that provides direct support for the gradient model comes from researchers who used phi motion to directly counteract the effects of the primer. In every case, the strength or frequency of motion experienced in the illusion is reduced (Miyauchi et al., 1992; Schmidt et al., 1998; Steinman et al., 1995). The most extensive work in this vein comes from Miyauchi et al. (1992) who examined the spatial and temporal parameters of the simple form of the illusion. Using a high-speed calligraphic display they presented a short probe line at various times and distances from the primer. The probe was actually drawn on over time toward the primer, and the time for the drawing was used to determine the magnitude of the facilitatory effect. Effects of speeding probe signals by between 17 and 50 msec were found for a simple primer. In addition it was found that the facilitatory effect rises over time to its maximum strength, decays somewhat around 150 msec and becomes stronger again after 300 msec, consistent with other methods that have detected two temporal profiles of attention. The early acting facilitation is referred to as transient attention while the later long-lasting effect is sustained attention (Nakayama & Mackeben, 1989; Müller & Rabbitt, 1989). When an object is extinguished the facilitation in its vicinity is strong for about 100 msec then gradually shrinks.

To recap, a series of experiments provide support for the gradient theory notion that gamma motion, and specifically ILM (polarized gamma motion), is caused by a temporal asynchrony of arrival times at a motion detection system. Luminance gradient bars which are known to differentially cause faster signal transmission from their bright regions (Roufs, 1963, 1974; Wilson & Anstis, 1969) elicit motion away from these regions even though they are presented all at once. These luminance gradients can be used to counteract gamma motion (Bartley, 1941), and ILM (von Grünau, Racette & Kwas, 1996; von Grünau, Saikali & Faubert, 1995), suggesting that the source of motion in each case is a temporal asynchrony of signals arriving at a motion detection system. The illusion has also been tied to TOJs, evoking similar PSEs in the two paradigms (Hikosaka et al., 1993a). ILM is likely a result of the same underlying mechanism as TOJs, the principle difference being that with the former, signals are presented in the intervening space. Finally, ILM can be neutralized by presenting stimuli drawn against the hypothetical gradient over time and space (Miyauchi et al., 1992; Steinman et al., 1995; Schmidt et al., 1998) providing further support that the source of the effect is modulated signals arriving over time and space at a motion detection system.

## WHAT IS THE ROLE OF ATTENTION IN GRADIENT THEORIES?

There is some confusion related to gradient theories because Hikosaka et al. (1993a) originally claimed that it was a "gradient of attention" that caused the illusion. They explained ILM by positing that attention is summoned to the location of the primer and this causes the transmission of signals in the visual system to be speeded. Consequently, whenever one mentions a gradient theory, many researchers automatically think one is talking about a "gradient of attention" and refer to the gradient hypothesis as the "attentional gradient hypothesis" (Baloch & Grossberg, 1997; Downing & Treisman, 1995, 1997; Tse & Cavanagh, 1995). Characterizing gradient hypotheses in this fashion makes them susceptible to easy falsification because one need only find an instance where some established measure of attention disagrees with the output of the illusion, and then conclude that the illusion is not caused by a gradient of attention (e.g., Klein & Christie, 1996).

Although Hikosaka et al. (1993a) proposed that the gradient of accelerated signal transmission was a gradient of "attention", there are reasons to suspect that the illusion is not caused solely by processes traditionally deemed attentional. First, the illusion can be experienced at multiple locations simultaneously (Fisher et al., 1993; Kawahara et al., 1996; Schmidt et al., 1998) whereas attention is traditionally taken to be confined to single contiguous spatial location (i.e., to act like a spotlight). If the gradient underlying ILM is attentional, then it is likely not be the same strain of attention responsible for spotlight phenomena (see Schmidt et al., 1998). Second, it has been demonstrated that the hypothesized spatial gradients exist around more than simply the items that are presumed to be attended. Hecht (1995) and others (Kawahara et al., 1996; McColl & Schmidt, 1995; Schmidt et al., 1998; von Grünau, Dubé & Kwas, 1994, 1996) have demonstrated that display stimuli believed to be undemanding of attentional resources (such as a fixation point or distractor stimuli) can influence the occurrence of ILM. Finally, ILM need not involve attention, as it can rely on perceptually-based methods of speeding signal transmission (Bartley, 1936; 1941; von Grünau, Saikali & Faubert, 1995).The speeding of signal transmission in the visual system can clearly be modulated by simple sensory properties independent of any effects that attention may bestow.

Von Grünau, Dubé and Kwas (1996) modified the "attentional gradient" theoretical framework by reporting two components to the illusion: a "preattentive" component which operates in a spatially parallel fashion without attentional allocation, and a modulating effect due to focused attention. They claimed that the illusion could occur without attention, but that it could be strengthened with an attentional manipulation. Hence simply demonstrating that attention is not involved in producing illusory motion is not sufficient to reject that a gradient of arrival times at a motion detection system is at work, or to conclude that attentional manipulations are unable to influence such arrival times.

Part of the evidence that led to the conclusion of separate attentional and perceptual contributions to the illusion came from finding an increased frequency of motion away from an orientation singleton embedded in a field of distractors, compared to the case where a probe line was simply presented between distractor items (von Grünau, Dubé & Kwas, 1996). Presumably attention, which is traditionally thought to be attracted to the location of pop-out items, was drawn to the singleton location resulting in the increased frequency of motion reported from there as compared to the distractor locations which attention presumably did not affect. Strong evidence for a different set of processes operating in these two conditions came from an experiment in which the primer-probe distance was manipulated. While the automatic effect showed a linear, spatially symmetric profile, the profile of motion frequency around the singleton item was quasi-exponential and showed a greater spatial extent.

Hikosaka et al.'s (1991, 1993a, 1993b, 1993c) claim that a gradient of attention is the source of the illusion has introduced a lack of precision into subsequent communications. Researchers take the words "attentional gradient" literally, bestowing upon them whatever properties their own concepts of attention posses. However, it should be noted that in their original discussion of attention, Hikosaka et al. (1993a)) provide some discussion and an operational definition that reveals that they originally recognized that more was going on than simply the effects of attention. Hikosaka et al. (1993a) say: "Because attention is a modulatory process, we cannot see attention *per se*. Only comparison between two perceptual states, with attention and without attention, based on overt behavioral responses or a subjective reports would reveal the presence of attention."

They went on to operationally define attention as "... a process by which limited sensory information is brought into perception with relatively greater *magnitude* and *efficiency*" (page 1219, italics and grammar errors were present in the original text). Implicit in this discussion is the claim that attention is likely to modulate signal arrival times and strength, but this does not make it the sole source of such signals as many interpretations of the gradient hypothesis represent.

## EXPLANATION OF PHENOMENOLOGY

It is instructive to examine the phenomenology outlined in Chapter 1 and to delineate how it is that gradient accounts can explain the various facets of the illusion. This should help clarify the reader's understanding of the phenomena and the gradient explanation. In places, the gradient account has needed to be expanded, elaborated or clarified in order to accommodate an effect.

Starting with the simple illusion as presented in Figure 1, the gradient account proposes that with the presentation of the primer comes the effect of a gradient of facilitation that radiates outwards from the primer in all directions. The strength of the facilitatory effect is strongest nearby the priming object and weakens with distance from it. The subsequent presentation of a probe bar abutting the primer causes the transmission of probe bar signals nearest to the primer to be accelerated relative to the signals further away from the primer. The temporal asynchrony of these signals trigger a motion detection system which indicates motion in the direction of arriving signals -- away from the primer.

A similar explanation applies to the stimulus configuration in Figure 2. Here the primer is only briefly presented, yet the effects of that brief presentation remain, affecting the system for hundreds of milliseconds (at least 900 msec -- Hikosaka et al., 1993b; Schmidt, 1996). This has led to the postulation of a top-down influence on the illusion as well as bottom-up stimulus-driven effects. It is uncommon for non-attentional effects to survive such long blank intervals suggesting that the attentional modulation of the primer's input may allow the primer to have its long-lasting influence.

Hikosaka et al. (1993a) reported that primer offsets set up a gradient just as primer onsets do (see Figure 3). The resulting facilitatory effect was found to grow more slowly and to last for less time than the gradients caused by primer onsets (Miyauchi et al., 1992; Hikosaka et al., 1993a).

Figure 4 presents a display in which it can be determined that brief transients can cause a gradient to be automatically created around a flashed item. In the experiment related to Figure 4, Hikosaka et al. (1993b) instructed subjects to endogenously attend one of the items. When the attended item was the non-flashed primer, motion was away from the transient for several hundred milliseconds after the flash. This demonstrated that not only can endogenous attention modulate the gradient, but that exogenous attention can override the effects of endogenous attention.

The experiment of Figure 5 was designed to test exactly whether endogenous attention has an influence on the gradient by pitting the gradient effects arising from the presentation of two isoluminant colored primers against one another, and having subjects attend one or the other primers. Here the gradient that arises from the primers is presumably modulated in a top-down fashion by endogenous attention, resulting in motion away from the attended location. The experiment outlined in Figure 6 was a further test of the modulatory effect of endogenous attention's influence on the illusion. Four priming objects initially appear. A brief transient occurred with one of the objects to signal which primer the subject was to endogenously track as the objects moved counterclockwise through time and space. The presentation of a probe line between a tracked and non-tracked object resulted in the perception of motion primarily away from the tracked item. This again suggests that endogenous attention is capable of influencing bottom-up aspects of the illusion.

In the display of Figure 7, a line is presented and after some time it is extinguished leaving only a part of the line. This observation poses a problem for the original gradient theory which talks about the acceleration of signals but failed to make any claims regarding the duration of signal transmission. As was apparent from the work of Miyauchi et al. (1992), the gradient arose from baseline around display items like a mound and returns to baseline in a similar fashion. Considering the duration of such an effect at any distance from the mound's center leads one to conclude that the spatial gradient not only accelerates the initial arrival of signals but transmits those signals for a longer period of time the closer they are to the gradient's center. Schmidt and Klein (1997; Schmidt & Pylyshyn, 1994) proposed this extension to the gradient account to explain this post-cueing reversal of the illusion. They also proposed it independently to explain the TMP illusion which will be elaborated shortly. To recap this "extended gradient account" explanation, the initial presentation of the line in Figure 7 causes a gradient to arise around entire display objects, evenly strongly across the line's extent. Extinguishing the line but leaving the primer at one end causes the sustained component of dissipating signals nearby the primer to continue to be modulated by the primer's gradient (i.e., to be transmitted for a longer duration) than signals arising more distally. The resulting input to motion detectors would be reverse to that of the simple illusion resulting in motion toward the remaining primer.

The finding that a collision is experienced in the double priming paradigm (see Figure 8) is accommodated by the gradient account's hypothesis that gradients arise around each of the primers. The presentation of a probe line between the primers taps the strongest parts of both gradients resulting in motion away from each of the primers colliding centrally. The introduction of a temporal delay between the presentation of the primers (see Figure 9) results in net motion away from the later-appearing primer. As the gradient mound for the initial primer builds, motion becomes away from it in a subsequent probe. The presentation of a second primer causes a new gradient to arise which has the added benefit of attracting attention exogenously causing an imbalance in the modulatory effect of the two gradient mounds, such that the latter is stronger and exerts more influence on the resulting motion percept as measured by the probe line.

The configuration outlined in Figure 10 presents a challenge to the simple gradient theory. This is a modification of the double-primer paradigm in which the color of one of the primers and the bar are the same. Under such circumstances motion is always away from the identically colored primer regardless of whether it appeared temporally second or first. In order to accommodate this finding, the gradient account must either hypothesize a separate mechanism is at work, or make the prediction that intraattribute priming (an effect of the primer and probe within the same attribute dimension -- e.g., color) is substantially stronger and more influential in the double-priming paradigm compared to the simple form of the illusion. Recall that von Grünau and Faubert (1992, 1994) reported that for the simple ILM, intraattribute priming is stronger than interattribute priming, so this is not an unfeasible scenario. Furthermore, the finding that the double-primer paradigm is more sensitive to early acting system mechanisms (i.e., monoptic input - Faubert & von Grünau, 1995) suggests that such mechanisms may dominate this form of the illusion. Further research is required to investigate these issues. Suffice it for now to hypothesize that intraatribute dimensions are integrated before interattribute dimensions (von Grünau & Faubert, 1992, 1994)

The result of Figure 11, that the addition of a flanking bar causes motion to be experienced in one primary direction is the focus of a pair of experiments and discussion in a later chapter. This example presents a problem for gradient theories if the collision normally experienced between the two primers ceases to occur with the addition of the flanking bar (Downing & Treisman, 1997; Faubert & von Grünau, 1992, 1994). As will be demonstrated, although the collision does not disappear on every trial, it is strongly overridden by the dominant motion direction percept in the display. This, and other work with the illusion (Experiment 9 this paper; Faubert, 1996) leads to the hypothesis that there is an integration of motion direction signals across the motion system (as in motion coherence paradigms) to derive a net motion effect and it is the output of this integration that determines the overall motion direction in the display (see Sutherland, 1961 for an early version of this ratio principle and Mather, 1980 and Mather and Moulden, 1980 for an elaboration; Williams & Sekuler, 1984). In the example of Figure 12, when the motion detector output is once again balanced in terms of the proportion of signals indicating various vectors, the collision experience once again is dominant as predicted by the gradient account.

The finding that the direction of motion within the probe line reverses at large primer-probe distance separations can be attributed to center-surround mechanisms of the motion detection system (Loomis & Nakayama, 1973; Kim & Wilson, 1997; Murakami & Shimojo, 1995; Norman et al., 1996). Although Steinman et al. (1995) regarded the center-surround antagonism as a property of visual attention (under the acceptance that the gradient was a gradient of attention), the fact that motion detectors show this effect while many attentional effects do not, suggests that it may be characterized better at a more basic level. Because the motion detection system is a component of gradient theories, they inherit properties of that system such as center-surround antagonism and motion integration effects.

In Figures 14, 15 and 16 three different forms of the TMP illusion are illustrated. The extended gradient model, in which it is proposed that the gradient speeds and temporally extends signal transmission along a spatial gradient from display objects, accounts for the fact that if a line is only briefly flashed, motion is experienced first away from the primer location and then back toward the primer location (Schmidt & Klein, 1997). The explanation for this illusion is similar to a combination of the simple form of the illusion (Figure 1) and the post-cueing illusion (Figure 7).

The examples presented in Figures 15 and 16 require careful consideration. The extended gradient model suggests that if a dot is successively displaced at an appropriate speed away from the primer location (see Figure 15), then it might be possible because of the gradient's modulatory effect on the duration of signal transmission, for signals nearby the primer location to be in the process of being transmitted, while signals arising far from the primer have already reached the motion detection system and ceased to be transmitted. The percept of motion predicted by such an occurrence would be motion away from the primer due to the accelerative effect of the gradient, followed by motion back toward the primer as a result of signals distant to the primer turning off before signals close to the primer.

If a dot is moving at an appropriate speed toward the primer location (see Figure 16), then the extended model predicts that because of the accelerative effects of the gradient, signals nearest to the primer could reach the motion detection system before distant signals, even though the more distant signals began being transmitted earlier. Furthermore, because the duration of signal transmission is temporally extended along the spatial gradient, the distant signals could be expected to cease before signals arising nearby the primer, resulting in a subsequent percept of motion back toward the cued location. The extended model made a number of predictions about the robustness of the TMP illusion under various presentation conditions, and these predictions were tested and supported (see Schmidt & Klein, 1997 for details).

The examples of Figure 17 are accommodated by the extended gradient account which suggests that motion should be away from the primer which modulates the greatest proportion of probe signals. The spatial proximity of the probe to the left primer in each of these cases guarantees that this primer will exert more influence over the probe than will the competing primer on the right. More of the probe bar's signals arising from nearby the left primer will signal motion away from it than will signals from nearby the right primer. Furthermore, the signals nearby the left primer are stronger than those arising from the right, again overriding these weaker, minority signals. The result is motion away from the left primer.

The extended gradient explanation of ILM is further informed by the example of Figure 17c which suggests that spatial integration is a more important factor than interattribute priming. Faubert and von Grünau (1995) found that attribute priming is a powerful method of manipulating the illusory motion direction perceived. However, the example of Figure 17c would suggest that attribute priming is less important than spatial contiguity of the primer and probe. Although there may be a modulatory gradient in the color dimension surrounding the primers of Figure 17c, the proximity of the primer on the left and the probe bar (that is the spatial integration of the visual signals) is a more important determinant of the direction of perceived motion. Extending the probe so that it is equal on the spatial contiguity dimension however, will cause the direction of motion to reverse because under such circumstances the color gradient's effects will be influential.

The example of Figure 17b provides the gradient account with a slight challenge. After presenting priming boxes as outline figures, one of the box edges disappears as the rest of the probe figure is drawn. There is no spatial contiguity advantage for one primer over the other here, nor is there an attribute priming effect. Based on the extended gradient account one possible explanation is that the offset of the left primer's edge which is speeded relative to the rest of the probe bar is sufficient to grant it prior entry. One might hypothesize based on this explanation that this form of the illusion could be weak and susceptible to various stimulus manipulations.

The examples presented in Figures 18a and 21 are counterexamples to the gradient hypothesis. One might expect that gradients surround both of the primers with a larger gradient (in terms of spatial area) surrounding the large vertical priming bar. As such, it would be expected that motion would be away from this larger primer, or that at the least, a collision would be experienced within the probe. The result of this configuration for many observers however, is motion within the probe completely away from the smaller primer. The gradient account fails to supply a feasible explanation of this stimulus configuration.

The other examples of Figure 18 do not pose a problem for gradient theory. In Figure 18b, the majority of motion signals in the probe bar are away from the left primer, resulting in a motion percept in that direction. In Figure 18c, assuming that the gradient radiates outwards perpendicular to the primer, conflicting direction signals would arise from around the concavity of the primer on the right. Hence motion signals in the probe would be converging inwards, with convergence being a factor of the deepness of the concavity. The introduction of converging (and conflicting) motion signals would make the motion direction unclear.

The gradient hypothesis does not supply an obvious explanation for the display presented in Figure 19. A rather speculative explanation is that separate gradient representations for the two colors are maintained and that motion direction is determined at the point where the two spatial gradients are integrated. In Figure 19a, no motion is experienced because the integration of the two colour spatial gradients results in no difference. A collision or a result of no net motion might be expected, and is experienced, if this figure is presented all in the same color. In Figure 19b, the integration of the two color maps results in motion away from the primer on the right. There is a spatial overlap of primer and probe signals on the left side of the image, resulting in no motion away from the primer on the left. Spatial integration on the right side of the image results in a primer-probe pair, with the primer and the probe presented on different spatial maps within the same attribute (color). A gradient prediction that will go untested in the current work suggests that there could be some overlap between the probe and the primer on the right without devastating the resulting motion direction effect. The gradient account would predict that as long as the proportion of direction signals on the right side is greater than those on the on the left, leftwards motion would ensue.

The result of no motion in the probe item to the right of the large vertical rectangle in Figure 20b, as reported by Tse et al. (1998) directly challenges gradient theory predictions of motion away from the primer, even within this probe item. The gradient account prediction is that motion would be expected within the probe regardless of the presence of an occluder (Figure 20a) or the presence of boundaries. Although boundaries and gaps would be expected to weaken the gradient percept because it would weaken motion integration across the intervening space and decrease the proportion of signals indicating motion away from the primer. Such boundaries would not be expected to nullify motion within the distant portion of the probe. This issue is further examined in Experiment 6.

The experiment portrayed in Figure 22 demonstrated that gradients can exist at multiple locations simultaneously resulting in ILM away from any of numerous priming dots. There is however a capacity limit of between 5 and 7 display locations which has been attributed to the requirement of a limited set of visual indexes in order to individuate instances of the illusion (see Schmidt et al., 1998). This should not be taken as a limitation in the number of gradients that can exist simultaneously, but rather as a limit in the processes used to access the gradient representation. Further evidence that there were separate mounds of facilitation as opposed to an annulus comes from the finding that when the probe line was presented with one end between two of the priming dots, inwards motion was less frequent than when the end of the probe line appeared near the location of the a dot.

The multiple location ILM display of Figure 23 can similarly be explained by the generation of multiple small gradients upon presentation of the primer display. When these primers are replaced with lines, motion away from any one can be experienced at a fine spatial scale when focally attended. When the display as a whole is attended, motion is experienced globally in a direction consistent with the illusion. This global motion percept is accounted for by the integration across a large spatial scale, of multiple motion direction signals from the individual simple presentations of the illusion. Similar integration mechanisms are likely to account for the finding that the addition of a flanking bar weakens the illusory percept of a collision as in the example of Figure 11. More will be presented on this in a later chapter.

The remaining phenomenology discussed in Chapter 1 can be explained by applying the explanations of gradient theories from the examples delineated. The next section summarizes the assumptions of a gradient theory that need to be made in order to accommodate the examples presented. I take this summarization as the theory under test in the current thesis and will refer to it as the gradient model or the extended gradient model.

## ORIGINAL AND EXTENDED GRADIENT HYPOTHESES

In summary, several extensions to the original gradient model of Hikosaka et al. (1991, 1993a, 1993b, 1993c) have been made, and all of these extensions will be adopted here to provide the model under investigation.

As outlined above, several groups of researchers have argued that there is an automatic component to ILM and an additional attentional effect (Hecht, 1995; Kawahara et al., 1996; McColl & Schmidt, 1995; Schmidt et al., 1998; von Grünau, Dubé & Kwas, 1994, 1996). The automatic component operates in a spatially parallel fashion and is responsible for the ability to elicit ILM at multiple simultaneous locations (Schmidt et al., 1998). There are multiple local gradient maxima, and motion can be experienced away from each given the appropriately placed probe line.

Schmidt and Klein (1997; Schmidt & Pylyshyn, 1994) have proposed that the spatial gradient modulates not only the speed of signal arrival, but also the duration of signal transmission. The closer a probe is to a primer location, the faster its signals reach further processing centers, and the longer its signals are transmitted to those centers.

The attentional effect on the gradient is both bottom-up, elicited by exogenous cueing manipulations (such as transients produced by onsets and offsets) and top-down, elicited by endogenous cueing manipulations (Hikosaka et al., 1993b). The latter may be overridden by the former (Hikosaka et al., 1993a, 1993b) suggesting that exogenous attention may have a greater influence on the illusion than endogenous attention. In any case, attention is assumed to bestow a benefit in processing to information at the attended location.

Steinman et al. (1995) have extended the model to note that ILM phenomenology has an excitatory center and an inhibitory surround, just as studies of motion detectors have revealed (Loomis & Nakayama, 1973; Kim & Wilson, 1997; Murakami & Shimojo, 1995; Norman et al., 1996).

Studies of different combinations of primer and probe attributes (von Grünau & Faubert, 1992, 1994) have revealed that although an illusion can occur as the result of the mixing of attributes, indicating a late stage of signal integration, the strength or quality of the motion produced is most dependent on the attribute of the probe bar. Intraattribute ILM is generally stronger than interattribute ILM suggesting that multiple spatial maps may occur with integration within each map before signals are integrated across attributes and maps. Spatial contiguity even between attributes seems to be an especially powerful factor in this integration. The finding that in the double-primer paradigm when one of the primers and the probe share the same color, motion is away from that like-colored primer indicates that within attribute priming for color may be especially important (Faubert & von Grünau, 1992, 1995).

Studies in which various components of the illusion have been selectively delivered to different eyes have revealed that the eye of origin is not particularly important for the simple version of the illusion. This finding has led to the conclusion that the locus of the motion experience is probably cortical (Hikosaka et al., 1993a). Eye of origin does matter in the more sensitive double-primer paradigm, implicating that there is an early source of signal integration as well as later sources. This same finding suggests that multiple motion detection sites may be involved.

Several studies suggest that the output of the motion detection system is integrated into a coherent motion direction. The clearest example of this is Faubert's (1996) demonstration that global motion can be produced from the aggregate presentation of many simple forms of the illusion. Motion counter to the majority motion signal in the display is also made less effective, presumably because of motion signal integration across space (Schmidt, unpublished results).

The author proposes that the spatial gradient be conceptualized as representing the visual scene, akin to a 2D sketch (Marr, 1980) or feature map (Cave & Wolfe, 1990; Koch & Ullman, 1985; Treisman & Gelade, 1980). There may be several intermediate maps specifically representing different feature dimensions (i.e., color, luminance, stereo, etc.) which are later integrated before sending their outputs to visual motion detectors. The processes that modulate signal transmission top-down in the visual system do so in a local fashion by operating on these intermediate spatial representations. Any modulation of signal transmission that takes place at the level of these representations is prior to the operation or modulation of those signals at subsequent levels of processing in the visual system. Such subsequent levels of processing could include other spatial maps, the merging or integration of signals from two or more spatial representations, or the motion detector stage itself.

# CHAPTER 3: PROPOSED HIGH-LEVEL EXPLANATIONS

In the past few years several high-level accounts have been proposed to explain ILM phenomena. An account presented by Downing and Treisman (1995, 1997), which is not necessarily an alternative to the gradient account, suggests that the illusion is classical apparent motion augmented with an impletion process that infers and fills in what logically must have happened in the display. Much of the empirical work presented in later chapters provides an examination of the arguments made on behalf of the impletion account. A related account proposed by Tse and Cavanagh (1995; Tse, Cavanagh & Nakayama, 1996, 1998) proposes that the simple form of the illusion is an example of a broader class of phenomena that they have labeled "morphing motion" (Tse & Cavanagh, 1995), and later renamed Transformational Apparent Motion (TAM; Tse, Cavanagh & Nakayama, 1996, 1998). This account has met with much success at accounting for many ILM phenomena, even supplying example stimuli that are difficult to explain using the extended gradient account.

The apparent motion impletion account was introduced by Downing and Treisman (1997) through the presentation of a number of experiments that they took as problematic for gradient accounts of ILM. This chapter will first present these experiments and explain why they are or are not problematic for gradient theories. The phenomena outlined in Chapter 1 will then be explained by the application of the apparent motion impletion hypothesis. A similar approach follows for TAM, the other high-level proposed alternative explanation for ILM. Major criticisms and discussions of possible revisions to these accounts based on the empirical findings in the literature and presented in later chapters will be reserved for the summary and discussion in Chapter 9.

## APPARENT MOTION IMPLETION

Recently, Downing and Treisman (1995, 1997) have presented what they view as an alternative to gradient explanations of ILM and related phenomena. Although Downing and Treisman often treat the terms "attention" and "gradient" synonomously leading one to suspect that the target of their work is Hikosaka et al.'s (1993a) simple gradient account, and not gradient accounts in general, their claim is that ILM is *not* caused by the temporal asynchrony of signals arriving at motion detectors, which makes their thesis address the entire class of gradient models which propose that gradient-modulated signals are transmitted to a motion detection system.

Downing and Treisman's alternative proposal is that the illusion is better explained as a byproduct of a classical apparent motion impletion process. They define classical apparent motion "... as an illusory impression of motion induced between two stimuli presented in succession or alternation at different locations" (page 768), and note that: "If the time interval and the distance between the two presentations are within the appropriate ranges, observers report seeing one object jumping through space, rather than two independent perceptual events" (page 768). Downing and Treisman argue that a "... filling-in process known as impletion ... reflects an implicit inference made by the visual system, which interprets ambiguous stimuli in terms of the most likely real-world state of affairs" (page 768).

For ILM, it is proposed that the visual system interprets the successive primer and the probe line as a single object traveling in classical apparent motion, and that an impletion process concludes that for Figure 26 "... the dot (small square) jumps the minimal distance and then grows in length from there. We suggest that it is this impletion transformation that is seen as the illusory line motion, rather than the firing of motion detectors resulting from an attention-induced asynchrony" (page 769).

## EXPLANATION OF PHENOMENOLOGY

The fact that an illusory impression of motion, identical to the experience of ILM, can occur as the result of the simple presentation of a single object (i.e., gamma motion) presents the apparent motion impletion explanation of ILM with a problem. With such a stimulus there is no need for the implicit inference of motion in the scene, and there is clearly no need for motion within the item presented. Furthermore, the finding that gamma motion can occur for ground as well as figure (Bartley, 1936) demonstrates that objects need not even be the target of the motion experience.

For the simple version of the illusion in which the primer remains upon the presentation of the probe line (the majority of cases), Downing and Treisman (1997) argue that the impletion system automatically interprets this as "... if one object was occluding another identical one and then moved to a new location, unmasking the previously occluded object" (page 778). A similar explanation would apply to the stimulus configuration of Figure 2, although one might ask how it is that impletion survives long ISIs between the presentation of the primer and the probe. Elsewhere Downing and Treisman (1997) wish to draw parallels between apparent motion and ILM, claiming that they act similarly across spatial and temporal parameters. However, it is well known that apparent motion generally breaks down with long, blank, ISIs. The apparent motion of random dot patterns is undetectable with ISIs of 100 msec, (Baker & Braddick, 1985) and 300-500 msec is enough to time to remove the sensation of motion for long-range displacement (Kolers, 1972). Hence, one would assume that impletion, which is reportedly dependent on apparent motion, should break down with such ISIs as well. ILM however, survives long, blank, ISIs with little degradation (Hikosaka et al., 1993a; Kawahara et al., 1997; Schmidt, 1996).

An impletion account of the stimulus configuration presented in Figure 3 might be that the probe bar is taken to be the same object as the primer on the right which briefly disappears (because it is occluded?) before reappearing and growing to merge with the primer on the left. Downing and Treisman (1997) address the case of stimulus offsets used by Hikosaka et al. (1993a) by saying: "Note that these conditions are even more favorable for apparent motion than those using an onset cue: The first stimulus appears, then disappears before the second appears. This sequence is consistent with a single object appearing and jumping to a new location" (page 777-778). Presumably they were ignoring the primer that was present throughout the trial and the fact that there really is no spatial displacement involved in Hikosaka et al.'s experiments. An equally plausible prediction of the impletion account, which follows from its explanation of the simple form of the illusion, is that the remaining primer expanded. This however, would produce motion within the probe that is opposite to that which is experienced.

The impletion account naturally describes the finding of the post-cueing version of ILM presented in Figure 7, and the TMP illusion as elicited by the brief presentation of a line both preceded and followed by a primer (see Figure 14). In both these cases, the probe could be said to be expanding or contracting. It also provides a good account of motion within double-primer displays in which one of the primers and the probe line share the same attribute (see Figure 10), and the case where a flanking bar causes a global percept of motion (see Figure 11).

The impletion account may be able to describe the motion experienced in Figure 17, though not without making further assumptions about how impletion works. In Figure 17c for instance, the account must assume that color is inconsequential to the impletion mechanism. Similarly, it must make assumptions in Figure 17d and for the stimuli of Figures 18, 19 and 20, regarding how the impletion mechanism infers that the probe is part of the primer away from which motion is directed.

Impletion's ability to explain a simple collision in the double-primer displays of Figures 8 and 12 (and similarly Figures 27 and 28) is handled by Downing and Treisman (1997) in their statement: "This result, however, is also consistent with an impletion account. It is known that apparent motion is readily seen to split or converge in displays for which there is no strict one-to-one mapping between successive stimuli (e.g., Kolers, 1972)" (page 770). Although apparent motion does this, one might question what reason there is for impletion to infer that the probe objects transform in the way that they do? What likely real world situation exists which would cause a retinal projection of these sorts? Simply because apparent motion has been found to cause motion that splits or converges under conditions such as these does not mean that a process which interprets these stimuli in terms of real world situations would be expected to behave similarly.

A simple impletion account for the results of the configuration presented in Figure 4 is difficult to come by. One might argue that impletion would predict that motion should collide in this situation due to Downing and Treisman's (1997) argument that apparent motion (and impletion) causes items to split and converge when faced with ambiguous situations. On the other hand, later claims in their paper suggest that attention is drawn to the flashed object and this biases impletion to conclude that this most recently attended object undergoes a transformation. A similar explanation applies to the configuration presented in Figure 5, although this time it is endogenous rather than exogenous attention. In both cases (as with the stimulus configuration of Figure 3) the impletion account tells us nothing of what is going on with the second primer that presumably did not undergo a transformation. Is it occluded by the object that did undergo a transformation, or does become a part of that object?

The impletion account seems to provide some rather unsatisfyingly *post-hoc* explanations regarding the stimulus configuration presented in Figure 6, which is even less appealing when applied to a similar set of displays used by Downing and Treisman (1997) in their Experiments 2A and 2B (see Figures 29 and 30 respectively). Even though in Experiment 2A (see Figure 29) the primer does not disappear on presentation of the probe, the impletion claim is that these two objects (the circle primer and its identical circle probe) are actually part of a single object undergoing apparent motion from the location of the attended circle toward the location of opposite circle. As discussed earlier, Downing and

Treisman (1997) address the fact that ILM occurs whether or not the primer is extinguished upon probe presentation by suggesting that in the case where the primer remains throughout the duration of the probe line, the impletion system automatically interprets this as "... if one object was occluding another identical one and then moved to a new location, unmasking the previously occluded object" (page 778). However, an impletion process that interprets such an "ambiguous display in terms of the most likely real-world state of affairs" (page 768), should more naturally distinguish each of the moving dots and the fixation dot as distinct objects. Arguably, the appearance of the probe at the fixation circle's position could just as easily be interpreted as the fixation object (which had been present at this point for several seconds) undergoing a single transformation.

In the case of Experiment 2B where the probe is simply a circle identical to the moving peripheral dots (see Figure 30) it seems that a more likely real world state of affairs is that a simple size change would be perceived, such as when an object moves closer or further away from the viewer. What is more likely: 1) a circle object happens to be occluding another circle object identical to it, and one of the two jumps through intervening empty space seven times its size and precisely occludes another smaller circle object that happened to be occupying that spot, or 2) a single object in the middle of the display moves closer thereby increasing the size of its retinal projection? The impletion account requires the first option presented above.

The role of temporal delays between primers modifying the collision point of double-primer displays as presented in Figure 9 is not accounted for by impletion as it currently is presented, nor is the reversal of motion within the bar given large primer-probe separations (see Figure 13). Impletion is also at a loss at explaining the forms of the TMP illusion illustrated in Figures 15 and 16, where motion away from and then back toward the primer is experienced whether a dot is drawn quickly toward or quickly away from the primer.

There is no reason for an impletion account to expect motion within a simple luminance gradient (Figure 24) and it does not account for von Grünau et al.'s (1995) finding that ILM can be directly affected by the use of a luminance gradient probe. Furthermore, impletion cannot account for the precise manipulations that von Grünau et al. (1996) carried out in order to derive an estimate of the degree to which an exogenous cue accelerates visual system signal transmission. It is also unclear how impletion can accommodate the finding that multiple presentations of the illusion can cause a percept of global motion when on the impletion account, there is no asynchrony of neural firing at motion detectors (see Figure 23).

## TRANSFORMATIONAL APPARENT MOTION (MORPHING MOTION)

Tse and Cavanagh (1995; Tse, Cavanagh & Nakayama, 1996; 1998) present an account of ILM-related phenomena that is similar to Downing and Treisman's (1995; 1997) impletion explanation in that it too claims that ILM is a high-level effect of the visual system that is based on a transformation of stimuli from one time frame to the next. Tse et al. (1998) note that in a typical apparent motion display one shape disappears at one location and a second shape then appears elsewhere. With ILM-related phenomena however, it is common for the second shape to overlap the first in location and time and the latter is seen as an extension, growth or transformation of the first (hence the name Transformational Apparent Motion, or TAM). It is claimed that both TAM and standard (translational or rotational) forms of apparent motion are created from the same high-level motion processing mechanism.

Tse et al. (1998) claim that the use of overlapping elements reveals a predominance of figural effects over proximity effects which cannot be seen in traditional apparent motion displays. According to this account, in the high-level motion processing pathway it is parsed figures that are matched to parsed figures from one view to the next, and in some cases proximity between these figures is not the dominant matching cue. Tse et al. (1998) state: "By "parsed figures," we mean the attended portions of the completed segmentation which would occur with unlimited viewing of each individual frame" (page 5). "Whereas standard apparent motion is generally insensitive to shape and color constraints so long as the two stimuli presented remain within the optimal range of spatio-temporal offsets (see, e.g., Cavanagh, Arguin, & von Grünau, 1989; or Kolers & von Grünau, 1976), Transformational Apparent Motion *is* sensitive to such constraints, because these are used by the parser to disambiguate figures in scenes that can only be ambiguously parsed" (Tse et al., 1998, page 6, italics in the original). Motion perception is assumed to follow this critical stage of figural completion, parsing and matching.

Illusory line motion is presented as an example of the more general class of TAM. The stimulus configuration presented in Figure 10 is taken as evidence that more is going on with the illusion than a gradient. Recall that Faubert and von Grünau (1992; 1995) presented two primers of different colors and then presented a bridging line of the same color as one of the priming spots. Unlike other cases where two competing primers are presented, motion is not inwards resulting in a collision, but instead motion seems invariably to begin only from the spot that is the same color as the probe. Faubert and von Grünau found this to be the case even if the odd colored primer was presented temporally later than the primer that was the same color as the probe. This is taken by Tse et al. (1998) as evidence that a parsing mechanism is operating in which the similar color of the primer and probe causes them to be grouped as a single object regardless of the presence or dynamics of the other primer.

Tse et al. (1998) examined a number of competing cue stimulus configurations and determined what they claim is a set of guiding principles which make sense of how TAM operates. These rules are quite similar to Gestalt principles of grouping.

## PROPOSED PRINCIPLES OF TAM

One principle discussed by Tse et al. (1998) is that of spatial contiguity. The idea is that the spatial relationship between the probe and primer is an important factor in determining the direction of motion that will be experienced in the probe (see also Kanizsa 1951, 1979 for the use of this rule). If the probe is spatially contiguous with one of the primers then motion will be frequently experienced away from that primer (see Figure 17a). This is even the case when color information is in conflict with contiguity information (see Figure 17c). Examples of this principle from Tse et al. (1998) are presented in Figure 17. In general then, it appears that the matching operator matches successive parsed figures that overlap in space-time as instances of the same object, perhaps regardless of other properties such as color.

A second quality identified by Tse et al. (1998) as important for determining the behaviour of TAM is the role of contour continuity and deep concavities. As first reported by Kanizsa (1951; 1979) motion may more frequently be experienced when the primer and probe form a smooth continuous contour with one another than when there is an abrupt edge between the two. This holds even when there is an intervening space between the primer and probe. Although with the simple form of the illusion, motion is frequently experienced in the probe regardless of this factor, when two primers are competing this property seems to exert a greater effect. Tse et al. (1998) present the examples of Figure 18 as demonstrations of this principle.

A third principle of TAM is that it is figure-centered rather than being image-centered. According to Tse et al. (1998), TAM operates on figural changes of shape, not image-centered changes in shape. Hence in Figure 19 when the primers are partially occluded (Figure 19a) no motion is experienced within the probe. However, when the probe occludes only one of the primers and abuts the other (Figure 19b), motion is away from the primer that is abutted (Tse et al., 1998). Although there is no overall change in shape between these two presentations, there is a change in the motion experienced that is dependent on the figural parsing of the sequence. Note that in this latter example the claim is that the probe bar is part of the primer on the right even though it is of a different color than the primer, and even though it is not continuous with this contour.

In support of their notion of TAM operating on figural parsing, Tse et al. (1998) report that motion survives occlusion, but when scene elements are arranged such that distinct figures appear in the same configuration then only figures spatially associated with a primer show motion. Hence in Figure 20a, motion is experienced within the entire probe line away from the primer, even though there is an occluding object. However, in Figure 20b it is reported that there is no motion within the probe object that is presented off to the right of the large rectangle, while there is motion within the object that is spatially contiguous with the primer. Tse et al. (1998) conclude that the perception of TAM was transmitted behind an occluder, but the failure of TAM to transmit behind the occluder when there are distinct items involved indicates that amodal surface completion occurs before the perception of TAM (more on this topic will be presented in Chapter 7).

As a final example, Tse et al. (1998) presented a stimulus configuration which combines several principles of TAM in order to override motion energy accounts of motion direction. This display, which is reproduced in Figure 21, is an extension of the stimulus configuration presented in Figure 18a. Smooth contours on the left side of the probe continue the left primer. On the right side of the display the probe is smaller than the primer and is not continuous with it, rather, there are concavities between the right primer and probe deterring them from being grouped. Motion is away from the side with the smaller primer that is continuous with the probe. This example demonstrates that more is involved than the matching of luminance centroids, otherwise the large centroid on the left from frame 1 would be matched with a large centroid toward the center on frame 2, resulting in net motion toward the left. As discussed in Chapter 2, this example is problematic for the gradient account.

## EXPLANATION OF PHENOMENOLOGY

As with the impletion account, the fact that gamma motion can occur as the result of the simple presentation of a single object is problematic for TAM. There is no need for parsing and matching to occur with such a stimulus because there is nothing to match over time (see also Figure 24). Consequently there is no reason on the TAM account, for a transformation to occur in the display. Additionally, the finding that motion can occur within ground as well as within figure (Bartley, 1936) prevents TAM from being a comprehensive account of gamma movement.

TAM has no difficulty explaining the simple illusion as presented in Figure 1, or other simple stimulus configurations such as are presented in Figures 7, 11, 14 and 22.

Why collisions (e.g., Figure 8) would be experienced on the TAM account is not entirely clear. Certainly there is a set of transformations involved, but the parser clearly isn't matching a single item in one scene to a single item in the next. Rather than removing ambiguities (as is the role of the parsing and matching mechanism according to Tse et al., 1998) in the case of Figures 8, 9,12, 27 and 28 it would appear that the parsing mechanism is accepting the ambiguity and relaying an impossible percept -- collision of two objects growing or extending into a single object. It is only when other figural information exists that further informs the parser that ambiguity would seem to be removed.

Little is said about the ability of TAM to survive long temporal lapses as in Figure 2, or spatial gaps as in Figures 26, 27 and 28. One might suspect that completion mechanisms, which are claimed to occur before the parser acts (see the explanation of Figure 20) complete these gaps before the matching stage occurs. This is speculative however, given the results of the Experiments that will be presented in Chapter 7.

In the configuration of Figure 3, presumably the probe is experienced as an extension of the item that has recently disappeared, though is difficult to know why the scene parser doesn't match it with the primer that has remained. Tse et al. (1998) have defined parsing as the attended portions of the completed segmentation which would occur with unlimited viewing of each individual frame, which suggests that the line would be matched with the remaining primer. However, which direction motion occurs in this display is temporally dependent. As the temporal window after the disappearance of the primer on the right increases, motion is more likely to be away from the primer on the left.

Exogenous attentional cues (such as the onsets in Figures 4 and 9) presumably, like endogenous attention (Figures 5 and 6) can act to direct the parser to specific objects early in a sequence, which are then matched as the more likely source of growth, extension or transformation.

TAM clearly cannot explain why motion would be experienced toward the primer given a suitable distance between the primer and probe (Figure 13), though it may invoke this as a property of the motion detection system. As such, one might argue that the transformation in TAM, which is qualitatively identical to this reversed motion, is also derived by the motion detection system.

TAM is also unable to account for the finding that a luminance bar alone is sufficient to cause illusory motion (Figure 24) and the fact that this stimulus interacts with the illusion (von Grünau, Saikali & Faubert, 1995).

The two versions of the TMP illusion that are generated when a simple moving dot is presented toward or away from the cue (Figures 15 and 16) also seems to be unexplained by the TAM account.

Finally, the global motion results of Faubert (1996), to be accommodated by the TAM account, would require a very sophisticated parser and matcher. Such a mechanism would be required to parse and match each of the many instance of the illusion presented.

## SUMMARY

In closing, the proposed high-level explanations of ILM present some interesting stimulus configurations for the gradient account to accommodate, though they seem unable to make sense of all of the data collected to date. Like most high-level versus low-level arguments in perception, the correct account is likely to be a combination. Human observers report late in processing, after both low-level and high-level processes have operated making it such that the latter generally have some influence over responding. Similarly, high-level processes cannot operate without the prior influence of earlier-acting perceptual organization mechanisms, making it such that they too generally have some influence over responding.

# CHAPTER 4: PROPOSED LOW-LEVEL EXPLANATIONS

Several low-level alternative models have been proposed to explain ILM phenomena. In each case, the proponents refer to the models as low-level though they may involve what others deem as both low and high-level motion processes. This chapter briefly introduces the accounts proposed by Zanker (1997) and Baloch and Grossberg (1997), and examines how they explain the basic phenomena outlined in Chapter 1.

## ZANKER'S SIMPLE MOTION DETECTOR ACCOUNT

Zanker (1996) took offense to the entire endeavor of Hikosaka et al. (1991, 1993b) and von Grünau et al. (1994, 1995, 1996). He states: "This effect referred to as 'motion induction', has been attributed to mechanisms which 'speed up' the signals in regions of the visual field where the subjects pay attention... This explanation relates directly to our knowledge about the effects of attention, but a low-level explanation in terms of simple motion detection mechanisms for this type of stimulation should be considered before invoking such high-level effects" (page 1953). According to Zanker (1996) the crucial aspect of the stimulus to consider in determining the direction of motion is the centroids of the intensity distributions between frames. This centroid shifts in the simple illusion (see Figure 1) from the center of the primer to the center of the probe causing motion detectors to signal motion in the direction of the shift. According to Zanker, "the shift of the intensity profile could be extracted by any luminance-based mechanism, and similarly the edges of the dot and bar could be matched by a feature-tracking mechanism (Ullman, 1981), leading to the same perceived illusion. Thus, the basic phenomenon of motion induction can be explained without the *necessity* to assume changes in temporal processing such as speeding up signals at certain locations" (italics were present in the original text, page 1953).

A closer look at these claims reveals some initial problems. First, the gradient account creators did consider simple motion detector explanations of the illusion, but as will be demonstrated, they do not suffice in a number of circumstances. Centroid shifts over time allow detectors to report on the direction of motion, but they do not provide for the phenomenology of even the simplest form of the illusion, contra to Zanker's claims above. Centroid accounts cannot explain why motion is experienced within the probe bar as if it were being drawn on over time. Zanker's response to this point in his general discussion is: "The model clearly requires further elaboration... The localization of motion signals, not only in motion induction but also for simple stimuli, is clearly an important question for future research" (page 1958).

Zanker (1997) realized that his simple account could not explain all stimulus differences found with the illusion. For instance in the work of von Grünau et al. (1996) a search array populated with oriented lines is displayed and a probe line is presented between two primers which differ in orientation. Motion is experienced away from the primer that is of a different orientation from other display distractors - an orientation singleton. The response of a simple motion detector for such a configuration would be balanced with respect to the two priming stimuli and the centroid model would predict two conflicting outputs for motion direction because there were two shifts in the centroids of the intensity profile toward the center of the probe bar. Zanker claims: "Again, effects of attention on the temporal processing are not the simplest way to explain these experimental data... The influence of a pre-attentive pop-out target on the induced motion effect is simulated by a local change in gain, in which the strength of the motion detector input is modulated by some sort of feature contrast, which is here the difference in local orientation" (page 1954). However, Zanker's explanation is no better than the attentional account which claims that an attentional effect is providing the same sort of top-down modulation. Whether Zanker provides a "simpler" explanation is questionable.

## EXPLANATION OF PHENOMENOLOGY

Further problems are provided for the account by some of the basic phenomenology. The case of simple gamma motion produced by the simultaneous presentation of a single object is problematic for a centroid shift explanation unless the assumption is made that arrival times are at the heart of the effect. Under such an assumption an argument might be made that there is a shift in the luminance centroid for the portion of the figure that arrives earlier in time than other portions of the figure. Such an assumption could allow the account to explain the luminance gradient stimulus of Figure 25. The phenomenology of the motion experience is still unexplained.

It is not clear how the account can handle the finding that ILM survives primer-probe ISIs (see Figure 2) as long as 900 msec (Hikosaka et al., 1993a; Schmidt, 1996). Unmodulated, motion mechanisms seem only to last for at most a few hundred milliseconds (Baker & Braddick, 1985; Kolers, 1972). Motion away from recently removed display objects also causes a problem for this account (see Figure 3). Zanker suggests that this sort of an effect might be accounted for by second-order (non-luminance-defined) motion mechanisms. Again, until such a time as a demonstration of this claim is provided, it is not a constructive explanation.

Zanker's model can accommodate stimulus-induced onset effects (such as those involved in Figures 4 and 9) by manipulating temporal parameters of the model with a time decay function. It cannot account for endogenous attentional effects in any way other than through the assumption that focused attention can still somehow affect the motion system in a top-down fashion (see Figures 5 and 6). Presumably endogenous attention would affect the strength of the input to Zanker's motion mechanism in a manner similar to the example he provided where this was done by feature contrast.

The simple form of the Zanker's (1997) model can accommodate the examples from Figures 7, 8, 12, 14, 17, 18b, 19a, 20a and 23, except that it does not produce the phenomenology of motion within the probe items. This model suffers from the same problem as gradient accounts in simply handling the data from examples depicted in Figures 10 and 11.

The TMP illusion generated from the drawing of a simple dot (see Figures 15 and 16) provides a problem for centroid-shift accounts, as they would predict a motion series faithful to the true moving of the dot. Similar problems for the centroid-shift account are raised by the stimuli of Tse et al. (1998). In Figures 18a and 18c, the centroid-shift account would either predict motion toward the center or motion leftwards, when the result obtained is motion rightwards. Similarly, there is no basis for a centroid account of the effect depicted in Figures 18a, 19b or Figure 21. The centroid-shift account would presumably cause motion away from the primer for both of the probe bars presented in Figure 20b.

Until such a time as this model is demonstrated to be capable of accounting for even the basic phenomenology of motion within the probe, it is likely not to be worth further consideration. There are too many ad hoc additions required to cover the basic ILM phenomenology for this model to be taken as a serious contender, or to provide fruitful predictions for research.

## BALOCH AND GROSSBERG'S FORMOTION ACCOUNT

An interesting account of ILM-related phenomena has been proposed by Baloch and Grossberg (1997) using a rich set of mechanisms previously postulated for use by processes responsible for recovering boundaries and completing surfaces of three dimensional forms, given a two dimensional representation of the visual input (Francis & Grossberg, 1996a, 1996b; Grossberg, 1991; Grossberg & Rudd, 1989, 1992).

In an extension of this work, Baloch and Grossberg (1997) propose that there are two parallel processing streams in visual cortex, one for form and one for motion (see Figure 31). Interaction between these streams also occurs, and both streams receive direct visual input. The form stream is further decomposed into two interacting streams, one that performs boundary form extraction (the Boundary Contour System, or BCS) and the other is responsible for surface form extraction (the Feature Contour System or FCS). These form extraction streams feed into the short-range motion processing stage of a parallel stream responsible for motion processing. Short-range motion mechanisms contribute inputs to long-range processes, which in turn interact with focussed attention. It is the input of the form processing stream into the motion stream that enables form and color information to contribute to the generation of motion percepts. Such form and motion interactions are referred to as "formotion" percepts.

According to Baloch and Grossberg (1997) motion is detected whenever a wave of neural activity crosses the processing level that computes long-range motion. This can occur directly within the motion stream, or indirectly via form-motion stream interactions. The latter is termed a G-wave. According to these authors: "G-waves occur in the motion stream at the long-range motion filter, whose functional role is to combine motion estimates from multiple orientations, contrast polarities, and both eyes into a pooled estimate of motion direction. Here we show that when evolving boundary and surface signals input to the motion stream... then almost all formotion data known to us can be explained" (page 3039).

The role of visual attention in this scheme is to interact with long-range motion mechanisms which assist attention in tracking object movement. G-waves assist in this tracking by smoothly interpolating intermittently viewed positions. In addition, endogenous or top-down attention is said to influence ambiguous motion signals thereby defining an object's global direction and speed of motion.

Baloch and Grossberg (1997) introduce a number of properties of their boundary processing streams that create G-waves. These are briefly presented here. First the Boundary Contour System (BCS) will be introduced followed by the Feature Contour System (FCS).

The BCS was originally introduced to explain how the brain generates three dimensional boundary segmentations. In the BCS, bipole cells are created by the combination of output from the more primitive simple, complex and hypercomplex cells. Bipole cells are named because they have a receptive field with two polarized lobes surrounding a cell body (see Figure 32). Bipole cells cooperatively group inputs from the simpler hypercomplex level, and they fire if they receive enough input to both lobes, or one lobe and the cell body. Their firing feeds back to the hypercomplex layer beneath them thereby strengthening the likelihood that they will continue to be activated. In this way, the strongest boundary signals are activated at the expense of less strong boundary signals.

Boundary waves are created by the BCS through two properties: bipole cells that detect similar orientations facilitate each other through long-range cooperation and bipole cells that detect dissimilar orientations inhibit one another through short-range competition. According to Baloch and Grossberg (1997), bipole cells situated on boundary edges may not fire because they may have only one of their lobes activated, but they may still be activated subthreshold. When an edge is extended (for instance, by the appearance of a probe adjacent to a primer), partially activated bipole cells reach threshold earlier than cells further away and consequently fire sooner. Because "Bipole cell activities become gradually smaller as a function of their distance from the priming edge" (page 3041) a wave of boundary completion follows the extended edge, and motion is experienced.

Short-range competition between bipole cells detecting dissimilar orientations causes disimilarly oriented edges to inhibit each other thereby decreasing the likelihood that they will fire and that a wave of boundary completion will ensue from them. Hence short-range competition at T-junctions decreases the likelihood that motion will ensue away from boundary intersections, or deep concavities.

The FCS was originally postulated in order to explain how the brain fills in surface representations. A filling-in wave can occur in parallel with a boundary wave. The first stage of the FCS is a monocular preprocessing stage containing on-off center-surround cells that equalize illumination. These cells feed into a "filling-in domain " or FIDO, which is an array of interconnected, mutually excitatory cells. Each FIDO also receives inhibitory input from the BCS such that boundaries inhibit the spread of filling-in activities. Activation initiated by FCS signals is diffused and averaged within boundaries. This mechanism is evoked to explain the spread of motion within an item. For instance, when a probe is presented adjoined to a primer, the boundary between them disappears while new boundaries are formed around the conjoined primer and probe and the surface fills in from the primer side. The color signals existing in the primer, no longer inhibited by a boundary, spread outwards and are perceived as a wave of color filling-in.

According to Baloch and Grossberg (1997), waves of boundary and surface completion can influence perception in at least two ways. They can generate a percept of moving form via the ventral stream, or they can act dorsally and generate the perception of motion (or "formotion" as they refer to the illusion).

Francis and Grossberg (1996a) propose that the motion mechanisms also react to transients of the BCS. These BCS transients cause yet another type of wave referred to as a continuous G-wave, which is distinct from surface filling-in waves and boundary induced G-waves. Discrete events generate a continuous long-range motion wave between spatially and temporally separated inputs under three conditions: if the trace of one event decays while another grows, if the trace of one event decays more quickly than another, or if the trace of one event grows more quickly than another (see Figure 33). The continuous G-wave can add its motion to the motions derived from waves of boundary completion and surface filling-in.

A final contribution to this framework is directed attention. The notion here is that long-range motion mechanisms interact with a long-range attentive grouping process. Attention therefore can influence the creation of the continuous G-wave.

As the reader is no doubt aware at this point, there is a lot going on in the Baloch and Grossberg (1997) model. The next section will attempt to use the model to explain the phenomena outlined in Chapter 1.

## EXPLANATION OF PHENOMENOLOGY

The formotion model (Baloch & Grossberg, 1997) has no difficulty explaining the simple form of ILM presented in Figure 1. In frame 1 of Figure 1, bipole cells that are closest to the right edge of the primer are partially activated, and upon presentation of the probe in Frame 2, will reach threshold sooner than more distant bipole cells. Because there is a graded response of bipole cells with distance from the primer, a horizontal boundary wave ensues away from the primer. When the bar is removed such as illustrated in Figures 7 and 14, bipole cells at the location of the primer continue to receive input from the primer item and therefore decay more slowly than more distant cells, causing motion back toward the primer.

A second factor in this simple form of the illusion is color filling-in. When the primer is presented in frame 2 of Figure 1, the boundary is removed and color fills in from the left to the right. A third factor comes from the form and motion interaction and the formation of a continuous G-wave. The offset of the edge at the right of the primer, coupled with the onset of the edge at the far end of the probe causes a G-wave away from the primer. Similarly, when the probe is removed, there is a G-wave toward the primer.

To explain the example presented in Figure 2, Baloch and Grossberg (1997) must make the assumption that stimulation of bipole cells and the occurrence of transients can survive some critical amount of time. For ILM, this has been found to be as long as 2176 msec (Kawahara et al., 1996). Alternatively, if attention has been directed to the location where the primer was it might play a role in causing the illusory motion. However, in the Baloch and Grossberg (1997) model as it is now formulated, there is no attentional penetration of the BCS and FCS systems. Rather, attention acts at the level of the long-range motion processing system and not at earlier levels. In order to posit an attentional role in explaining the survival of long ISIs, a role for attention in affecting the BCS and FCS is required.

In the example of Figure 3, one might suspect that the model would incorrectly predict motion away from the primer that remains on because of long-range cooperative processes within bipole cells and because of color filling-in from the primer which remains in frames 2 and 3. Alternatively, Baloch and Grossberg (1997) might invoke transients or attentional mechanisms drawn to the offset of the primer on the right.

Transients could play a role in the explanation of Figures 3 and 4 by assuming that the transient caused by the primer offset (in Figure 3) or brightening (in Figure 4) results in the creation of a continuous G-wave away from these transient occurrences. A further assumption must be required that the G-wave can override input from the form system which predicts a motion signal in the opposite direction.

To use attention as an explanation of the effects in Figures 3 and 4, Baloch and Grossberg (1997) would have to elaborate on the role of attention because as outlined above, attention would be required to penetrate to the BCS and FCS systems in order to affect the percepts forming there. The examples of Figures 5 and 6 require that attention be involved in the explanation. Attention can presumably bias the direction of the G-wave when all other things are equal.

Next consider the case presented in Figure 8. According to Baloch and Grossberg (1997) boundary growth and color filling-in favor both directions equally while continuous G-wave motion does not favour either direction because there is no temporal difference in the presentation of the primers. When the probe is presented, bipole cells receive long-range cooperation from each of the primers and boundaries grow from both ends meeting in the middle. Color filling-in surface waves follow suit. The result is the perception of a collision within the probe. Similar principles apply to the example in Figure 12.

When the SOA between the primers in the double-primer paradigm is non-zero (see Figure 9) boundary signals for bipole cells on the right are still growing while signals for the primer presented earlier are at an advantage, or have reached their peak values. Therefore the bipole cells close to the first appearing box are at an advantage, causing the boundary wave to progress from the left. Although this is the opposite of the motion percept, Baloch and Grossberg (1997) claim it is the transients of the boundary signals that activate the motion system. The second box has generated a greater transient signal because it has appeared most recently, hence motion is experienced away from the later appearing primer. A further contribution to motion away from the later appearing primer comes from the boundary wave. The boundary signal is assumed to be smaller at the more recent primer causing its boundary to collapse more quickly than the boundary at the earlier primer, again resulting in motion away from the second primer.

The problem with this explanation is that it relies on a difference strength of the transient of the later-appearing primer to drive motion away from itself. The effect of the transient dissipates with time which should cause a weaker motion effect on the formotion account. In reality the opposite relation holds: the greater the SOA, the stronger the motion effect. Similarly, this explanation relies on a weaker boundary for the later-appearing primer because it presumably has not had time to build up. This boundary is said to collapse more easily than the established boundary of the first-appearing primer, again causing motion away from the second primer. Again though, with increased SOA motion is more likely to be away from the second primer, whereas with the above account the more established the second primer's boundary becomes, the less likely motion is to be away from it. Hence not only is the direction of the boundary signal incorrect, but the description supplied by Baloch and Grossberg may be sensitive to particular parameters used in their model. More modeling and empirical work with humans needs to be done to validate the model's predictions with this paradigm.

The formotion model can account for the situation where motion in the probe in the double-primer paradigm is away from the similarly colored primer (see Figure 10). Here, when the SOA between the primers is zero there is no advantage for either side in terms of boundary growth by the bipole cells. However, the green color of the primer on the right inhibits the generation of red boundaries through the inhibitory effects of color-opponency cells in the FCS. When the probe is presented in frame 2, color filling-in occurs from the primer that is similarly colored to the probe, and the boundary is facilitated from that end of the probe. A G-wave is generated from the fast decaying boundary signals to the slower decaying signals. Motion ensues toward the differently colored primer.

The flanking bar example presented in Figure 11 is likely to present the formotion account with some problems. Bipole cells should be equally stimulated on either side of the primer on the right, hence upon the presentation of the probe, boundaries should collapse and color FIDOs should form on both sides of this primer, resulting in a motion collision within the central portion of the probe and motion away from the flanker on the right side in the flanking bar. However, as discussed earlier, observers most frequently report motion only to the right within the entire length of the probe. It might be argued that a continuous G-wave forms due to the transients presented at the primer locations and at the far end of the flanker, causing motion in that direction. Further modeling work would be required to determine precisely how the formotion account handles this example.

It is not readily apparent how the formotion account can accommodate the finding that ILM shows a center-surround motion direction organization (see Figure 13), though Baloch and Grossberg claim in passing that it does. Why the direction of motion in the G-wave would reverse with distance between the primer and the probe is unclear. Such a mechanism would have to affect the long-range transient system as well as BCS or FCS.

Formotion does a good job of explaining the examples presented in Figure 17. When there is no spatial contiguity between a primer and probe, boundaries are slower to be formed by the BCS than when the probe is continuous with the primer. Similarly, gaps on the right prevent a color FIDO from being established. The example of Figure 17b demonstrates how the removal of a single boundary can result in motion away from the priming item (via a boundary wave) providing strong support for the formotion explanation. Similarly, this account can handle the examples presented in Figures 18a and 21. Recall that these examples are problematic for gradient theories. Bipole cells of different orientations inhibit one another causing the boundaries where there are T-junctions to form more slowly than boundaries that are continuous. Hence a boundary wave forms from the smaller primer toward the large primer in each of these Figures. Color filling-in follows this signal from the BCS.

A similar explanation applies to Figure 18b though here some primer-probe continuity biases motion away from the primer on the left. Although Baloch and Grossberg (1997) claim that long-range cooperation ensues at the left end of the probe due to the pooling of signals from a range of orientations, one might wonder whether it is more appropriate to expect inhibition here because dissimilar orientations, such as those found along this contour, are expected to inhibit one another. Similarly, there is direct inhibition at the opposite end of the probe due to the clear orientation conflict. Hence the formotion account could predict either motion from the center outwards in both directions within the probe, or assuming that the inhibition is greater where there are T-junctions, motion away from the primer with which the probe is continuous.

To explain the example of Figure 18c, the formotion account suggests that bipole cells inhibit one another for the right hand primer whereas they do not for the left primer. Coupled with local activation of horizontal bipole cells by the primer on the left could cause a boundary wave to occur rightwards.

The example in Figure 19a is balanced with respect to the FCS and BCS, transients and attention. Hence in this case, no motion would be expected on the formotion account, or perhaps a collision. In Figure 19b, it is difficult to predict what would occur on the formotion account. There is clearly a T-Junction at the right end of the probe, which should result in an inhibition of boundary formation at that end of the line. No such inhibition takes places at the left side of the figure, and color opponency would be expected to be equal for both the left and right sides of the bar. Hence, one might incorrectly expect motion toward the T-junction.

The formotion account explains Figure 20a by postulating that amodal completion occurs behind an occluding rectangle. Different depths are separated out by the model, and the boundary wave is formed in the far plane. In Figure 20b amodal completion would not occur because of the gaps. Hence color filling-in and a boundary wave would not be expected in the portion of the probe that is distant from the primer. Although this is the result reported by Tse et al. (1998), it is further examined in Chapter 7.

Baloch and Grossberg (1997) add a new ILM stimulus configuration, and provide an explanation for this finding in terms of their formotion model. The effect was told to them by Shinsuke Shimojo, and is cited as a personal communication in their paper. The stimulus for this configuration appears in Figure 34. The claim is that when one presents an arrowhead as a primer followed by a probe line that either forms an arrow by connecting to the arrowhead (as in Figure 34a), or forms a line that juts out of the arrowhead in the direction that it is pointing (as in Figure 34b), that motion is invariably in the direction that the arrowhead is pointing. The formotion explanation is that the arrowhead in Figure 34a competes with the horizontal line due to orientation competition. This competition slows down boundary growth near the arrowhead and the probe bar is experienced as growing toward the arrowhead. In Figure 34b however, there is cooperative orientation pooling by horizontal bipoles between the arrowhead and the probe bar which expedites boundary formation causing motion away from the arrowhead.

To explain the capacity limit observed with the illusion at multiple loci (see Figure 22) and the global experience of motion derived from the simultaneous presentation of many small presentations of the illusion (see Figure 23) the formotion model requires further assumptions. For the capacity limit finding, a mechanism of selection is required that operates at multiple locations on the output of the formotion system. The simple assumption that attention has access to this output is not sufficient (see Schmidt et al., 1998). For the global motion experience, some further motion integration mechanism is required.

It is not straightforward how to apply the model in cases where there are large gaps between the primer and probe items (see Figures 27 and 28). The model has completion mechanisms, though it is not clear how these interact with the establishment of boundary waves. To this end it is also not clear that the model can accommodate the TMP illusion as generated using simple moving dots (see Figures 15 and 16). Finally, when the primers are removed upon presentation of the probe (i.e., Figure 26) some of the motion producing mechanisms are no longer active yet the experience within the probe seems unchanged. Whether the formotion account can handle all of these detailed observations warrants further, more detailed investigation.

## SUMMARY

Although Zanker's (1997) low-level approach to ILM seems not be fruitful, it is evident that the formotion account of Baloch and Grossberg (1997) provides a rich set of mechanisms capable of explaining many of the observed phenomena. Although the account is precisely specified, it may have too many free parameters and duplicate mechanisms to make it falsifiable. Further investigation and discussion of this issue is saved for Chapter 7.

# CHAPTER 5: ILM AND APPARENT MOTION EQUIVALENCY

Several groups of researchers have made the argument that ILM is classical apparent motion (Downing & Treisman, 1995) or that it is apparent motion augmented with other processes (Downing & Treisman, 1997; Kawahara et al., 1996; Tse et al., 1998). As discussed earlier, apparent motion can be used to counteract ILM (Hikosaka et al., 1993a; Miyauchi et al., 1992; Fisher et al., 1993; Schmidt et al., 1998; Steinman et al., 1998) suggesting that whatever the mechanism, these phenomena at least share some common processing. This seems to be an accepted inference (Downing & Treisman, 1997; Kawahara et al., 1996; Tse et al., 1998).

Although the conclusion that ILM and apparent motion share mechanisms at some level would be expected if both apparent motion and ILM feed into a similar motion detection system, not everybody accepts that a motion detection system is even involved. Downing and Treisman (1997) for instance, argue that ILM is not caused by the neural asynchrony of signals arriving at motion detectors. They instead argue that long-range apparent motion and ILM are the result of a cognitive process that requires attention to link successive elements as unitary moving objects (Downing & Treisman, 1997; Horowitz & Treisman, 1994). Kawahara et al. (1996) on the other hand, simply assume that apparent motion processes must involve motion detectors. Tse et al. (1998) postulate that a motion processing stage occurs after boundaries and surfaces are recovered from the two dimensional visual input.

Kawahara et al. (1995; 1996) had subjects search for an ILM directional singleton while ILM distractors were presented in the opposite direction at several other locations in an array. Using display sizes with up to eight items, they found only a slight reduction in observers' ability to detect the presence of an illusory motion direction singleton. This led them to conclude that ILM was more than just attentional because attention is believed to be limited to a single spatial locus. They instead concluded that ILM had contributions from apparent motion mechanisms which are not spatially confined.

In a second experiment Kawahara et al. (1996) changed the probe stimulus in their paradigm from a line to a simple dot (0.1°) at the midpoint of the replaced line (0.75° away). Similar results were observed between their line and dot probe experiments, though no statistics were performed to evaluate the degree of similarity (or difference). The observed similarity of the results obtained for the so-called apparent motion and line probes led them to conclude that apparent motion processes produce illusory line motion perception. An account of how motion within the probe is produced was not provided.

Like Kawahara et al. (1996), Downing and Treisman (Experiment 1C, 1997) made an argument for the similarity of ILM and apparent motion simply by replacing the line probe with a similarly positioned probe that was identical to the primer. They found that these probes were able to elicit similar motion ratings within certain ranges of SOA and distance. The similarity of subjects' motion judgments for these two probe stimuli was interpreted as evidence that ILM (using the line probe) is classical apparent motion supplemented by an apparent motion impletion process. Downing and Treisman claimed that: "If our account is correct, apparent motion and the line-motion illusion should show the same effects of temporal and spatial separation of the two stimuli. We tested this prediction by having participants make ratings both on line-illusion displays and on comparable apparent motion displays, in which the line was replaced by a dot identical to the cue, located where the nearest end of the line would appear on equivalent line trials" (page 771).

There are a number of problems with the approach of claiming equivalency between ILM and apparent motion by simply replacing the line probe with a dot probe. First, it is not clear that the motion percepts that occur using an identical primer and probe are what is traditionally thought to be classical apparent motion. As Downing and Treisman (1997) noted, unlike classical apparent motion, they 1) were able to elicit the illusion using long

SOAs, 2) did not need to remove the primer upon presentation of the probe, and 3) did not alternate the presentation of stimulus items.

A second problem concerns the set of percepts that would arise had probes been delivered at distances different from those examined in the aforementioned experiments. The shortest distance between primer and probe that Downing and Treisman (1997) used was 1° degree of visual angle, whereas Kawahara et al. (1996) used a primer-probe separation of 0.75°. Because ILM is strongest when the primer and the probe are close to one another (as discussed earlier, the strongest portion of the gradient is hypothesized to lie directly adjacent to the primer), strong ILM percepts should ensue at small primer-probe distances. Thus it is unclear what the outcome of small distances would be on the dot probe's motion. Previous work suggests that even here motion should be experienced (Biederman-Thorson, Thorson, & Lange, 1971; Exner, 1888 cited in Sekuler et al., 1990), but its phenomenology in relation to ILM is unknown.

A third problem is that an alternative interpretation (which follows naturally from the gradient account) of these data suggests that both the line probe and dot probe displays tap the same underlying mechanism: a spatial gradient. Hence one cannot invalidate the gradient account, or conclude equivalency between ILM and apparent motion simply by demonstrating that two different probes behave similarly under a restricted set of conditions. Gradient theories raise the possibility that the phenomenology will differ between different primer and probe stimuli depending upon their interaction with the underlying gradient representation.

A final concern which applies to Downing and Treisman's (1997) experiment is that the basis of subjects' motion judgments was unclear. In the line probe displays motion is perceived in the displacement from the primer to the probe (beta motion), and a separate motion percept occurs within the probe (gamma motion). Observers were required to rate their motion percepts only with a single judgment, which raises several questions: Were subjects making a rating of object displacement from the primer to the probe position? Or were they rating motion within the line? Or were they somehow combining these two components into an overall rating of their motion gestalt? In the dot probe displays on the other hand, there is only motion in the displacement from the primer to the probe because the probe has negligible spatial extent. Yet despite the apparent phenomenological differences between these displays, Downing and Treisman found no difference between their apparent motion displays and line-motion displays, leading them to conclude that ILM is apparent motion impletion.

Setting aside the epistemological problems raised above with drawing an equivalency between ILM and apparent motion, Experiments 1 and 2 were designed to re-examine the similarity between ILM and what Downing and Treisman (1997) referred to as classical apparent motion. This was done in order to more extensively manipulate distance, SOA, the effects of primer offset, and the effect of similarity between the primer and the probe objects. If the gradient account is correct one would not expect an equivalency in motion judgments across all combinations of these parameters for a simple dot probe versus a line probe, because these two probe stimuli differ with respect to the degree to which they assess the underlying gradient representation. The use of a line probe would be expected to generate a greater percept of motion because it produces a greater number of motion signals offset from the primer. An effect of primer-probe similarity would similarly be expected based on the spatial extent of the probe, whereby the greater the probe's spatial extent the stronger the expected effect of motion.

Experiment 1 was designed to replicate and extend Downing and Treisman's (1997) Experiment 1C, examining the effect of distances smaller than those they originally used because the gradient account predicts stronger motion the closer the probe is to the primer. Experiment 2 was similar, but was designed to examine the effects of manipulating the inter-stimulus interval (ISI) rather than SOA. A blank ISI is commonly found to be disruptive to the resulting apparent motion percept. For classical apparent motion undergoing large spatial displacements, a blank ISI of 300 to 500 msec is sufficient to remove the sensation of motion (Kolers, 1972). Although Downing and Treisman (1997) investigated temporal effects using SOA looking for a difference between probe types, it is ISI that is likely to yield such an effect if one is to be found. Both Experiments 1 and 2 required subjects to provide separate motion ratings for motion between the primer and probe (object displacement or beta motion), motion within the probe (ILM; impletion or gamma motion), as well as an overall motion rating for the display.

## EXPERIMENT 1

In contrast to what others have claimed (Downing & Treisman, 1997; Kawahara et al., 1996; Tse et al., 1998) the gradient account of ILM suggests that ILM can be phenomenologically different from classical apparent motion depending upon the interaction of the primer and probe stimuli with the spatial gradient mechanism, so participants were asked three questions about their motion percept. First, subjects were asked to rate the strength of their overall motion percept. Presumably this rating should correspond to the methods used by Downing and Treisman (1997) at least for the SOA and distance conditions replicated here. Second, subjects were asked to rate their percept of motion within the second-appearing object (the probe). This rating should correspond to the component of ILM in which motion appears over time and space in the probe item. The strength of motion within the probe was predicted, on the gradient account, to be a function of the area of the gradient that the probe item covered, and was expected to weaken with increasing primer-probe distance. Third, subjects were asked to rate their percept of motion between the first-appearing object (the primer) and the second-appearing object (the probe). This motion rating should reflect object displacement between the primer and the probe, and assuming that subjects could ignore the other motion components in making their judgments, was not expected to vary with the type of probe used.

The apparent motion impletion process purportedly attempts to link successive percepts as parts of a single object moving through space, so the question of what happens to motion perception when the primer and probe are identical, similar or dissimilar objects was examined. Orlansky (1940), who observed impletion-like effects (as cited in Downing & Treisman, 1997) concluded that although disparity of shapes does not rule out illusory motion it may make it less compelling and narrows the range of its appearance. Hence, just as one might expect if some process were attempting to draw an inference of motion from an object at location one as having moved to location two, identical or similar primer and probe objects should aid this matching process and produce stronger, clearer motion compared to a less similar match. Support for this conclusion was found by Orlansky (1940) and by Kolers and Pomerantz (1971). Rock (1983) acknowledges this as a prediction of intelligence based theories of apparent motion, though he notes that such effects are likely to operate at later perceptual stages (Navon, 1976).

The issue of item similarity was briefly re-examined in the context of ILM. While an impletion account would be expected to show stronger overall or between-item motion with increased primer-probe similarity (Kolers & Pomerantz, 1971; Orlansky, 1940; Rock, 1983) the gradient account predicts that the object that best taps the gradient around the primer should produce the strongest overall motion percept. The gradient account does not make a prediction for the between-item motion rating because it is neutral regarding whether observers would use centroids or endpoints of the items for such judgments. For the probe stimuli used in the current experiment, overall motion strength would be expected to parallel the area of the gradient that is covered. The impletion prediction is the opposite because as the area of the probe increases, it becomes more dissimilar to the primer and should therefore be more difficult to link, thereby producing weaker motion.

The experimental displays were modeled after Downing and Treisman's Experiment 1C so that a rough comparison could be made to their data. A number of parameters were manipulated. First, and most importantly, distance was varied and small primer-probe separations were used. Second, the effect of turning the primer off when presenting the probe was examined, because in classical apparent motion the first object is extinguished before the second object appears, a measure which is not necessary for ILM. Third, the effect of SOA was investigated because ILM is believed to be robust over long SOAs. Finally, the primer-probe similarity was manipulated. A thin vertical line acted as the primer, and one of three lengths of probe object followed this. As depicted in Figure 35, the probe could either be identical to the primer (the apparent motion condition), a small square, or a long horizontal bar.

*Method*

*Observers.* Fourteen undergraduates participated in a single 50 minute experimental session in exchange for course credit. All observers reported normal or corrected-to-normal vision.

*Apparatus and Stimuli.* The stimuli were presented on a Macintosh Color Plus display controlled by a Macintosh LC630 microcomputer running the author's SplayPicts 1.1 experiment software package.

All of the stimuli presented were black on a white background. The display layout was similar to that of Downing and Treisman's (1997) Experiment 1C. A small cross in the middle of the display (composed of two lines 0.2° wide and 1.0° long) acted as a fixation marker. The primer object was a black vertical line (0.3° high and 0.1° wide) and the subsequently presented probe object was either identical to the primer, a small square (0.3° high and wide), or a long horizontal bar (0.3° high and 10.0° long; see Figure 35). As in the Downing and Treisman (1997) experiment, the horizontal bar stimulus was centered horizontally in the display and its endpoints defined the positions that the square or vertical line stimuli would occupy. The primer and probe stimuli were presented 3.0° above the center of the fixation cross, and the primer was 6°, 1°, 0.5°, or 0.1° to the left or right end of the horizontal bar position (hence the primer positions were 11°, 6°, 5.5°, or 5.1° in the periphery, while the probe's most peripheral edge was 5.0°).

Observers were required to select a point along a 17° scale partitioned into 20 equal portions marked with "Leftwards" at the left, "No Motion" in the center, and "Rightwards" at the right. Hash marks were drawn along the scale separating the intervals, with the exception of the two most central divisions demarcating the "no motion" response. The side of the primer presentation (left or right) was counterbalanced.

*Procedure.* Each observer sat in a dimly lit room at a distance of 57 cm from the computer monitor, with their head steadied by a chinrest.

The top portion of Figure 36 illustrates the relative presentation times of the primer and probe items in Experiment 1. On every trial, a beep signaled the trial's beginning and the fixation cross was presented for 1000 msec, followed by the primer for 150 or 750 msec (hence SOAs were 150 or 750 msec). The following instruction was superimposed on the bottom of the display 750 msec after the probe's appearance, along with a rating scale: "Please rate your overall motion percept." After the subject indicated the direction and magnitude of the strength of their motion percept by moving the mouse cursor along the scale and clicking, two further instructions were supplied with identical scales: "Please rate motion within the 2nd object:", and "Please rate motion from the 1st to the 2nd object:". Subjects were reminded to take breaks every 50 trials, and at these times they had to press the computer's mouse button to continue the experiment.

Before the experimental session began, subjects were informed that they would be given practice with a single trial from each of the experimental conditions. This was to ensure that they would experience the entire range of motion that would be presented during the experiment, and to assist them with assigning motion strengths to their percepts. Data from the practice session were discarded. The order of practice and experimental trial presentation was randomized separately for each observer.

*Design.* There were 288 experimental trials: 6 replications from each of 48 experimental conditions (half cued left of center and half right). The experiment was a 3 (identity of the second object presented - vertical line, square, or bar) X 4 (distance - 6°, 1°, 0.5°, or 0.1°) X 2 (primer offset status - remains on when probe appears, or is extinguished) X 2 (SOA -- short (150 msec) or long (750 msec)) repeated measures design.

### *Results and Discussion*

Each motion rating ranged from -100 to +100, where negative values indicated motion toward the primer and positive values indicated motion away from the primer. The 'no motion' portion of the rating scale stretched from the center of the scale to the -12 and +12 locations. The value of the rating was used to indicate motion strength. Observers' mean ratings of the strength for motion within the probe, motion between the primer and the probe, and overall motion were subjected to separate 3 (probe identity) X 4 (distance) X 2 (SOA) X 2 (primer offset status) repeated measure ANOVAs. The results of these analyses will be discussed in turn.

*Within probe motion ratings.* Mean ratings of motion strength within the probe for all cells of the analysis appear in Appendix A. The analysis of motion within the second appearing item revealed a single significant main effect of the type of item presented as the probe ($F(2,26)=31.80$, $MS_e=3383.06$, $p<.0001$). Motion within the horizontal bar was strongest (59), within the square second strongest (33), and within the identical probe item, the weakest (15). As predicted by the gradient model, the strength of motion within the probe was a function of the probe's area.

The only significant interaction was between the type of probe item presented and the distance between the primer and the probe ($F(6,78)=3.55$, $MS_e=138.40$, $p<.005$). The interaction means are presented in Figure 37. To further examine this interaction, separate ANOVAs were carried out for each probe type. When the probe was a long horizontal bar a main effect of distance was obtained, $F(3,39)=3.01$, $MS_e=157.27$, $p<.05$. Hence, the gradient hypothesis of a drop off of motion strength within the probe as the primer-probe distance increased was supported (means in the minimal, half, one and six degree conditions were respectively 67, 63, 63 and 59).

Judgments of motion within the square probe were relatively constant regardless of the experimental manipulations (all $p$'s $>.05$). Finally, observers rated motion within the vertical bar quite low, though ratings increased with distance, $F(3,39)=3.65$,

$MS_e$=635.31, $p<.05$. Ratings were 15, 15, 17 and 22 for the minimal, half, one and six degree conditions respectively. Because it doesn't really make sense to give a motion rating within such a small item, it is likely that not all observers were able to completely distinguish motion within the item from overall and between-item motion. Hence there may have been some merging of judgments across these distinct qualities. No other main effects or interactions were significant.

*Between primer and probe motion ratings*. Mean ratings of motion strength between the primer and probe for all cells of the analysis appear in Appendix B. A single significant interaction was observed between the type of probe item presented and the distance between the primer and the probe ($F(6,78)$=3.02, $MS_e$=120.55, $p<.02$). Simple effects tests at each level of distance revealed that observers rated motion between display items similarly for all but the smallest level of distance ($F(2,26)$=4.33, $MS_e$=61.22, $p<.03$; all other distance simple effects revealed no difference, all $p$'s>.05). A simple contrast performed on the distance main effect when the primer-probe distance was minimal, contrasting the strength of motion between the primer and the bar with motion between the primer and the other probe items revealed significantly stronger motion ratings ($F(1,26)$=7.32, $MS_e$=448.06, $p<.02$) for the bar probe (34) than the other probes (25 for the vertical line, 29 for the square).

Main effects of distance ($F(3,39)$=21.01, $MS_e$=564.61, $p<.0001$) and SOA ($F(2,26)$=4.97, $MS_e$=407.66, $p<.05$) were also significant. The mean between-object motion ratings at the short SOA was 40 versus 36 at the long SOA. The distance effect reflected increasing between-item motion ratings with increasing primer-probe distance. Mean ratings were 29, 35, 38 and 49 for the minimal, half, one and six degree conditions respectively. Hence regardless of the probe item, between-item strength was a function of primer-probe distance. No other main effects or interactions were significant.

*Overall motion ratings*. Mean ratings of overall motion strength for all cells of the analysis appear in Appendix C. The analysis of the overall motion in the display revealed a single significant interaction between the type of probe item presented and the distance between the primer and the probe ($F_{(6,78)}$=21.68, $MS_e$=123.97, $p$<.0001). The interaction means are presented in Figure 38. It is apparent that at all levels of distance when the probe object was a horizontal bar (clearly producing ILM), observers rated overall display motion more strongly than when the probe item was identical to the primer, or when it was a square. Simple effects tests for each of the probe items revealed that when the probe was a horizontal bar, there was no change in overall motion ratings with changes in primer-probe distance. In contrast, motion strength increased significantly with distance for the square probe (quadratic trend $F_{(1,39)}$=5.39, $MS_e$=310.07, $p$<.05) and the vertical line probe that was identical to the primer (linear trend $F_{(1,39)}$=112.69, $MS_e$=5754.54, $p$<.0001).

Apart from the significant interaction, only the main effects of distance ($F$(3,39)=23.39, $MS_e$=289.03, $p$<.0001) and probe type ($F_{(2,26)}$=16.05, $MS_e$=1730.58, $p$<.0001) were significant. The mean overall motion ratings when the probe was identical to the primer, a square or a bar were 42, 44 and 62 respectively. For the 0.1°, 0.5°, 1.0° and 6.0° distance conditions, mean overall motion ratings were 43, 47, 49, and 58.

Planned contrasts were used to investigate whether ILM was qualitatively different from the apparent motion condition with respect to SOA. Overall motion ratings from long and short SOA presentations were compared for the ILM and the apparent motion conditions separately. These ratings were expected to be comparable with ratings observed by Downing and Treisman (1997). As noted earlier, ILM is reported to be robust across long blank intervals while classical apparent motion has not traditionally been viewed as such. Contrary to previous findings of no differences with respect to either probe type or SOA, here ILM ratings did not differ significantly with SOA (63 at short versus 61 at long SOA, $F_{(1,78)}$=2.11 $MS_e$=119.30, $p$>.05), while in the apparent motion condition motion was rated more strongly ($F_{(1,78)}$=14.60, $MS_e$=824.23, $p$<.0005) overall at short (44) versus long (40) SOAs.

It would appear that the strength of overall motion is a combination of within-object motion and between-object motion. Unlike the within-object motion ratings, there was not a decrease in overall motion strength of the bar with increasing primer-probe distance. Yet, like within-object motion ratings, overall motion was stronger for the bar probe than the square probe or the apparent motion probe that was identical to the primer. Precisely as predicted by the gradient model, short primer-probe distances resulted in stronger percepts of illusory motion. These strong percepts of motion within the bar translated into higher ratings of overall motion regardless of the primer-probe distance. The ILM and apparent motion conditions (identical primer and probe objects) differed as a function of distance between the primer and probe objects, especially at the smallest levels of distance that were previously not considered.

## EXPERIMENT 2

The use of a blank ISI is traditionally expected to be a manipulation under which apparent motion breaks down. Kolers (1972) reports that classical apparent motion is not robust using ISIs of 300 to 500 msec. Schmidt (1996) reported ILM data in which the illusion was robust with ISIs as long as 900 msec, and Kawahara et al. (1996) present data where ILM occurred 70% of the time even after an ISI of 2176 msec! If there is a temporal difference between the bar probe and apparent motion probe it is likely to be evident when a blank ISI is included.

The bottom portion of Figure 36 illustrates the relative presentation times of the primer and probe items in Experiment 2. The primer could either remain throughout the trial or disappear after 150 msec. On half the trials the primer was presented for 150 msec at which point it disappeared for 0, 300 or 600 msec before the probe was presented (hence SOAs were 150, 450 or 750 msec). On the other half of trials the primer remained throughout the trial presentation. Only two probe types were used (a horizontal bar, and a probe item identical to the primer).

*Method*

*Observers.* Twenty undergraduates participated in a single 50 minute experimental session in exchange for course credit. All observers reported normal or corrected-to-normal vision. To encourage comprehension of the task instructions, only native English speakers were run.

*Apparatus and Stimuli.* The stimuli and apparatus were identical to those from Experiment 1.

*Procedure.* Each observer sat in a dimly lit room at a distance of 57 cm from the computer monitor, with their head steadied by a chinrest.

On every trial a beep signaled the trial's beginning and the fixation cross was presented for 1000 msec. When there was a blank ISI the primer was presented for 150 msec at which point it disappeared for the remainder of the trial. Otherwise the primer was presented for 150, 450 or 750 msec and remained present when the probe appeared (see Figure 36). Shortly after the probe's appearance (750 msec) the same instructions and task as used in Experiment 1 were presented.

*Design.* There were 288 experimental trials: 6 replications from each of 48 experimental conditions (half cued left of center and half right). The experiment was a 2 (identity of the second object presented - probe identical to the primer, or horizontal bar) X 4 (primer-probe distance - 6°, 1°, 0.5°, or 0.1°) X 3 (SOA - 150, 450, or 750 msec) X 2 (primer offset status - remains throughout the trial or disappears) repeated measures design.

*Results and Discussion*

As in Experiment 1, observers' mean ratings of the strength for motion within the probe, motion between the primer and the probe, and overall motion were subjected to separate 2 (probe identity) X 4 (distance) X 3 (SOA) X 2 (primer offset status) repeated measure ANOVAs. The results of these analyses will be discussed in turn.

*Within probe motion ratings.* Mean ratings of motion strength within the probe for all cells of the analysis appear in Appendix D. The analysis of motion within the second appearing item showed a significant interaction among the factors of primer status, probe type, and SOA ($F(2,38)=4.53$, $MS_e=54.83$, $p<.02$). A plot of the interaction cell means appears in Figure 39. While motion within the identical probe was negligible at all levels of SOA (mean 12), motion within the bar was always rated significantly more strongly (mean 52; $F(1,38)=51.32$, $MS_e=304.08$, $p<.0001$). Though motion ratings within the bar decreased with increasing SOA (from 55 to 49), this effect was not significant ($p>.65$). When the primer remained present throughout the trial, motion ratings were slightly (53), but not significantly ($p>.70$) stronger than when the primer was extinguished during this period (50). The primer status difference did not differ significantly at any level of SOA for either probe type (all *p*'s>.05).

A significant interaction between probe type and SOA ($F(2,38)=4.39$, $MS_e=156.62$, $p<.02$) reflected the aforementioned effect of a decrease in motion strength within the bar probe (55, 51 and 49 for SOAs of 150, 450 and 750 respectively), combined with no change within the probe identical to the primer (13, 12, 12) as SOA increased.

Figure 40 presents the cell means from the significant probe type by distance interaction ($F(3,57)=12.58$, $MS_e=127.10$, $p<.0001$). As reflected in the figure and as in Experiment 1, bar motion ratings decreased linearly with increasing distance from the primer ($F(1,57)=4.89$, $MS_e=217.35$, $p<.05$, with ratings decreasing from 53, 53, 52 to 49), as expected if a spatial gradient were underlying the illusion, while motion ratings within the identical probe increased with the distance factor ($F(1,57)=26.50$, $MS_e=581.86$, $p<.0001$, with ratings increasing from 8 to 11, 13 and 16).

The main effect of SOA ($F(2,38)=7.12$, $MS_e=161.65$, $p<.005$) which was qualified by the aforementioned interactions, reflected decreasing motion ratings with time (34, 31 and 30 for SOAs of 150, 450 and 750 msec respectively). The only other significant effect was the probe type main effect ($F(1,19)=59.02$, $MS_e=6346.01$, $p<.0001$), caused by a lower rating of motion strength within the identical probe (12) than within the bar probe (52).

*Between primer and probe motion ratings*. Mean ratings of motion strength between the primer and probe for all cells of the analysis appear in Appendix E. When the primer remained present throughout the entire trial, between-object motion ratings were significantly stronger (37; $F(1,19)=6.54$, $MS_e=1233.64$, $p<.02$) than when the primer was extinguished (32). However, this main effect was qualified by an interaction with probe type ($F(1,19)=7.51$, $MS_e=340.85$, $p<.02$). For the apparent motion condition, extinguishing the primer was significantly detrimental to between-object motion ratings (36 when the primer remained versus 27 when it disappeared, $F(1,19)=9.12$, $MS_e=90.03$, $p<.007$). In contrast, for ILM, removal of the primer did not result in significantly poorer motion ratings (39 when the primer remained versus 36 when it disappeared, $p>.20$).

Probe type also interacted significantly with distance ($F(3,57)=24.41$, $MS_e=125.44$, $p<.0001$), and the interaction cells means appear in Figure 41. As can be seen in this figure, between-object motion ratings were significantly lower for apparent motion at the smallest primer-probe distance (35 bar versus 20 identical, $F(1,38)=8.00$, $MS_e=268.99$, $p<.008$), while there was no significant difference between the probe types at greater primer-probe distances (all $p$'s $>.05$). Again, these observations confirm a dissociation between the apparent motion stimulus and bar probe.

*Overall motion ratings*. Mean ratings of overall motion strength for all cells of the analysis appear in Appendix F. The use of a blank ISI created several differences in the phenomenology of ILM and the simpler apparent motion stimulus. The highest order interaction that was significant involved primer status, probe type, and distance ($F(3,57)=4.55$, $MS_e=114.50$, $p<.01$). All of the two-way interactions were significant: probe type by distance ($F(3,57)=6.30$, $MS_e=164.51$, $p<.0001$), primer status by distance ($F(3,57)=6.60$, $MS_e=163.98$, $p<.001$), and primer status by probe type ($F(1,19)=6.34$, $MS_e=360.25$, $p<.03$).

An inspection of the plotted cell means for the triple interaction (see Figure 42) shows that while the bar probe display's overall motion ratings did not change across levels of distance ($F(3,57)=1.61$, $MS_e=46.53$, $p>.18$), there was a significant increase with distance in ratings elicited by the apparent motion probe ($F(3,57)=87.78$, $MS_e=47.49$, $p<.0001$). Furthermore, turning the primer off resulted in weaker motion ratings (36) for the apparent motion condition ($F(1,36)=3.77$, $MS_e=269.41$, $p-.05$), than did leaving the primer on (47). In contrast, removing the primer did not reduce motion ratings of the horizontal bar (62; $F(1,36)=0.90$, $MS_e=328.63$, $p>.35$) compared to leaving the primer on (57). Finally, the continued presence of the primer increased apparent motion ratings at small distances more than at large distances ($p<.05$ for the minimal and half degree conditions, and $p>.05$ for the one and six degree conditions), while this manipulation did not affect ratings of motion for the bar probe at any distance (all $p$'s>.05).

As in Experiment 1, the bar probe and the apparent motion probe elicited different overall motion judgments as a function of distance between the primer and probe objects, especially at the smallest levels of distance. More important, while the apparent motion stimuli produced weaker motion ratings when the primer was extinguished, this manipulation did not hurt ILM ratings.

No other interactions approached significance. The main effect of probe type ($F(1,19)=38.10$, $MS_e=2238.23$, $p<.0001$) showed that bar probe ratings (59) were stronger than apparent motion ratings (41), and the significant main effect of distance reflected that collapsed across all factors, overall motion ratings increased with distance ($F(3,57)=51.70$, $MS_e=294.35$, $p<.0001$).

A main effect of primer status reflected the finding that removal of the primer resulted in significantly weaker ($F(1,19)=17.10$, $MS_e=434.31$, $p<.0006$) motion ratings (47) than leaving the primer on (53). This finding is contrary to the impletion hypothesis prediction of the opposite effect. Downing and Treisman (1997) noted that conditions which extinguish the primer stimulus "... are even more favorable for apparent motion than those using an onset cue: the first stimulus appears, then disappears before the second appears. This sequence is consistent with a single object appearing and jumping to a new location" (page 778-779). Because the conditions that evoked the strongest motion in these displays had the primer remain throughout the trial, it is questionable that this impletion explanation is correct. Note however, that the current results are expected under a gradient explanation: when the stimulus remains present throughout the trial, perceptual contributions to the gradient remain suggesting that a stronger illusory motion percept should occur. This is a result of sustained inputs to the motion detection system (Baker & Cynader, 1994; Bischof & Di Lollo, 1995). Turning the primer off in the interim causes the perceptual components of the gradient to subside with time, leaving only non-perceptual contributions to drive the illusion.

As with the within motion judgments, the overall motion judgments clearly differentiated the effects of apparent motion from ILM. Not only were motion judgments clearly stronger for the bar probe, but they were strong even after a blank ISI of 600 msec (see Figure 39), well over the range where classical apparent motion is reported to break down (Kolers, 1972). This finding calls into question whether ILM is a classical apparent motion phenomenon as several authors have argued (Downing & Treisman, 1997; Kawahara et al., 1996; Tse et al., 1998).

## DISCUSSION

The results from both Experiments 1 and 2 stand in contrast to claims of others (Downing & Treisman, 1997; Kawahara et al., 1996) by clearly showing several differences between the motion resulting from the presentation of a horizontal bar (a line) versus the motion experience resulting from an object identical to that of the priming object. As the gradient account predicts, but the apparent motion impletion account does not, these stimuli do not show the same spatial and temporal effects unless one is simply concerned about motion between successive items. Even then, differences were apparent at short primer-probe separations.

The judgments of motion within the probe items, and of the overall display clearly show a difference between the bar probe and the apparent motion probe. Further, as predicted by the gradient account, there was a decline in within motion strength judgments for the bar probe with increasing primer-probe distance.

In Experiment 1, a manipulation of the spatial area of the probe supported the gradient hypothesis prediction that motion strength would increase with probe length. Similarly it invalidated cognitive-based theories' prediction that figural similarity between the primer and probe items would be expected to produce stronger motion (Kolers & Pomerantz, 1971; Orlansky, 1940). Despite increased ease in linking of successive views of a single object in apparent motion, the resulting beta motion was not improved. This claim, which follows from the impletion account was not validated for any of the motion qualities assessed.

In Experiment 2 when the primer was removed well before the presentation of the probe, overall motion judgments for the display were unaffected for the bar probe. In contrast, when there was a blank ISI before the apparent motion probe, overall motion strength was rated more strongly at small primer-probe distances (see Figure 42). This finding is again opposite to the impletion account's prediction that removal of the primer prior to the probe's presentation should be beneficial to the apparent motion impletion process because it would assist in the linking of a single object across successive views (Downing & Treisman, 1997, page 778-779). However, as discussed earlier, these data are compatible with the gradient account.

Regardless of the distance between the primer and the probe objects, judgments of overall motion generally differed for a horizontal bar probe and a vertical line probe identical to the primer (the "apparent motion" probe). Of the three types of motion ratings used, overall motion would be expected to correspond to the motion judgments of Downing and Treisman's (1997) Experiment 1C because they simply had observers rate the motion strength of their displays. However, unlike the present results, their data showed no reliable differences between motion ratings at any of the larger distance levels used. Perhaps this discrepancy in results follows from the current experiment's use of an expanded rating scale which gives observers the opportunity to make a greater range of motion judgments, combined with the opportunity to make more than a single motion strength rating.

The closest data from the current experiment to those of Downing and Treisman's Experiment 1C is the between-object motion ratings considered only at distance levels which overlap with their experiment (1° and 6°). Assuming that their subjects were primarily reporting judgments of motion between the primer and probe items, then the current work has replicated their results, and shown them to be unrepresentative of ILM phenomena at large.

Clearly the phenomenology of ILM and what others have refereed to as classical apparent motion (Downing & Treisman, 1997; Kawahara et al., 1996; Tse et al., 1998) can differ depending upon the aspect of the display being judged. Moreover, using smaller primer-probe separations than were previously examined has uncovered several differences as predicted by the gradient hypothesis. Whether simply replacing the bar probe with a probe that is identical to the primer is classical apparent motion is questionable given that the expected decline in between-object motion strength with an increasing blank ISI duration (Kolers, 1972) was not observed with such a stimulus.

# CHAPTER 6: ILM AND ENDOGENOUS ATTENTION

As discussed in the Introduction, Hikosaka et al. (1993b) reported that ILM is sensitive to, and can be driven by, both exogenous (or stimulus-driven) and endogenous (or voluntary) forms of visual attention. The proposed mechanism for this effect involved the attentional modulation of signal transmission in the visual system. Hikosaka et al. (1991, 1993a, 1993b) hypothesized that a spatial gradient centered at the attentional focus acted to speed signals arising nearby the primer causing them to reach a motion detection system earlier than signals arising distally, thereby triggering the motion detection system in a fashion similar to a moving stimulus. This hypothesis has come to be known as the attentional gradient hypothesis. Von Grünau, Dube and Kwas (1996) modified this original theoretical framework by reporting two components to the illusion: a "preattentive" component which operates in a spatially parallel fashion without attentional allocation, and a modulating effect due to focused attention. Similar conclusions have been reached by Hecht (1995) and Kawahara, Yokosawa, Nishida and Sato (1995, 1996).

Downing and Treisman (1997) questioned whether attentional gradients (either exogenous or endogenously influenced) can act as a source for ILM. This chapter focuses on their failed attempt to confirm and replicate an effect of endogenous attention on the illusion, as was reported by Hikosaka et al. (1993b; Experiment 2). In the original work, participants (two of the three authors of the paper and a naive observer) were presented with a fixation spot followed by two square primers, one red and one green (made equiluminant via the minimum flicker technique), positioned above and on either side of fixation. Observers were instructed to direct their attention to a square of a particular color, and after a variable SOA, a probe line appeared connecting the two colored primers (see Figure 10). The observer's task was to indicate the side from which the line had appeared to be drawn. Hikosaka et al. (1993b) found that after about a 400 msec SOA between the appearance of the colored boxes and the line, subjects frequently reported motion away from the colored box that they had been instructed to attend. Hence, ILM appeared to be sensitive to endogenous attentional manipulations.

Downing and Treisman (1997; Experiment 3), supplemented Hikosaka et al.'s (1993b) methods with a letter discrimination task using response time (RT) as a dependent measure in order to verify that attentional processing effects were present at the instructed display location. Primers were presented for either 150 or 405 msec. On letter discrimination trials a target letter (either an X or a T) appeared at the endogenously cued location (validly cued trials) or at the location opposite the cued location (invalidly cued trials). On line motion trials a probe line appeared for 45 msec, centered in the intervening space between the cue positions. An "apparent motion" condition substituted a dot probe for the line probe. In addition to these conditions, trials containing the presentation of the simple illusion were included to ensure that at least some presentations of clear illusory motion were present.

Work since the original Hikosaka et al. (1991) report, using what has been called the "double-priming" paradigm (Faubert & Grünau, 1991, 1995), has revealed that when two primers are joined by a line, the line frequently appears to be drawn from both ends, colliding centrally (an effect called split-priming by Faubert & Grünau, 1991, 1995). To incorporate this result, rather than use a 2AFC methodology as in the original experiment, Downing and Treisman (1997) added further response options so that subjects were not forced to report motion from a single direction. Observers were first asked whether they saw lateral, inward, or no motion. For inward (collision) trials, observers then reported whether the motion collided centrally or was biased in a principle direction. A simple motion strength rating was collected on an 8 point scale for all trials in which motion was experienced.

The results of the discrimination task revealed that subjects were endogenously attending the instructed colored box (RT was faster when targets appeared at validly cued locations than at invalidly cued locations). However, observers were no more likely to experience line motion (or apparent motion) from the attended location than from the unattended location. There was also frequent reporting of collisions and no motion. Downing and Treisman (1997, page 776) state: "We remain puzzled as to the source of discrepancy between our results and those of Hikosaka et al. (1993b). One difference between our procedure and theirs is that we used untrained, naive observers, whereas their data were taken from a few highly trained observers... Another difference is that Hikosaka et al. (1993b) used a two-alternative forced-choice response, in which motion is assumed and the observer notes only its direction. These conditions allow even the slightest biases to determine the choice of direction."

The goal of the current investigation was to determine whether ILM is sensitive to endogenous orienting. A second goal was to determine whether the differences Downing and Treisman (1997) noted were responsible for their failure to find an effect of endogenous attention on ILM, or whether several more subtle implementation differences from the Hikosaka et al. (1993b) work may have played a role.

From an implementation standpoint, there were several differences between Downing and Treisman's stimulus presentation and those of Hikosaka et al. (1993b) that might be expected to influence ILM. First, in Hikosaka et al.'s (1993b) original experiment the probe line joined the priming boxes. This is important, because if (as gradient hypotheses suggest) the modulatory effects of a gradient are strongest at its peaks, then presenting the probe line at a distance from the primers is likely to weaken the ability for gradient modulated signals at the probe location to influence perception. Several investigations have shown that what appears to be a gradient, drops off with distance from the primer in a quasi-exponential fashion (Miyauchi, Hikosaka & Shimojo, 1992; Steinman, Steinman, & Lehmkuhle, 1995; Stelmach & Herdman, 1991; Stelmach, Herdman & MacNeil, 1994; von Grünau, Racette & Kwas, 1996). Downing and Treisman's (1997) gaps between the primer and the line probe were 1.25°, 208% the size of their primer. It is common in ILM experiments not to have a gap at all. Tse, Cavanagh and Nakayama (1998) even go so far as to distinguish this class of motion effect from traditional apparent motion because of the spatial and temporal overlap between the elements[1].

A second implementation difference that would be expected to influence observers' motion percepts involves the probe duration. Hikosaka et al. (1993b) presented the probe line until their participants responded,[2] whereas Downing and Treisman (1997) flashed the probe line for 45 msec. Several studies have shown that the brief presentation of a probe line results in two directional percepts of motion relative to the focus of endogenous attention (Holt-Hansen, 1970, 1973) and relative to the location of an exogenous primer (Schmidt & Pylyshyn, 1994; Schmidt & Klein, 1997). When a line is briefly presented, motion is first away from the primer, followed by motion back toward the primer. If attention were to have a modulatory effect on motion, observers would be expected to experience two conflicting directions of motion within a briefly presented probe line. Such an effect would yield a high frequency of collision or no motion responses, and a null result as reported by Downing and Treisman (1997).

Yet another difference between the failed replication and the original experiment that may have had an effect on weakening observers' endogenous motion experiences concerns Downing and Treisman's (1997) removal of the primers on presentation of the probe. As mentioned above, Tse, Cavanagh and Nakayama (1998) attribute motion within the probe, in part, to a temporal overlap between the primer and probe stimuli. It is customary in ILM research to not extinguish the primers while the probe is displayed, and to display the probe for an extended period of time. Experience with such displays reveals that removal of the primer often results in a less clear percept (see Experiment 2) due to the offset transient created by the primers in conjunction with the onset transient created by the probe. Motion between scene elements is increased with this technique and there it removes contributions of sustained inputs to the motion system (Baker & Cynader, 1994; Bischof & Di Lollo, 1995) making for a less clear motion percept.

In summary, there are several differences between Downing and Treisman's (1997) failed replication and Hikosaka et al.'s (1993b) original experiment that could have contributed to their inability to detect an effect of endogenous attention's influence on ILM. Experiment 3 was modeled after Downing and Treisman's (1997) methods in order determine whether leaving the primers on during probe presentation, displaying the probe line for a long duration, and presenting the probe close to the primers, would result in the ability to detect an endogenous ILM effect. In addition, untrained naive observers were tested and a 2AFC response was not used, thereby correcting for two factors that were raised as possible reasons for the failed replication. Finally, to bolster confidence that observers were attending at the time that the probe line was presented, trials were self-initiated.

## EXPERIMENT 3

In order to investigate whether more conventional stimulus presentation methods would lead to different results, the current experiment was used to reinvestigate the issues raised by Downing and Treisman's (1997) Experiment 3.

### *Method*

*Observers*. Sixteen members of the university community participated in a single 45 minute experimental session in exchange for partial course credit or financial remuneration. All observers reported normal or corrected-to-normal vision.

*Apparatus and Stimuli*. The stimuli were presented on a Macintosh Color Plus display controlled by a Macintosh LC630 microcomputer running SplayPicts 1.1 tachistoscopic software (Schmidt, 1995). All of the stimuli were presented on a white background. A small black cross in the middle of the display (composed of two lines 0.2° wide and 1.0° long) acted as a fixation marker. The primers were red and green square boxes (0.6° per side) presented 5.0° to the left and right of fixation, and 3.0° above fixation. The probe line was a solid black bar, 0.6° high and 10.0° long, that joined the two primers. The letters used in the discrimination task were T, X, S, and C, presented in Helvetica 28 point type. These letters (1.0° high and 0.8° wide) were presented in black.

*Procedure.* Each observer sat in a dimly lit room at a distance of 57 cm from the computer monitor, with their head steadied by a chinrest. On each trial a beep sounded to indicate that the trial was beginning, and then a fixation cross appeared in the middle of the screen. The observer was told to fixate the cross and not move their eyes from it. Shortly afterwards (1000 msec), two differently colored boxes appeared; one above and to the left of fixation, and the other above and to the right of fixation. Each observer was assigned a color to attend, and told that once they had allocated their attention to the box of that color, to press the mouse button with their right hand while their left hand was poised over the keyboard ready to respond.

The experiment was executed in three phases as in Experiment 3 of Downing and Treisman (1997).

In Phase 1, subjects were told that either a 'T' or an 'X' would appear in the display (along with a 'C' or an 'S' distracter) at the location of one of the two colored boxes, and they were to indicate which of these letters had appeared by pressing one of two keys on the keyboard. The left cursor key was marked with the letter 'T', and the right cursor key was marked with the letter 'X'. Subjects were instructed to press the key corresponding to the letter that was presented, as quickly and accurately as possible.

In Phase 2, subjects were informed that a solid bar would appear between the colored boxes once they had indicated that their attention was allocated. These line motion trials displayed the probe line, which joined the primer locations, until the participant entered their first response. Observers were instructed that their task on these trials was to report on their experience of motion.

To examine motion perception, the following query appeared superimposed at the bottom of the display 750 msec after the probe line's appearance: Enter motion percept: "1) in one direction, 2) toward center, 3) no motion." If observers experienced motion in a single direction, they were to enter 1, and if they experienced no motion within the bar, they were to enter 3. A response of 2 was reserved for the perception of the bar growing inwards from the primers and colliding centrally.

If the observer entered a response of either 1 or 2, then they were further questioned about their perception of motion. First, the direction of motion was queried by clearing the screen and presenting the following prompt: Enter principle direction of motion: "1) Leftwards, 2) Rightwards". If the observer had indicated that they perceived a collision then a third option was presented: "3) Collides in center". Second, the clarity of the motion percept was questioned with the prompt: "Enter clarity of motion in the range 1 ... 9". Observers were told that a response of 1 indicated a very weak motion percept, while a response of 9 indicated a clear percept of motion.

In Phase 3 of the experiment, the trials from Phases 1 and 2 were randomly intermixed. Subjects were again instructed to press the mouse button with their right hand once they had allocated their attention to the appropriately colored box. They were further instructed to be sure to have their left hand positioned over the 'T' and 'X' response keys in case the trial should be a discrimination trial. Subjects were told to respond appropriately according to the type of trial that was presented.

In each phase, trial order was randomized separately for each subject, and twenty randomly selected practice trials preceded data collection. Data from practice trials were discarded.

Unlike the original Hikosaka et al. (1993b) or Downing and Treisman studies, the trials in the current experiment were all self-initiated. Rather than assuming that subjects had allocated their attention within 400 msec, observers were required to take the initiative of signaling that their attention had been allocated before the critical stimuli were presented.

*Design*. In each phase, half of the trials presented the red square on the left, and the other half presented it on the right. Half of the subjects were instructed to attend the red box, and half were to attend the green box.

In Phase 1 there were 64 experimental trials. The target letter was presented at the location of the attended box on 75% of the trials (valid trials), and at the opposite location on the remaining trials (invalid trials). The distracter letter was a 'C' or a 'S' equally often.

In Phase 2 there were 40 experimental line motion trials.

Phase 3 consisted of 104 trials resulting from the combination of the trials from Phases 1 and 2.

*Results*

Separate data analyses were used to examine each phase for effects of cue-validity and the frequency of illusory line motion elicited.[3]

*Phase 1.* Phase 1 was a discrimination task. Mean RTs for correct discrimination trials were calculated for each observer and subjected to a 2 X 2 mixed effects analysis of variance (ANOVA). The attended box color was a between-subjects factor and target validity was a within-subjects factor. Cell means appear in Appendix G.

The box color attended did not significantly affect the discrimination results, as demonstrated by a non-significant main effect of attended box color and a non-significant interaction between box color and target validity. Targets appearing at the validly cued box were responded to significantly ($F_{(1,12)}$=10.62, $MS_e$=8309.99, $p$<.002) more quickly (653 msec) than at the invalidly cued box (765 msec). Hence using a RT measure, observers showed a 112 msec cueing effect. An identical analysis of the frequency of discrimination errors revealed no significant effects.

*Phase 2.* Phase 2 was a line motion judgment task. The frequency of observer responses was calculated for each of the five possible motion classifications. Complete cell means appear in Appendix H. The line was reported as colliding in the middle between the attended and unattended box 16% of the time, and as being drawn all at once with no motion 13% of the time. A further 8% of reports involved a collision, with the principal direction of motion being away from the attended box 6% of the time and principally away from the unattended box 2% of the time. When no collision was perceived, the line was reported as drawn away from the attended box 30% of the time, and toward it 32% of the time. Hence the line was principally away from the attended box 36% of the time versus principally away from the unattended box 34% of the time.

The subjects' mean frequencies were analyzed using Wilcoxon Signed Rank tests (a violation of independence prevented the use of parametric statistics). The attended object did not elicit motion away from itself more than did the unattended object, regardless of whether a collision was experienced (all $p$'s>.05).

A 2 (attended box color) X 5 (motion classification) mixed effects ANOVA was carried out with motion strength as the dependent variable to ensure that the box color attended did not systematically affect observers' motion ratings. The between groups box color factor was not significant ($F_{(1,12)}=1.45$, $MS_e=15.06$, $p>.25$). Complete cell means appear in Appendix H.

Strength ratings for trials that produced motion away from the location that was to be attended were contrasted against those that produced motion away from the unattended side. These included both trials reported as motion in a single direction, and trials that involved a collision with motion dominating in one direction. Motion away from the attended box was coded as a positive strength value, while strength ratings for motion perceived toward the attended box were made negative. The average of the values yielded a net motion effect whose sign indicated direction. A mean motion strength value of -1.08 was obtained, which did not differ significantly from zero ($t_{13}=-.996$, $p>.15$). Hence there was no net effect of motion strength in Phase 2. An examination of the data on a subject by subject basis revealed a variety of response patterns.

*Phase 3.* In Phase 3 the discrimination and line motion judgment tasks were combined. Trials for these tasks were separated and analyzed as in Phases 1 and 2 above. Complete cell means appear in Appendix I.

*Phase 3 - discrimination.* As in Phase 1, the box color attended did not significantly affect discrimination results, as demonstrated by a non-significant main effect of attended box color and a non-significant interaction between box color and target validity. Targets appearing at the validly cued box were responded to significantly ($F(1,14)=20.44$, $MS_e=4324.37$, $p<.0005$) more quickly (657 msec) than at the invalidly cued box (762 msec). Hence observers showed a 105 msec cueing effect. An examination of the data on a subject by subject basis revealed that all participants conformed to this pattern of effects. An identical analysis of discrimination errors revealed no significant effects.

*Phase 3 - line motion.* As in Phase 2, the frequency of report was calculated for each of the five possible classifications. The complete breakdown of observer responses are presented in Figure 43 collapsed across the attended color factor. The line was reported as colliding in the middle between the attended and unattended box 29% of the time, and as being drawn all at once with no motion 10% of the time. A further 11% of reports involved a collision, with the principal direction of motion being away from the attended box 8% of the time and principally away from the unattended box 3% of the time. When no collision was perceived, the line was reported as drawn away from the attended box 33% of the time, and toward it 18% of the time. Hence the line was principally away from the attended box 41% of the time versus principally away from the unattended box 21% of the time.

The subjects' mean frequencies were analyzed using Wilcoxon Signed Rank tests. Illusory motion was experienced away from the attended item more frequently than from the unattended item ($T_{-}(16)=19.0$, $p<.02$) even when the contribution of motion trials with collision were excluded ($T_{-}(15)=18.0$, $p<.02$). An examination of the data on a subject by subject basis revealed that 14 of the 16 observers conformed to this pattern of effects.

A 2 (attended box color) X 5 (motion classification) mixed effects ANOVA was carried out to ensure that the box color attended did not systematically affect observers' motion ratings. The between groups box color factor was not significant ($F(1,12)=0.50$, $MS_e=10.04$, $p>.25$).

The average strength ratings for trials that produced motion was computed as in Phase 2. A mean motion strength value of 1.44 was obtained, which was significantly different from zero ($t_{15}$=2.31, $p$<.05). Hence, a net effect of motion away from the attended location was observed.

### *Discussion*

The current experiment demonstrated the elicitation of ILM using endogenous attentional cueing methods in conjunction with a RT task verifying the allocation of attention. Note however, that only in Phase 3, where discrimination task trials were randomly intermixed with the line judgment task, did the latter show an effect of endogenous attention on ILM direction and strength. Mixing discrimination task trials, which require that attention be allocated in order to successfully carry out the task (Phase 3), resulted in significantly more ($t_{13}$=-3.21, $p$<.007) reports of line motion away from the attended location, compared to simply presenting the probe (Phase 2), as revealed by a paired t-test using observations from the 14 subjects who completed both phases. It may be the case that unmotivated participants require that measures be taken to ensure that they are fulfilling task requirements (i.e., attending as instructed) - particularly with demanding tasks such as covertly directing endogenous attention.

This observation of an endogenous effect on the directionality and strength of ILM was accomplished using untrained naive observers and without requiring that participants select one of two distinct motion directions (no-motion and motion collision classifications were allowed). This finding suggests that these factors were unlikely to be critical in Downing and Treisman's (1997) failure to replicate Hikosaka et al. (1993b).

One surprising outcome of this experiment was the weakness of the ILM judgments and the low frequency of motion reports (compared to Hikosaka et al., 1993b) consistent with the attentionally modulated gradient hypothesis. If the illusion is not influenced by attention, one might suspect a weak effect was found because of demand characteristics of the experimental situation. Several lines of evidence mitigate against this conclusion. First, subjects were free to choose among alternative motion classifications, and there was no more demand for one direction versus the other (both toward and away from the attended item were legitimate responses). Second, observers had the option of reporting that they experienced no motion in the line, or motion from both ends colliding in the center; again, there was just as much demand for such responses as for the response consistent with the attentional hypothesis. Finally, there was a difference between phases 2 and 3 in the frequency of motion report consistent with an effect of endogenous attention on the illusion. Had demand characteristics been responsible for the replication of Hikosaka et al. (1993b), those same characteristics would have been in effect in both phases of the experiment. The fact that only an effect of endogenous attention was present when observers were required to attend as instructed, strengthens the conclusion that endogenous attention modulates ILM.

Weak motion may be present for a number of reasons. The use of undergraduate participants as compared to experienced psychophysical observers (as in Hikosaka et al., 1993b) undoubtedly played a role. One subject, whose data are averaged with the rest, consistently reported motion opposite in direction to the classic illusion. The debriefing of undergraduate subjects has revealed that confusion over the use of the terms "rightwards" and "leftwards" is common in such experiments conducted with undergraduates using exogenous cueing (see Experiment 5). Such participants may not only be less motivated than their experienced counterparts, but they may not understand precisely what is meant by the term 'motion' as applied to these displays. The term "motion" commonly refers to the spatial displacement of an object, though here, because there is no spatial displacement (as there is in the case of a display with a gap between the primer and probe) it is used to refer to the extension of an object over time and space.

A more worrisome source for the finding of a weak effect is the possibility that it may be an artifact of eye movements. An experience of motion may have been induced away from where subjects were fixating (Bartley, 1936), or it may have been introduced by eye movements themselves. Although observers were instructed not to move their eyes from the fixation cross, they may have done so anyhow. Had observers fixated the object that they were to instructed to attend, then the possibility exists that motion away from the foveated region (which may transmit signals faster than the periphery) could be responsible for the endogenous ILM effect observed (see Bartley, 1936).

## EXPERIMENT 4

A second experiment, similar to Experiment 3 was undertaken in which eye movements were monitored to ensure that observers remained fixated. Before the experimental session, observers were presented with a simple demonstration of the exogenous form of the illusion in order to familiarize them with what was meant by "motion" in the displays. Additionally, to exclude potential worries about luminance differences between the attended boxes, the colored boxes were replaced with a black circle and a black triangle. Making the display items a uniform color was expected to strengthen the motion experience because intra-attribute motion has been found to be slightly stronger than inter-attribute motion (von Grünau & Faubert, 1994).

### *Method*

*Observers*. Eight undergraduates participated in a single 40 minute experimental session in exchange for partial course credit. All observers reported normal or corrected-to-normal vision.

*Apparatus and Stimuli*. The apparatus from Experiment 4 was augmented with an EyeTrak Model 210 eye movement monitoring system interfaced to the computer through a National Instruments NI DAQ I/O card. Rather than presenting colored boxes for participants to attend, the current experiment used a circle and an equilateral triangle, each of which would fit into a square 0.9° on all sides. These shapes were centered around the vertical meridian and joined by a probe bar that was 0.9° high and 9.2° long and centered 2.5° above a fixation cross. There was a slight, 0.2° gap between either shape and the bar. A rating scale, consisting of a thin horizontal line (10° long) with a set of 20 evenly spaced hash marks (including marks on the ends), appeared 3° below fixation. Above the left end of the scale was the word "Leftwards"; above the right end of the scale was the word "Rightwards"; and above the middle of the scale were the words "No Motion". The two central-most hash marks were absent to indicate a distinct "No Motion" area. All display elements were black presented on a gray background, and letter stimuli were identical to those of Experiment 3.

*Procedure.* The procedure was identical to Experiment 3 with a few exceptions. Before the experiment began, participants were given the text in the Appendix J to read. They were then shown a brief Microsoft Powerpoint demonstration of the exogenous version of the illusion so that they would know what was being referred to as 'motion' in the display. The demonstration consisted of the simple presentation of exogenous ILM in the rightwards direction produced by a cue on the left side of the display followed by a bar, and then after an intervening blank screen, by ILM in the leftwards direction produced by a cue on the right side of the display followed by a bar. The experimenter was careful not to mention direction of motion, but simply ensured that the participant experienced the line as being drawn over time. Each observer was assigned a shape to attend and told that if they moved their eyes from fixation on any trial, they would have to repeat that trial later. In order for data from a trial to be accepted, fixation was required from the time that the participant initiated the trial until 500 msec after the probe line or letter stimuli appeared. The eye movement monitoring system was calibrated before the beginning of each session. The experiment consisted of two blocks similar to Phase 3 from Experiment 3. The first block was intended to familiarize the participant with the task. Data from the second session were of interest.

The response was relayed using a simple rating scale with "Leftwards Motion" on the left side of the scale, "No Motion" in the middle, and "Rightwards Motion" on the right side of the scale. Participants were told to report the principal strength and direction of illusory motion by moving a cursor with the mouse to a location on the scale and clicking. The magnitude of the effect was indicated by the extremity of the response and the direction was indicated by the laterality of the response. If an experience of motion from either side colliding in the center of the display ensued then they were to click in the "No Motion" region of the response scale. The rating scale was superimposed at the bottom of the display 500 msec after the probe line's appearance. Strength ratings were recorded on a scale from -100 to 100, where the sign indicated the direction of motion relative to the location of the object that the participant was instructed to attend (positive being away and negative being toward). Participants did not need to use the entire length of the scale, but were encouraged to do so. The no motion portion of the scale stretch from -12 to 12.

*Design.* Only one phase was run. It contained mixed motion judgment and discrimination task trials. Half of the trials presented the circle on the left and the triangle on the right. Half of the subjects were instructed to attend the circle, and half were to attend the triangle.

The target letter ('T' or 'X') was presented at the location of the attended shape on 75% of the trials (valid trials), and at the opposite location on the remaining trials (invalid trials). The distracter letter was a 'C' or a 'S' equally often.

The number of line motion trials was increased from Experiment 3 to 27 per side from 20 per side, for a total of 54. There were 64 discrimination trials as in Experiment 3.

*Results*

Trials for the line motion and discrimination tasks were analyzed separately for the experimental block. Complete cell means for all measures are presented in Appendix K.

*Discrimination.* A 2X2 repeated measures ANOVA contrasting target validity (valid versus invalid) and target identity (T versus X) revealed only a significant main effect of target validity ($F(1,7)=5.95$, $MS_e=41316.57$, $p<.05$) for trials on which correct discriminations were made. Responses were on average 175 msec faster when the target appeared at the location which subjects were instructed to attend (754 msec) versus the invalid location (929 msec). Six of the eight subjects showed this pattern of valid faster than invalid RT.

Errors were also analyzed using a 2X2 repeated measures ANOVA contrasting target validity (valid versus invalid) and target identity (T versus X). The only significant effect was a main effect of target identity ($F(1,7)=6.52$, $MS_e=1.92$, $p<.05$). Participants made more errors when the target was an X (1.25) versus T (0.68). There was no difference ($p>.05$) between errors on valid (1.13) and invalid (0.81) trials.

*Illusory line motion.* Wilcoxon Signed Rank tests were used to contrast the frequency of motion classifications. Motion away from the attended location was reported 62% of the time while motion toward it was reported 30%, and no motion was reported 8% of the time. ILM occurred significantly ($T_{-}(8)=1.50$, $p<.03$) more frequently away from the attended shape than toward it. Seven of the eight subjects demonstrated this pattern of effects. The illusion also occurred more frequently than experiences of no motion ($T_{-}(8)=0.0$, $p<.02$) for all observers.

Strength ratings were on a scale from -100 to 100, where the sign indicated the direction of motion relative to the attended location (positive being away and negative being toward). The average strength rating was 25.17, which was significantly greater than zero ($t_7=2.53$, $p<.05$). Hence, a net effect of motion away from the attended location was observed. Six of the eight subjects showed this pattern of motion strength.

### *Discussion*

The results of Experiment 4 replicate the finding that endogenous attention can influence the perceived direction of ILM as verified by the concomitant administration of both an ILM and a RT task. Furthermore, these results were obtained using untrained naive undergraduate subjects who were free to make several choices regarding their motion experience. Even more rigorously, subjects maintained fixation, thus ensuring that observer reports of motion were not artifacts of eye movements.[4]

The frequency of motion away from the attended location increased significantly in Experiment 4 versus Experiment 3 as was verified using an unpaired t-test on the frequencies of motion away from the attended locations in these two experiments ($t_{22}=3.65$, $p<.002$). This is likely due to a couple of factors. First, a demonstration of what was meant by "motion" in such experiments was added. Rather than requiring subjects to judge the motion of a spatially displaced object, it is the within-object experience of the line appearing over time that is required to be judged. In executing Experiment 1-2 (and other work with the illusion) it became clear that many untrained naive subjects do not immediately apprehend what is meant by the term "motion" in the context of motion within an object. The addition of a pre-experiment demonstration makes it clear precisely what component of the percept on which observers are to base their report. A second difference between the first two experiments concerns the attribute dimensions of the primer and probe. In Experiment 3, the primers differed from the probe in terms of color and luminance, whereas in Experiment 4, the primers and probe shared the same color and luminance attributes. Although the exogenous form of the illusion is robust across intra-attribute primer-probe differences, von Grünau and Faubert (1994) reported that intra-attribute effects were marginally stronger than between attribute effects. Apparently the extra integration involved across attribute dimensions can cause the illusory percept to be weakened.

## EXPERIMENT 5

Introspectively, endogenously produced ILM is weaker than exogenously produced ILM. Combining these two different forms of eliciting the illusion in a single experiment may cause observers to rate the weaker endogenous motion experience as negligible compared to the over-powering experience of exogenous ILM. Experiment 5 reproduced Experiment 4 with the addition of exogenously cued trials in order to quantify the (expected) difference in the illusion resulting from the two forms of cueing, and to determine whether mixing the two cue types weakens the resulting endogenous ILM motion ratings.

### *Method*

*Observers.* Nine undergraduates participated in a single 40 minute experimental session in exchange for partial course credit. All observers reported normal or corrected-to-normal vision.

*Procedure.* Experiment 5 was run without eye movement monitoring, otherwise the apparatus and stimuli were identical to Experiment 4. Exogenous elicitation of the illusion was accomplished by presenting only a fixation cross until the subject initiated the trial. One of the shapes was then presented (the circle and triangle were presented equally often, and appeared on the left or right equally often), followed by the line probe 360 msec later. After 500 msec, the rating scale appeared at the bottom of the screen and observers were required to indicate the strength and direction of their motion percept. As in Experiment 4, participants were given the instruction sheet in the Appendix to read, and were shown a simple demonstration of exogenous ILM before the experiment began.

*Design.* The design was similar to Experiment 4. There were 26 line motion trials per side for each of the endogenous and exogenous forms of eliciting the illusion (104 total). There were 64 discrimination trials as in Experiments 3 and 4. Practice was reduced to 50 randomly selected trials.

### *Results*

Trials for the line motion and discrimination tasks were analyzed separately. As in Experiment 3, one subject reported the exact opposite pattern of motion compared to the exogenous form of the illusion. Although this subject likely confused "leftwards" and "rightwards", the means and analyses include these data. Complete cell means for all measures are presented in Appendix L.

*Discrimination.* A 2X2 repeated measures ANOVA contrasting target validity (valid versus invalid) and target identity (T versus X) failed to reveal any significant RT effects for trials on which correct discriminations were made (all $p$'s > .05).

However, reanalyzing the data after excluding RTs more than two standard deviations above each subject's mean, in addition to trials in which discrimination errors were made (in total, 12% of trials), revealed a significant main effect of target validity ($F_{(1,8)}$=8.13, $MS_e$=6348.54, $p$<.05). Responses were on average 76 msec faster when the target appeared at the location which subjects were instructed to attend (931 msec) versus the invalid location (1007 msec). Seven of the subjects showed this pattern of valid faster than invalid RT.

Discrimination errors were also analyzed using a 2X2 repeated measures ANOVA contrasting target validity (valid versus invalid) and target identity (T versus X). None of the effects was significant (all $p$'s < .05). Valid trials were erroneously responded to 4% of the time versus 5% for invalid trials.

*Exogenous illusory line motion.* Wilcoxon Signed Rank tests were used to contrast the frequency of motion classifications. Motion away from the primer was reported 84% of the time while motion toward it was reported 12%, and no motion was reported 4% of the time. ILM occurred significantly ($T_-$(8)=6.5, p=.05) more frequently away from the primer than toward it. Eight of the nine observers showed this pattern of responding. The illusion also occurred more frequently than experiences of no motion ($T_-$(8)=0.0, p<.02).

Strength ratings indicated strong motion (37/100) away from the exogenous cue, which was significantly greater than zero ($t_7$=3.17, $p$<.01).

*Endogenous illusory line motion.* Motion away from the attended primer was reported 37% of the time while motion toward it was reported 18%, and no motion was reported 45% of the time. ILM occurred significantly ($T_-$(8)=0.0, p<.02) more frequently away from the primer than toward it. Eight of the nine observers showed this pattern of responding. The frequency of the illusion and responses of no motion did not differ significantly ($T_-$(9)=28.0, p>.50).

Despite the lower frequency of motion away from the attended location, the motion strength measure (13/100) indicated significant motion away from the attended location

($t_8$=2.56, $p$<.05) as compared with zero. The motion strength represents the average of all the motion strength ratings including no motion responses.

Contrasting the reported motion strengths for endogenous versus exogenous cueing methods using a one-tailed paired t-test revealed, as expected, that the exogenous method elicited significantly stronger motion ($t_8$=2.21, $p$<.05) than the endogenous method.

*Discussion*

The results clearly show that eliciting ILM exogenously resulted in a stronger motion percept compared to eliciting it endogenously. Although mixing cueing methods in the same session resulted in a less frequent report of endogenously elicited motion (37%) compared with Experiment 4 (62%), it did not significantly reduce the strength of the motion reported as determined by an unpaired t-test on the motion strength measure ($t_{15}$=1.19, $p$=.25). Hence, mixing endogenous and exogenous trials is not likely to be the main reason for Downing and Treisman's (1997, Experiment 3) failure to elicit ILM endogenously. One other factor that may have contributed to the reduced endogenous effect (with both RT and ILM measures) in Experiment 5 versus Experiment 4 may be the lower cue validity resulting from the inclusion of more motion trials in Experiment 5. The fact that both ILM and RT demonstrated a similar reduction in strength suggests that both may be affected by cue validity, as would be expected if both were influenced by endogenous attention.

The inclusion of exogenous ILM cueing methods had the expected effect of increasing the frequency of no motion responses. Hence the juxtaposition of strong illusory motion with weaker illusory motion, had the effect of changing observer's criterion for reporting motion within the probe. The frequency of no motion responses (ratings that fell within the range -12 to 12, corresponding to the words "No Motion" on the scale) to endogenous cueing in Experiment 4 (8%) was significantly less ($t_{14}$=4.16, $p$<.001) than in Experiment 5 (45%) as revealed by an unpaired t-test.

Once again, endogenous attention was shown to influence the perceived direction of ILM for untrained, naive observers, as verified by the concomitant administration of an ILM and a RT task.

## GENERAL DISCUSSION

Hikosaka et al. (1993b) reported that ILM was influenced by stimulus-induced and voluntary attention. Downing and Treisman (1997) reported a failure to replicate an important piece of this original work when they used untrained naive subjects and allowed freedom in observers' motion classifications, thereby suggesting that voluntary attention did not modulate the illusion in this paradigm. Several subtle implementation differences may have contributed to this failure to reproduce an endogenous effect. First, the primer and the probe stimuli were separated by a substantial gap. Because the allocation of attention is frequently confined to a limited spatial region, the probe may have been outside of endogenous attention's focus, and the effect may have been weakened at the probe's location. Second, Downing and Treisman's (1997) probe stimulus was presented only briefly, which would be expected to result in two directionally conflicting percepts of motion within the line, not motion in a single direction (Holt-Hansen, 1970, 1973; Schmidt & Pylyshyn, 1994; Schmidt & Klein, 1997). Finally, the primer and probe stimuli did not overlap temporally. The simultaneous offset of the primers in conjunction with the onset (and subsequent offset only 45 msec later) of the probe could have disrupted observers' abilities to detect motion.

The goal of the current chapter was to investigate whether an endogenous effect of attention could be detected with spatially and temporally overlapping primer and probe stimuli and a longer presentation of the probe line while still using untrained naive observers and allowing a range of motion classifications. In three separate experiments, an effect of endogenous attention on ILM was found that was consistent with, though weaker than, the original Hikosaka et al. (1993b) report.

In Experiment 3 an effect of endogenous attention on ILM was found using a double-priming paradigm (Faubert & von Grünau, 1992, 1995). When observers attended one of two non-isoluminant colored priming boxes presented at either side of the display, motion within a black probe bar was more frequently experienced away from the attended location than away from the unattended location. This was the case only when the task was accompanied by a letter discrimination task confirming the traditional pattern of RT effect taken to indicate the operation of attention. These observations suggest that endogenous attention had the effect of modulating one of the two competing cues at the will of the naive untrained observer. Participants were allowed to make a range of motion strength assignments, including opting for reporting no motion or collisions within the probe bar, yet they more frequently reported motion away from (or primarily away from) the attended location.

In Experiment 4, eye fixation was monitored to ensure that the reported effects of motion were not artifacts of eye movements being systematically made. Additionally, the primer stimuli were altered to be black shapes (a circle and a triangle) from the same stimulus dimensions as the probe (i.e., matched for luminance and for color) because von Grünau and Faubert (1994) have reported that for the exogenous form of the illusion, intra-attribute illusory motion effects are more robust than inter-attribute effects. Additionally, observers were shown a pre-experiment demonstration of the basic illusion so that they understood what was meant by the term "motion" in the experimental context, and an expanded rating scale was used. Stronger effects of endogenous attention on ILM directionality were found as a result of these manipulations.

Experiment 5 supplemented Experiment 4 with a set of exogenously cued illusion trials in order to confirm that endogenous motion effects are phenomenologically weaker than exogenous effects. In addition, the experiment sought to determine whether the juxtaposition of endogenous and exogenous forms of the illusion would result in the report of "no motion" for endogenously produced ILM compared to the stronger motion elicited by exogenous cueing. Although significantly more ratings of no motion occurred on endogenous trials as a result of the inclusion of exogenous trials, there was a still a significant net motion away from the endogenously attended location.

*Other studies of ILM involving endogenous attention*

Several other investigations involving the relation between endogenous attention and ILM have been reported. Intrilogator and Cavanagh (1994) reported on the use of a line probe in an object tracking task. Observers were instructed to endogenously track a moving object and a line probe was presented at various times from the onset of the task, and at various locations on the trajectory of the tracked or untracked objects. Illusory motion occurred away from the projected trajectory of the tracked object more often than away from similar locales for untracked distracter objects. Motion away from locations where the tracked moving object had been was reduced compared to where the object was expected to go. These results were interpreted as suggesting that ILM revealed the focus of endogenous attention as it was involved in the tracking task.

Klein and Christie (1996) undertook an extensive examination of endogenously versus exogenously elicited ILM. Using a double-primer paradigm (Faubert & von Grünau, 1992, 1995) these investigators mixed trials with exogenous cues, endogenous (central arrow) cues, lines drawn over time, and simple detection trials. Fixation was monitored, naive subjects were used, and a response scale was employed. No effect of endogenous attention was found even though a simple detection RT measure suggested that attention was allocated endogenously.

Although the source of the discrepancy between the current work and that of Klein and Christie is unclear, a number of factors may have contributed to their results. The mixture of drawn motion and exogenous illusory motion may have made subjects devalue their motion experiences for the weaker endogenous case, as in Experiment 5. More likely though, is that collisions may have occurred frequently in the endogenous case and subjects would have had difficulty classifying such percepts on a scale that did not take collisions into account. In Experiment 3, 48% of trials resulted in collisions while in Downing and Treisman's (1997) experiment, collisions were reported 85% of the time. Collision information was not independently sought in Experiments 5 and 6, though subjects had been instructed to report the principal motion experienced. If collisions occurred frequently on Klein and Christie's (1996) endogenously cued trials, but not on the exogenously cued trials, then comparably low motion ratings in the former would be expected. A third potential source of difference relates to the luminance levels of the stimuli. Klein and Christie (1996) delivered their display using an oscilloscope while the current experiments used a simple computer monitor. Given that the illusion is sensitive to luminance and may be dominantly driven by luminance pathways (Steinman, Steinman & Lehmkuhle, 1997) it is feasible that swamping such pathways with an intense stimulus could make any endogenous modulation negligible.

### *Downing and Treisman's Experiment 2 Reexamined*

Downing and Treisman (1997) do not deny that attention influences ILM. What they do question is whether a temporal and spatial gradient of signals arriving at a motion detection system is responsible for the illusion. They conclude: "Manipulations of endogenously directed attention showed a clear dissociation between attention effects facilitating a letter discrimination and the strength *(their Experiment 2A)* or presence *(their Experiment 3)* of the line-motion illusion, casting doubt on the claim that a gradient of attention plays a causal role in the illusion" (page 777, italicized items did not appear in the original text). The bulk of the current chapter has presented data demonstrating why Downing and Treisman failed to find an effect of endogenous attention on ILM in their Experiment 3 while still finding a RT effect. The claim of a dissociation between endogenous attentional facilitation of a letter discrimination task and the strength of the illusion as reported in their Experiment 2A, will now be addressed.

In Experiment 2A, Downing and Treisman (1997) undertook a rigorous extension and replication of a different experiment previously reported by Hikosaka et al. (1993b) in which ILM was claimed to occur away from an exogenously cued, but endogenously tracked object. Hikosaka et al.'s (1993b) original presentation of this work did not attempt to confirm the operation of attention using traditional measures such as RT. As with their extension of Hikosaka et al.'s (1993b) other work, Downing and Treisman's modification included a test to confirm that endogenous attention was operating as expected in this paradigm by way of a discrimination task. This experiment revealed that the conditions under which attention was operating as revealed by a RT measure (valid letter discrimination trials faster than invalid), were precisely those conditions under which ILM was operating.

While the discrimination task results did not demonstrate an interaction between the extent of tracking and the magnitude of the cueing effect, the ILM was strongest at the first exogenously cued location, and was substantially weaker at the other two distances probed. Downing and Treisman (1997) interpreted this as demonstrating that attentional effects could not be responsible for both of the measures, or both measures would have behaved identically. Based on this RT and motion strength dissociation, they concluded that ILM was not measuring the effects of endogenous attention while RT was.[5] However, looking at the details of the experiment and results is informative and challenging to this conclusion.

In this paradigm four location markers were presented, and one of them was exogenously cued by disappearing for 300 msec and then reappearing for 75 msec. At this point, the line probe was presented in the 0° degree rotation condition, or the set of dots were rotated 90° or 180° degrees, at 60° degrees per second, on the circumference of an imaginary circle before the probe item was presented. The results revealed the highest motion rating away from the 0° (75 msec SOA) condition, and lower ratings in the 90° (1575 msec SOA) and 180° (3075 msec SOA) conditions. Ratings were 2.00, 0.64 and 0.73 for the 0°, 90° and 180° conditions respectively. This is precisely what would be expected given that exogenously cued ILM is stronger than endogenous ILM (see Experiment 5, and Hikosaka et al., 1993b). It is also expected given that the illusion has been found to result from a combination of perceptual and attentional factors (Hecht, 1995; McColl & Schmidt, 1996; Steinman, Steinman, & Lehmkuhle, 1995; von Grünau, Dube & Kwas, 1996; von Grünau, Saikali, & Faubert, 1995).

The interaction between ILM magnitude and rotational extent is likely to have derived from the difference at the 0° rotation condition (rating of 1.97) where primarily exogenous factors (the onset of the item to be tracked) contribute to the motion rating, and from the 90° (rating of 0.64) and 180° (rating of 0.73) conditions where endogenous attention is the primary contributor to the effect (i.e., there are and have been, no onsets at these locations). A re-analysis of Downing and Treisman's motion strength data reveals, as would be expected if the above account is correct, that the only decline to be found is the difference of the 0° from the 90° ($F(1,46)=38.39$, $MS_e=0.56$, $p<.0001$) and from the 180° conditions ($F(1,46)=33.20$, $MS_e=0.56$, $p<.0001$). There is no difference between the 90° and 180° conditions ($F(1,46)=0.19$, $MS_e=0.56$, $p=.67$). If there truly were a decline in the level of motion strength with spatial extent, the latter difference should be found. As it stands, it is not even in the right direction for a decline. Hence the claim of an endogenous attention dissociation between ILM and RT measures is unwarranted for these data because it rests with a single data point that is more exogenously than endogenously influenced.

### *Problems with the Proposed Attention-Biasing Account*

Instead of accepting that an attentionally modulated gradient of signal arrival times at a motion processing system might be the source of the illusion, Downing and Treisman (1997, page 774) proposed that "Rather than inducing a neural asynchrony that stimulates motion detectors, attention may bias the apparent motion binding process that selects which stimuli represent the same object across time." This binding process can, on their account, occur without attention or can use attentional selection as a starting point for the binding process. To explain data demonstrating an effect of attention of judgments of temporal order (Stelmach & Herdman, 1991; Stelmach, Herdman & MacNeil, 1994) Downing and Treisman give a new account of the notion of "prior entry" (Titchener, 1908). In the case of temporal order judgments "... the attended element takes precedence in initiating an object file, and the unattended one is subsequently bound to the same object file, giving rise to the perception of apparent motion" (page 777). That is, they claim attention's role is that it "... can bias which sensory data are given precedence in initiating a representation of a single object" (page 777). However, implicit in these claims are terms involving temporal asynchrony like "precedence" and "subsequent", as well as some sort of system capable of detecting motion. Hence even the impletion account relies on temporal asynchrony and a motion detector, thereby adopting the properties of the gradient account that they claim are incorrect.

Downing and Treisman (1997) predicted from their attention-biasing account that replacing the line probe with a dot probe should yield an attention-biased apparent motion, and confirmed this prediction in their Experiment 2B. They compared the number of observers showing an effect of motion away from the attended item in each of their Experiments 2A and 2B, and found the proportion of subjects showing a net effect of endogenous attention to be similar in the two experiments. One problem for Downing and Treisman's (1997) claim that simply replacing the line probe with a dot probe produces similar results (recall Chapter 5) because ILM is an apparent motion related process, is that there was a difference between ratings in their ILM and apparent motion displays in these experiments. Although it was not reported in their paper, an analysis of their motion data using a 2 (probe item) X 3 (target position) mixed effects ANOVA (where probe item is a between subjects factor and target position is a within subjects factor), reveals a significant effect of target position ($F(2,60)=47.76$, $MSe=31.24$, $p<.0001$), and a significant interaction ($F(2,60)=3.73$, $MSe=31.24$, $p<.05$). Though no simple effects tests of this interaction proved significant ($p$'s >.05) the source is apparently a greater rating of motion strength for the apparent motion probe at the 0° rotation coupled with a lower rating of motion strength at the 180° rotation, with equal strengths at the 90° rotation. While presenting their results, Downing and Treisman (1997, page 775) stated: "Directly comparing ratings between the two studies is not ideal, as participants were rating qualitatively different displays." However it is unclear why the same criteria were not applied to their earlier experiments which claimed that phenomenologically apparent motion and ILM produce similar motion judgments.

One further problem for Downing and Treisman's (1997) proposed alternative attention-biasing account is that it predicts an effect of endogenous attention in their Experiment 3. Although the reported dissociation between their ILM and RT findings (which has been demonstrated not to be a dissociation) was flagged as problematic for the gradient account, the same dissociation and problem applied to the attention-biasing account they accepted.

### *Impletion or gradient modulation by attention?*

Where does this leave the argument that ILM is due to apparent motion impletion and not an attentionally modulated gradient of arrival times at a motion detecting system? The current work demonstrates that evidence has not been presented against a gradient explanation regarding the role of endogenous attention. Further, the current experiments combined with those presented in Chapter 5, which were motivated by precise gradient theory predictions (i.e., the role of probing the space directly adjacent to the primer, and of leaving the primer illuminated), attest to the utility inherent in the gradient account. At the same time however, existing evidence between endogenous attention and ILM is still correlational, not causal.

Collectively, the current findings fit well with a gradient account in which multiple spatial gradients surround display objects and govern the arrival times of visual signals arising from nearby to those objects (Hikosaka et al., 1993a, 1993b; Schmidt, Fisher & Pylyshyn, 1998; Schmidt & Klein, 1997). The gradients, which have a large perceptual component (Hecht, 1995; von Grünau, Dube & Kwas, 1996; von Grünau, Saikali, & Faubert, 1995), may counteract one another (as in the case of split-priming; Faubert & von Grünau, 1992, 1995) resulting in a bi-directional motion collision or more fragile unidirectional motion percept. Endogenous attention fits into this framework in that it can have a modulatory effect on the speed of signal transmission in the visual system (as proposed by Stelmach & Herdman, 1991), and thereby influence the direction of ILM, particularly when perceptual contributions to signal arrival time are held constant. Such endogenous modulation is apparently weaker than exogenous modulation of the gradient, the latter being necessarily confounded with perpetual components of ILM.

# CHAPTER 7: COUNTEREXAMPLES TO GRADIENT THEORY?

Several apparent counterexamples have been raised to the gradient notion of ILM based on a number of stimulus configurations presented in Chapter 1. This chapter reexamines some of these effects in an experimental context in order to clarify what observers experience when presented with such stimuli. Experiment 6 presents the stimulus configuration from Figure 20 in order to determine whether it is the case that naive observers do not experience motion in a probe that is disconnected from the primer and presented on the far side of an occluder. Experiment 7 examines the arrow display shown in Figure 34 to determine if motion is found within a probe in the direction away from an arrowhead primer regardless of the primer and probe arrangement. Finally, Experiments 8 and 9 reexamine the flanker display of Figure 11 to determine whether it is legitimate to conclude that a gradient representation cannot underlie ILM because gradient theory predictions are violated when a priming bar is presented alongside a double-primer display.

## DOES A LACK OF AMODAL COMPLETION PREVENT ILM?

An interesting finding that conflicts with the gradient account was reported by Tse et al. (1998) as presented in Figure 20. It was reported that when the probe is presented behind an occluding object as in Figure 20a, motion continues behind the occluder as would be expected if amodal completion (the completing of the contours of a figure that are obscured by another occluding figure) were occurring before the motion detection stage. This is expected too, on the extended gradient account which hypothesizes multiple spatial gradients in different attribute maps which are integrated at a later time. The gradient is set up in the map of the primer and the entire probe is influenced.

The example in Figure 20b however, is claimed not to demonstrate motion within the portion of the probe bar that is on the opposite side of the occluder from the primer. While the prediction of the gradient model is that such motion may be weaker by virtue of the non-continuous motion within the probe, motion would still be expected to occur away from the primer in the portion of the probe on the opposite side of the occluder from the primer. Tse et al. (1998) claim that in this example, amodal completion does not occur because the presence of T-junctions associated with different parts of the probe make it clear that the probe is not a single object that is occluded by the large rectangle. Tse et al. (1998) state: "However, in (b), where we eliminated the T-junctions necessary for amodal completion, an entirely different percept is usually reported. Here the cue appears to transform into only the overlapping cue of frame 2. The distant portion of the bar is usually described by subjects as simply turning on all at once, simultaneous with the occurrence of the Transformational Apparent Motion of the overlapping cue. We argue that this occurs because now the overlapping (left-hand) portion of the bar is segmented as a separate figure from the more distant (right-hand) portion of bar. The small square of frame 1 is matched to only the overlapping portion, allowing a shape change to occur between it and the overlapping portion. The non-overlapping portion, because it is parsed as being a new figure, cannot undergo a shape change from anything else" (page 9-10).

## EXPERIMENT 6

To verify the claims of Tse et al. (1998) and to directly test the gradient hypothesis, an experiment was conducted that examined the motion percepts of observers using the stimuli presented in Figure 20, as well as a series of displays from Tse et al. (1995) in which it was claimed that modal completion (the completing of the contours of a figure that is there only in form but not in essence -- an illusory figure) occurs prior to motion analysis.

### *Method*

*Observers.* Six naive volunteers participated in a single 45 minute experimental session. Two volunteers were lab members and four were undergraduates earning partial course credit. All observers reported normal or corrected-to-normal vision.

*Apparatus and Stimuli.* The stimuli were presented on a Macintosh Color Plus display controlled by a Macintosh LC630 microcomputer running the author's SplayPicts 1.1 experiment software package. The stimuli are presented to scale in Figure 20 and in Figure 44. All of the stimuli were presented on a white background. A small black cross in the middle of the display (composed of two lines 0.2° wide and 1.0° long) acted as a fixation marker.

In the amodal completion stimuli of Figure 20, the square primer (1.5° per side) and the probe (15° long) were green while the rectangular object that served as an occluder was red (4.5° X 7.5°). In the amodal and modal completion stimuli of Figure 44, the primer (1.5° per side) and probe (14.5° long) which completed amodally (4.5° X 7.5°) behind the modally completed Kanisza (1979) triangle were yellow, while the triangle (9.5° per side) place holders were black.

*Procedure.* Each observer sat in a dimly lit room at a distance of 57 cm from the computer monitor, with their head steadied by a chinrest.

On every trial, a beep signaled the trial's beginning and the fixation cross was presented for 1000 msec, followed by the primer and either a rectangle or a Kanisza (1979) triangle for 45, 255, 750 or 1245 msec. The primer side was counterbalanced. The probe was then presented until the observer made a motion rating as in Experiment 1, except that observers were instructed to judge motion within the portion of the bar that was on the opposite side of the display from the primer.

There was a total of 200 trials presented randomly, 40 for each of the 5 displays. For each of the 4 SOAs there were 5 trials presented with the primer on the right and 5 with the primer on the left. Twenty practice trials were randomly selected and the data from them were discarded.

### *Results and Discussion*

The frequency of no motion report is of interest here, so the occurrence of no motion responses was tabulated and averaged for each condition collapsed over SOAs. A paired one-tailed t-test failed to reveal a difference between the frequency of no motion reported (*p*>.10) between the displays of Figure 20a and 20b . Hence there weren't even significantly more no motion responses in the display that did not involve occlusion (23%) than in the display that did (20%). It was clear that the majority of motion classifications were consistent with motion away from the primer regardless of the display (69% in the display with amodal completion versus 75% in the display without).

Motion strength ratings were subjected to a 4 (SOA) X 5 (display) repeated measures ANOVA. A complete report of the cell means appears in Appendix M. Only the main effect of display turned out to be significant ($F_{(4,20)}$=8.40, $MS_e$=266.19, *p*<.0005) reflecting different strengths of motion depending on the display. Observers rated motion within the portion of the bar opposite the primer as producing a strength of 43 in the amodally completing probe of display Figure 20a, versus 37 in the display which Tse et al. (1998) claim there is usually no motion experienced (Figure 20b). A planned contrast showed this difference not to be significant (*p*>.20).

An examination of the displays that required completion behind the illusory Kanisza triangle (Figure 44) revealed a similar pattern of effects. Again the most frequent motion reported in the probe item on the opposite side of the occluder from the primer was motion away from the primer (61%, 63% and 50% for Figures 44a, b and c respectively). No motion was reported in this probe item 28% of the time in the completion condition which is not significantly different from the non-completion conditions (24% and 34% respectively for Figures 44b and 44c) as assessed using one-tailed paired t-tests (all *p*'s>.35).

Observers rated motion strength within the portion of the bar opposite the primer as having a strength of 27 in the amodally completing display (Figure 44a) versus 28 and 18 in the two displays that do not complete in this fashion (Figures 44b and 44c respectively). A planned contrast revealed the difference between the mean motion rating of the probes that should not have involved completion, not to have differed significantly ($p$>.35) from the rating of the amodally completed probe.

Tse et al. (1998) stated "We have argued that parsing occurs prior to the perception of motion for displays such as we have shown. An integral part of parsing a scene is completing or inferring missing contour and figure information. ... If we are correct in our assertion that parsing takes place before Transformational Apparent Motion, then we must show that it demonstrates modal and amodal completion" (page 9).

Contrary to the results reported by Tse et al. (1995, 1998) the displays presented in Figures 20 and 44 appear to support the gradient model's predictions and do not provide evidence in support of their claim that ILM-related phenomena must occur after completion mechanisms have acted. The current experiment tested a range of SOAs to ensure that the effect was not being missed. Furthermore it used the displays that Tse et al. (1995, 1998) presented as demonstrating that parsing and completion occurs prior to the perception of motion.

Where does this result leave the conclusions and model of Tse et al. (1998)? A founding assumption of their account is that TAM operates on completed figures. For instance, this assumption is required in order for them to explain any examples in which there is a gap between the primers and probes yet motion ensues within the probe (e.g., Figures 26, 27 and 28). The current results cannot rule out that TAM operates on completed figures, or that the motion experienced does occur after edges are assigned to objects, but neither of these assumptions are problematic for the gradient hypothesis either. The current findings do demonstrate that there is no proof for these assumptions of the TAM account. Furthermore, and of central interest for the purposes at hand, it demonstrates another case in which gradient model predictions have proven to be correct.

One more interesting point related to the stimuli of Figure 20a concerns the explanation of this configuration by the formotion account. As discussed in Chapter 4, formotion explains this example by suggesting that different depths are separated out by the model, and the boundary wave is formed in the far plane. However, as would be expected on the gradient account, motion ensues from the primer to the far end of the probe even if all of the objects presented are of the same color. Under such circumstances the formotion account has no information suggesting different depths. It would then predict that boundaries are slowly formed where the large rectangle forms T-junctions with the probe due to the local inhibitory effects of differently-oriented bipole cells. This leaves faster-forming probe boundaries near the primer and in the portion of the probe opposite the primer. Hence motion within the probe would incorrectly be expected from either end toward the large rectangle.

## DO ARROWS REALLY PREDICT THE DIRECTION OF MOTION?

Baloch and Grossberg (1997) reported the results of an experiment allegedly carried out by Shinsuke Shimojo. They cited the results as a personal communication with Shimojo. The purported experiment demonstrated that if one decomposes an arrow figure and uses the arrowhead as a primer and the arrow's shaft as the probe, that motion is always in the direction that the arrowhead is pointing (see Figure 34).

This result goes against the gradient hypothesis prediction that motion within the probe (the arrow shaft) should be away from the priming item regardless of interpretive properties of the primer such as the direction that it is pointing (contra Figure 34a). Furthermore, normally with an arrow such as that presented in Figure 34a, the shaft is joining a concave figure which the gradient hypothesis suggests should produce weaker or less frequent ILM. Recall that the hypothesized reason for this is that the gradient surrounding such an item would reveal conflicting motion directions within the probe, resulting in a weaker integrated motion (as described in Chapter 2 regarding the example of Figure 18d).

## EXPERIMENT 7

Experiment 7 was designed to further examine the gradient predictions outlined above when the primer is an arrowhead and the probe is a horizontal bar.

### *Method*

*Observers.* Ten subjects participated in a single 30 minute experimental session. One volunteer was the author and the nine recruits were naive lab members or undergraduates earning partial course credit. All observers reported normal or corrected-to-normal vision.

*Apparatus and Stimuli.* The stimuli were presented on a Macintosh Color Plus display controlled by a Macintosh LC630 microcomputer running the author's SplayPicts 1.1 experiment software package. The stimuli are presented to scale in Figure 34. All of the stimuli were black presented on a white background. A small black cross in the middle of the display (composed of two lines 0.2° wide and 1.0° long) acted as a fixation marker.

The arrowhead was 3.5° tall and 1.5° deep, with a line thickness of 0.5°. The arrow shaft was of the same thickness, and 11.5° long. The stimulus presented was centered horizontally in the display and presented 3° above the center of the fixation cross.

*Procedure.* Each observer sat in a dimly lit room at a distance of 57 cm from the computer monitor, with their head steadied by a chinrest.

On every trial, a beep signaled the trial's beginning and the fixation cross was presented for 1000 msec, followed by the primer which was an arrowhead on the left or the right, facing either left or right. The primer was presented for 105 or 1005 msec before being accompanied by the arrow's shaft. In addition to the current stimuli the experiment included several other stimulus configurations unrelated to the arrow display (stimuli similar to those of Figure 18a), which will not be discussed. Observers were first asked to categorize their motion experience as either smooth motion, no motion or a collision, and then they were asked to rate the motion direction and strength as in previous experiments.

There was a total of 80 arrow trials presented randomly, 40 for each of the configurations displayed in Figure 34. For each of the 2 SOAs there were 20 trials presented, half with the primer on the right and half with the primer on the left. Twenty practice trials were randomly selected and the data from them were discarded.

*Results and Discussion*

Motion strength ratings and the frequency of motion ratings consistent with the predictions of the gradient model were subjected to separate 2 (SOA) X 2 (display) repeated measures ANOVA. The cell means appear in Appendix N. For the motion strength dependent measure, the main effect of display was significant ($F_{(1,9)}=7.16$, $MS_e=139.26$, $p<.05$) reflecting a stronger motion rating when the shaft was pointed at by the arrowhead (52; Figure 34b) than when it was part of an arrow (42; Figure 34a). In terms of the frequency measure, motion was significantly ($F_{(1,9)}=8.68$, $MS_e=3.73$, $p<.05$) more frequently away from the arrowhead pointing at the line probe (79%; Figure 34b), than away from the arrowhead forming a conventional arrow (70%). Hence contrary to the report of Baloch and Grossberg (1997) motion is not found to be consistently in the direction that the arrowhead primer is pointing when the primer and probe make up a conventional arrow figure. Rather, it is in the opposite direction, away from the direction the arrow indicates, 70% of the time. Furthermore, the motion strength is weaker for an arrow figure than for a figure composed of an arrowhead pointing at the line probe. These direction and strength effects were both predicted by the gradient account.

The main effect of SOA was found to be significant in terms of both motion strength and frequency. The illusion occurred more frequently at the early SOA (86% versus 63%; $F_{(1,9)}=9.46$, $MS_e=22.38$, $p<.05$). Similarly, the motion strength was rated as stronger at the early SOA than the later SOA (56 versus 39; $F_{(1,9)}=6.47$, $MS_e=463.22$, $p<.05$)

The incorrect report by Baloch and Grossberg (1997) was a personal communication to them. Nonetheless, they explicitly claim that, and show how, their model predicts such an effect. The current results not only demonstrate that the gradient account's predictions once again hold true, but in addition, they demonstrate that either

Baloch and Grossberg's (1997) model is incorrect, or that it has such a large number of degrees of freedom that it can too easily be applied to accommodate practically any finding. If it is the case that the model is so flexible that it can accommodate any finding then it is difficult to falsify and also difficult to use a predictive tool to put to empirical test.

## THE FLANKER DISPLAY

As discussed in Chapter 1, if a flanking probe bar (or flanker) is presented to one side of a double-primer display then it is frequently the case that no collision is perceived centrally, but instead motion is experienced in a single direction (see Figure 11; Faubert & von Grünau, 1995). This example presents a problem for gradient theories because there is no obvious reason why such an addition would be expected to disrupt motion within the bar that is presented centrally. Rather, if a set of gradients surrounding the priming stimuli were present then displaying a probe bar over top of them should cause a collision centrally, just as in Figure 8.

Downing and Treisman (1997) criticized the gradient account based on the above result. In an experiment they questioned naive observers on their motion percepts in the situation where two primers appear followed by two probe lines: one probe was presented between the primers and the other flanking one of the primers, either off to the left or to the right. In this situation they found that there is commonly a percept of motion in a single direction away from the priming stimuli (Downing & Treisman, 1997; Faubert & von Grünau, 1995). This led them to reject the gradient hypothesis of ILM in favor of a high level explanation of the illusion.

As previously discussed, several studies have demonstrated that phi motion (motion derived from the presentation of a number of temporally and spatially successive stimuli), or luminance gradient motion (von Grünau et al., 1995) can actually be used to counteract the ILM percept (Miyauchi, Hikosaka, & Shimojo, 1992; Schmidt et al., 1998; Steinman et al., 1995). These phenomena suggest that ILM is an effect of signals arriving over time and space at a motion detection system. Downing and Treisman (1997) claim that ILM is a cognitive process and not the result of graded signals arriving at a motion detection system.

Experiment 8 capitalizes on the ability to counteract ILM using apparent motion by investigating whether the presentation of a flanking bar in the double-primer paradigm affects the perception of signals that really are arriving over time and space within the area between the primers. If the flanking bar causes a deterioration of the motion experience for observers then it is highly likely that some other process (or processes) are obscuring or overriding the signals in this locale even though a gradient mechanism may still be operating. If on the other hand there is no effect of the flanking bar on the experience of actual signals arriving over time and space in this display, then it is legitimate to conclude that there is no illusory introduction of a signal delay occurring in this paradigm.

## EXPERIMENT 8

Experiment 8 was designed to examine whether the presentation of a peripheral bar, or flanker, can act to mask or impair the percept of actual as well as illusory motion between the two primers of a double-primer display. The display presentation conditions are presented in Figure 45. In one condition, called the central line condition, double-primer displays were used in which two primers appeared followed shortly afterwards by a central line joining them (see Figure 8). The gradient account suggests that a collision percept should be experienced by observers. In a second condition, called the simultaneous flanker condition, the presentation of the central line in the double-primer display was accompanied by a flanking line on either the left or the right hand side of the display (see Figure 11). These two conditions served as a baseline for three experimental conditions.

In the three experimental conditions, a collision in the central line was physically drawn over time. In the drawn collision condition, only a collision in the central line was presented over time - that is, dots were drawn inwards from either primer with a temporal delay. The remaining two conditions were similar, but included an accompanying flanker.

This peripheral flanking bar appeared either immediately before the collision was drawn (the drawn/flanker-before condition) or immediately after the collision was drawn (the drawn/flanker-after condition). If the temporal asynchrony of signals that are actually delivered to observers over time and space cannot be detected by subjects when a flanker is present, then this paradigm is not adequate to reject a gradient of arrival times as a mechanism underlying ILM under normal circumstances. Such a result would demonstrate that the presentation of the peripheral bar interferes with a subject's ability to report on the collision component of the central line; hence using this paradigm to reject the gradient hypothesis is problematic.

### *Method*

*Observers.* Ten undergraduates participated in a single 20 minute experimental session in exchange for course credit. All observers reported normal or corrected-to-normal vision.

*Apparatus and Stimuli.* The stimuli were presented on a Tektronix 604A oscilloscope equipped with a fast decay P15 phosphor. The oscilloscope was controlled by a National Instruments data acquisition card (NB-MIO-16) in an Apple Macintosh IIx microcomputer.

A single point in the middle of the display (0.2°) acted as a fixation marker. The primers were similar points located 1.5° to the right or left of fixation, and 2.0° above fixation. The central line stimulus was composed of 40 evenly spaced dots joining the two possible primer locations. When the central line was presented all at once, it appeared at the maximum speed of the apparatus (under 1 msec), as did the flanker. In conditions in which the central line was drawn on over time, this was determined as outlined below.

The flanker was a line segment of equivalent density that extended the collision display to the left or the right by 3.0° (the same length as the central line). The fixation point and the primers had a luminance of 3 cd/m$^2$, while a section of the line had a luminance of 12 cd/m$^2$.

*Procedure*. Each observer sat in a dimly lit room at a distance of 57 cm from the display. The observer's head was steadied by a headrest, and each trial was initiated by the observer's previous response, or in the case of the first trial, by the experimenter.

In the first phase of the experiment the drawing time required for observers to experience an illusory collision in the line was estimated for each participant, and this estimate was then used in the drawn conditions of the experiment's second phase. The use of this temporal interval matches the drawn collision situation as closely as possible to the illusory collision. Hence observers were equally good at detecting drawn and illusory collisions in phase two. This temporal parameter was estimated by having observers adjust the speed of a drawn collision so that it appeared indistinguishable from an illusory collision. Both the illusory and the drawn collision were presented on the same screen. To create the illusory collision a pair of primers appeared 2.0° above a fixation point for 150 msec after which a line appeared at once. At this time an identical line began to be drawn from both ends toward its center an equal distance below the fixation point. On each trial, observers were asked whether the top line was presented more quickly, more slowly or at the same speed as the bottom line. The rate of drawing in the bottom line was adjusted in order to present the two lines at the same perceived rate.

In phase 2 observers were told not to move their eyes from fixation and that on each trial two dots would appear followed shortly afterwards by the appearance of a line. The subjects were requested to categorize their percepts of the portion of the line that fell between the two dots[6] into one of three classes: 1) motion in the line from the right to the left (leftwards), 2) motion in the line from the left to the right (rightwards), or, 3) motion in the line away from both primers colliding centrally (collision). After providing this judgment, observers were prompted for an integer in the range of 1 to 9 indicating how strong their motion percept was, with a 9 indicating a well-defined motion percept, and a 1 indicating a weakly-defined motion percept. A pen and paper drawing was used to indicate to the subject precisely the portion of the display of interest.

There were five experimental conditions as illustrated in Figure 45. When the central line was drawn inwards to collide over time it was over a duration determined in phase 1 to be perceptually equivalent to the illusory collision. Two collision display sequences consisted of two primers for 150 msec followed by a central connecting line segment that either appeared all at once (central line condition) or was drawn inwards from both ends (drawn collision condition).

The remaining three conditions had flanking bars. In each of these displays two primers were presented followed by a central line connecting them, along with a flanking line segment to the left or right of one of the primers. In the simultaneous flanker condition, the flanking line segment appeared at the same time as the central line. In the drawn flanker-before condition, the flanking line appeared as the central line was beginning to be drawn. In the drawn flanker-after condition, the flanking line appeared upon the completed presentation of the central line segment.

There were 100 experimental trials: 20 replications of each of the 5 experimental conditions. Conditions with flanking line segments presented the flanker on the left side of the leftmost primer on half of the trials, and on the right side of the rightmost primer on the other half of the trials. Twenty randomly selected practice trials were presented before the experimental trials to give subjects experience with the range of motion that they would encounter within the displays. Data from practice trials were discarded. Practice and experimental trials were randomized separately for each observer.

### *Results and Discussion*

In phase 1, the average collision was estimated to occur over a duration of 19.8 msec. The range of estimates derived was from 7 msec to 38.5 msec.

The frequency of collision reported in phase 2, and the judged strength of motion in each of the five conditions (central line, drawn collision, simultaneous flanker, drawn/flanker-before and drawn/flanker-after) was determined and subjected to a one-way repeated measures ANOVA. The mean frequency of collision report and the associated

Table 1. The mean frequency of collision reported within the central line, and the associated mean strength of this percept on a scale from 1 to 9 in Experiment 8.

| condition | collision frequency | strength of percept |
|---|---|---|
| **flanker absent** | | |
| central line | 98.5% | 7.6 |
| drawn collision | 99.5% | 7.8 |
| **flanker present** | | |
| simultaneous flanker | 10.0% | 1.5 |
| drawn/flanker-before | 27.5% | 2.2 |
| drawn/flanker-after | 17.5% | 2.3 |

strength of the collision percept in each condition is presented in Table 1. If an observer contributed no observations for a cell, the weakest motion strength rating was substituted for that cell.

The frequency analysis revealed a significant main effect ($F(4,36)=773.60$, $MS_e=10.82$, $p<.0001$), as did the analysis of motion strength ($F(4,36)=75.28$, $MS_e=1.29$, $p<.0001$). These effects were investigated using planned comparison analyses.

Importantly, there was a difference in the frequency of collisions reported in the central line (98.5%) and simultaneous flanker conditions (10.0%; $F(1,36)=144.77$, $MS_e=10.82$, $p<.0001$), thereby confirming that observers infrequently report motion in the central line when a flanker appears simultaneously with it (Downing & Treisman, 1997; Faubert & von Grünau, 1995). Judgments of the percept strength paralleled this effect ($F(1,36)=183.99$, $MS_e=1.29$, $p<.0001$) with strong judgments of collision strength in the central line condition (7.6) and a weak judgment in the simultaneously flanked condition (1.5).

The purpose of the current experiment was to determine whether the presence of the flanker would interfere with an observer's ability to experience motion within the central portion of the line. A planned comparison contrasting the frequency of collision report when the line was actually drawn colliding (99.5%) revealed that regardless as to whether the flanker appeared before (27.5%) or after (17.5%) the collision, significantly more collisions were perceived in the flanker's absence ($F_{(1,36)}=146.12$, $MS_e=10.82$, $p<.0001$). Therefore, the flanker's presence masked subject's perceptions of motion in the central line. The results of the motion strength judgments mirrored those of frequency. When a collision was experienced, it was rated significantly more strongly in the drawn collision condition (7.8, $F_{(1,36)}=156.80$, $MS_e=1.29$, $p<.0001$) compared to when the flanker was presented either before (2.2) or after (2.3) the collision took place.

A final planned comparison was carried out contrasting the frequency of collision reported when the flanker appeared before the collision versus after. If the flanker was more disruptive to motion appearing before the flanker's presentation (backward masking) then a lower frequency of collision would be expected in the condition where the flanker appeared after the drawn collision. On the other hand, if the flanker disrupted subsequently presented motion (forward masking), then a lower frequency of collision would be expected in the condition where the flanker appeared before the drawn collision. The result of the planned contrast suggested that regardless of the time of presentation, the flanker was equally disruptive ($p>.15$). The frequency of collision when the flanker appeared before the drawn collision was 27.5% versus 17.5% when the flanker appeared after the collision. The strength of perceived motion did not significantly differ ($p>.90$) in these conditions, with strengths of 2.2 and 2.3 when the flanker appeared before versus after the central line.

These results are clear: in the presence of a flanking line even the presentation of visual signals across time and space were insufficient to produce a collision percept within the central line, demonstrating that the flanker's presence affected observers' perceptions of the display. The flanker had a masking effect on motion within the central line as revealed by the finding that observers are unable to detect a real gradient of arrival times that they independently judged as causing a collision experience. Because signals that were actually arriving over time and space could not be detected as such, it is not valid to draw negative inferences about the gradient model from the finding that the presence of a flanker tends to eliminate observers' reports of illusory collision. The output of a gradient mechanism may be masked under such stimulus presentation conditions, as is the experience of drawn motion from successively arriving stimulus signals.

## EXPERIMENT 9

Although Experiment 8 demonstrated that a gradient mechanism cannot be ruled out because of observers' frequent percept of motion in a single direction in flanker displays, the effect of the flanker remains to be explained. It is possible that this experience is an artifact of other perceptual factors. One possible explanation that is compatible with the extended gradient theory is that motion direction signal integration across space leads observers to conclude that motion in a single direction occurred, even though motion detectors may have received conflicting signals.

It is generally found that the most common motion direction signal in a display dominates the less frequently occurring direction signals (e.g., motion coherence phenomena; Sutherland, 1961; Mather, 1980; Mather & Moulden, 1980; Williams & Sekuler, 1984). Indeed evidence was found in Experiment 1 that the strength of motion perceived is a function of the area of the probe that taps the spatial gradient. According to the gradient account of the illusion, 75% of all the motion direction signals arising from the probe stimulus in the flanker display would have indicated a direction consistent with the percept that was found to dominate (50% of all signals indicating motion in the direction of the flanker would come from the flanker itself, and a further 25% from the central bar closest to the primer that is not adjoined to the flanker). According to this hypothesis, the remaining 25% of signals which were required to be detected in order to support the gradient account would have been nullified, or overridden. Note further, that this minority 25% of signals is embedded between signals indicating the opposite direction, further weakening the likelihood that they would be easily detected.

To test whether a motion integration explanation of the flanker display is plausible an experiment was conducted in which the size of the flanking bar was systematically manipulated. If a motion integration explanation is correct, then on the gradient account one would expect that as the area of the flanker is increased so that an increasing proportion of signals are producing motion toward the flanker, then observers' reports of motion in that direction should increase systematically.

Precisely what an impletion account would predict is unclear because there is no mechanism upon which to base a prediction. Because the impletion hypothesis rejects the notion of temporally asynchronous signals arriving at a motion detection system as the source of the illusory motion experience, it cannot appeal to motion integration processes as an explanation. If impletion is strictly concerned with matching object instances from one view to the next, then it shouldn't matter what size the flanker is, one would always expect the flanker to be matched as expanding away from the closest primer.

### *Method*

*Observers.* Ten undergraduates participated in a single 25 minute experimental session in exchange for course credit. All observers reported normal or corrected-to-normal vision.

*Apparatus and Stimuli.* The stimuli were presented on a Macintosh Color Plus display controlled by a Macintosh LC630 microcomputer running the first author's SplayPicts 1.1 experiment software package.

All of the stimuli presented were black on a white background. A small cross in the middle of the display (composed of two lines 0.2° wide and 1.0° long) acted as a fixation marker. The primer objects (see Figure 11) were black squares (0.6°), and the full flanker stimulus which connected one of the squares (either on the left or on the right) was 0.6°

thick and ranged from 0.7° to 7.0° long in 10 segments. The central bar connecting the two primers was 0.6° thick and 7.5° long. At the end of each trial, two questions were asked in turn at the bottom of the screen in an area 17° wide and 7° high.

*Procedure.* Each observer sat in a dimly lit room at a distance of 57 cm from the computer monitor, with their head steadied by a chinrest.

On every trial, the fixation cross was presented for 1000 msec, followed by the priming squares alone for 150 msec, and then by the squares accompanied by a central bar joining the squares along with an optional flanker of varying length. The side on which the flanker appeared was counterbalanced, and no flanker appeared on one half of the trials.

After a delay of 750 msec, the following question was superimposed on the bottom of the display "Please indicate the DIRECTION of motion between the two squares", along with a line divided into three equal parts by vertical dividers. The left portion was marked with the words "Leftwards Only", the center was marked with "Toward Centre", and the right portion was marked "Rightwards Only". The subject's task was to move the mouse cursor over the desired response then to click the mouse to select the response. A second question was then presented in the same area of the display 500 msec later; it read "Please indicate the CLARITY of this motion experience". Observers were required to select a point along a 17° scale partitioned into 18 equal portions marked with "Not Clear" at the left, "Clear" in the center, and "Very Clear" at the right. Answering the second query initiated the next trial.

*Design.* There were 200 experimental trials: 5 replications from each of 10 flanker size conditions presented on either the left or the right side of the double-primers, plus 100 trials presented without a flanking bar. The experiment was a 2 (side of flanker - left or right) X 10 (flanker size - 0.75°, 1.50°, 2.25°, 3.00°, 3.75°, 4.50°, 5.25°, 6.00°, 6.75°, 7.50°) repeated measures design. The no flanker condition was highly represented to ensure that observers recalled what motion toward the center of the central bar looked like.

### *Results and Discussion*

The mean frequency of report of a collision in the central bar for each subject for each condition was computed and subjected to a 2 (flanker side) X 10 (flanker size) repeated measures ANOVA. When collision was not reported, motion toward the flanker was reported on all but 1.6% of trials.

The main effect of flanker size was significant ($F_{(1,9)}$=11.63, $MS_e$=1.94, $p$<.0001). As predicted by a motion integration hypothesis, the highest frequency of collision was reported in the conditions with the smallest sized flankers. The flanker side main effect did not reach significance ($F_{(1,9)}$=4.34, $MS_e$=0.78, $p$>.05), nor was there an interaction between flanker size and the side of the flanker presentation ($F_{(9,81)}$=1.95, $MS_e$=0.40, $p$>.05). Although it was not included in the analysis because it cannot vary across the side variable, when no flanking bar was presented collision was reported an average of 91% of the time.

The means of the flanker size main effect are plotted in Figure 46 as a function of the percentage of the total area of the display, that on the gradient account, should cause the motion detection system to signal that motion occurred in the direction that dominated observers reports (toward the flanker). Consistent with a gradient and integration interpretation, as the percentage of incoming motion signals increased, there was a decrease in the frequency of collisions reported within the central bar. Hence a motion grouping, or integration effect is occurring, whereby the motion experience reported is the motion component that dominates the display, and is not necessarily the result of an impletion process that has nothing to do with multiple motion signals. In the flanker conditions, a collision was experienced in the central bar 6-27% of the time.

Clarity ratings for trials in which collisions were reported were excluded, as were trials inconsistent with the illusion of motion in the central bar toward the flanker (1.6% of the total). The means of the remaining motion clarity ratings (ranging from 0 to 100) were subjected to a 2 (flanker side) X 10 (flanker size) repeated measures ANOVA. Empty cells prevented the same being done for flanker trials for which collision was reported.

A motion integration explanation of the double-primer display finding, on the gradient model, suggests that the clearest motion in the central bar in a direction consistent with the most frequently occurring motion signal, should be a function of the size of the flanker. The integration hypothesis holds that the more signals consistent with a given motion direction, the more likely one would expect that the minority of conflicting signals to be ignored. Similarly, the fewer conflicting signals there are, the more likely the resultant motion percept is to be clear. This view was supported by a significant flanker size main effect ($F(1,9)$=5.00, $MS_e$=470.35, $p$<.0001). The means of this main effect are plotted in Figure 47. There was a strong linear relationship between motion clarity and the size of the flanker ($F(1,9)$=37.62, $MS_e$=3537.15, $p$<.05). The flanker side main effect did not reach significance ($F(1,9)$=0.54, $MS_e$=24.11, $p$>.05), nor was there a significant interaction between flanker size and the side of the flanker presentation ($F(9,81)$=0.54, $MS_e$=24.,11, $p$>.05). The frequency of motion toward the flanker and the rated strength of that motion appears to reach asymptote when the flanker is approximately 4.5° or when 69% of the signals in the display indicate motion in the reported direction.

The results from Experiment 9 clearly support the notion that the resolved motion direction signal in double-primer displays strengthens as the proportion of consistent direction signals increases. As the proportion of signals that on a gradient account would indicate motion toward the flanker increased, observers less frequently experienced a collision in the central bar, and rated their non-collision motion experiences more strongly. These findings suggest that a motion detection system is involved that favors the dominant expression of motion in the display. Note that while the gradient account was rich enough to predict this outcome, the apparent motion impletion account and the TAM accounts make no solid predictions. An inhibitory motion surround (Steinman et al., 1995) may have also played a role in this outcome. If signals far from the primer are inhibited, the presentation of a bar with one end far out in the periphery might be expected to yield strong motion away from the uninhibited central portion.

# CHAPTER 8: FURTHER OBSERVATIONS

## DOES ILM INVOLVE MOTION DETECTORS?

All of the theories outlined in the first few chapters except for the apparent motion impletion explanation, assume that the source of motion in ILM is a motion detection system. That is, they assume that signals arrive over time and space and that some neural apparatus detects the temporal asynchrony in those signals and indicates motion in a direction based on the detected asynchrony (see Reichardt, 1959 for the foundational account of how such a detector might work). The impletion account on the other hand claims that "...it is this impletion transformation that is seen as the illusory line motion, rather than the firing of motion detectors resulting from an attention-induced asynchrony" (page 769, Downing & Treisman, 1997). Hence one way to distinguish these accounts is to determine whether the motion system is implicated.

Kawahara et al. (1996) reported preliminary evidence that motion detection mechanisms are affected by ILM as revealed by the experience of a motion after-effect (MAE) after adapting to an ILM display. They briefly alluded to an experiment in which they adapted for three minutes to a star shaped cluster of lines undergoing illusory motion as a result of cueing along the circumference of an imaginary circle. The motion experience was one of an imploding asterisk. After adapting, a circle was drawn intersecting the locale of the lines and three observers reported that the circle appeared to be expanding outwards for approximately 10-20 seconds -- in the opposite direction from the ILM, consistent with a motion adaptation after-effect.

In the following experiment the reverse situation was investigated: Would an adapting field of moving dots influence the strength or direction of subsequently produced ILM? Previous work with MAEs has revealed an aftereffect when full-field stimulation is presented after adaptation (Grindley & Wilkinson, 1953). Hence some sort of an aftereffect was expected when presenting a discrete bar stimulus. A finding of an interaction with respect to motion direction or strength would be taken as evidence that ILM and the moving dot field stimulus share processing mechanisms. No interaction or only a weak influence of the moving dot field would suggest that the two phenomena were distinct with the moving dot field presumably affecting motion detection mechanisms, and with ILM arising by some other means.

In addition to using a bar probe following a square primer, a control probe stimulus that was identical to the primer was included for several reasons. First, Klein and Hamm (1996) discovered that after an ILM experience, measures of attentional performance reveal enhanced processing of stimuli presented at the end of the line opposite the primer. This suggests that attention may follow the direction of the illusory motion. Based on this finding it was suggested that if the result of the experiment showed motion away from the direction of motion in the moving dot field, then perhaps such a result could be attributed to the moving dot field pulling attention to the side of the field where the motion is directed, and causing ILM to be experienced always away from that direction (Shinki Ando, personal communication). The inclusion of a simple dot probe would allow us to check for such an effect, as attention would be expected to cause an asynchrony in the presentation of this stimulus (Stelmach et al., 1994) resulting in the perception of motion away from the first presented primer. A second reason for including the control stimulus was to compare a so-called apparent motion probe (Downing & Treisman, 1997) with the line motion probe. Based on Experiments 1 and 2, a difference in the perceived motion would be expected for different probes.

## EXPERIMENT 10

Experiment 10 was carried out in order to investigate whether the prior presentation of a moving dot field would influence ILM directionality or strength.

### *Method*

*Observers*. Six volunteer members of the university community participated in a single 45 minute experimental session. Several had previous experience with ILM. All observers reported normal or corrected-to-normal vision.

*Apparatus and Stimuli*. The stimuli were presented on a 15 inch SuperVGA display controlled by a Macintosh G3 250 MHz microcomputer refreshed with a frequency of 67Hz. All of the stimuli were presented on a black background. A small white cross in the middle of the display (composed of two lines 0.2° wide and 1.0° long) acted as a fixation marker. The bottom of the moving dot field was 1.0° above the fixation marker and was centered horizontally on the screen. The dot field was 400 pixels wide and 100 pixels high (15° X 4.5°) and was randomly generated such that 5% of the pixels were illuminated at a given time.

When the dot field moved it did so by being translated 3 pixels per screen refresh or at a rate of 7.12°/s, with new dots occupying the trailing edge and the disappearance of dots from the leading edge. When stimuli were presented they were superimposed on (and occluded) the dot field, and were centered within it. For the simple illusion the primers were grey squares (0.5° per side) and the bar probe covered the primer locations as well as the 4.0° area between (0.5° high and 5.0° long).

*Procedure*. Each observer sat in a dimly lit room at a comfortable distance (approximately 57 cm) from the computer monitor. A fixation cross was presented throughout the trial. The session began with an exposure period in which the observer viewed the moving dot array for a period of 30 seconds after which a beep warned of an impending stimulus to be presented. The moving dots ceased to move 2 seconds later and the primer and probe, or just a probe stimulus was presented and a motion strength and direction judgment was sought using the same scale as in Experiment 1. Observers were instructed to rate their percept of motion within the display. For the bar probe this was expected (from the results of Experiments 1 and 2) to be a combination of motion between the primer and probe, and motion within the probe. For the square probe presented distant from the primer, primarily motion between the primer and the probe was expected to contribute to the rating. Immediately upon registration of the response the dot field began to move again for 5 seconds before the next warning beep and stimulus presentation occurred. After every 10 trials observers were exposed to the longer 30 second adaptation period. The opportunity to take a break was presented every 50 trials.

The experiment was executed in 3 phases, each with either a leftward-moving, rightward-moving or stationary dot field. The order of phase presentation was random. For each phase the simple illusion was presented with the primer square on the left, the right, or no primer. When there was no primer, the probe line simply appeared all at once. When there was a primer, it was presented for 60 msec. In addition to the simple ILM stimulus there was an apparent motion control stimulus in which both primer objects were presented with the left square or right square being presented first, or in which both appeared simultaneously. The asynchrony of presentation in these conditions was also 60 msec.

*Design.* There were two possible probe items: a horizontal bar probe encompassing the entire area between and including the primer locations, or squares covering the primer locations. There were three adapting background movement conditions (leftwards, rightwards and stationary), and there were three primer conditions (on the left, on the right, no primers). Hence the design was a 2 (probe item) X 3 (background motion) X 3 (primer position) factorial, with 4 observations per cell, for a total of 72 trials. Each observer did an extra block of 10 randomly selected trials at the beginning as practice, and data from these trials were discarded.

### *Results and Discussion*

Examining the cell means revealed that motion within the probe bar was judged in the opposite direction of the moving background regardless of the cueing manipulation (see Figure 49). Hence, a MAE occurred as measured using the horizontal probe bar, and this MAE overrode the directional effects of cueing when the two illusions were in conflict.

When the probe was a second square identical to the primer, only weak motion was reported, and it was strongest when there was a stationary dot field (see Figure 50).

Separate 3 (background motion) X 3 (primer position) repeated measure ANOVAs were carried out for the bar probe and the square probe. For the bar probe, the interaction effect was significant ($F(4,20)=4.40$, $MS_e=844.29$, $p<.01$). An examination of the cell means (see Figure 49) suggests that motion was always experienced away from the direction that the background was moving regardless of whether or not there was a primer. When the background was not moving motion was away from the primer. When there was no primer and no background motion, there was little motion reported. A further examination of these effects are reported in a separate analysis of the magnitude (ignoring direction) of these effects below.

There were significant main effects of both background motion ($F(2,10)=47.30$, $MS_e=1070.60$, $p<.0001$) and primer position ($F(2,10)=22.61$, $MS_e=539.15$, $p<.0002$). Motion was always perceived to be the opposite direction to the background motion (ratings of 59 for left and 47 for rightward moving backgrounds) and the mean was near zero (5) when there was no background motion. The primer position main effect resulted from net motion away from the primer (mean strength ratings of 29 for a left primer and 23 for a right primer) and there was a net effect of little motion (1) when there was no primer presented.

The ANOVA for the motion strength measure for the square probe that was identical to the primer revealed only a main effect of the primer position ($F(2,10)=5.39$, $MS_e=340.06$, $p<.05$). Motion was reported away from the direction of the moving background (9 for a leftward background, and 11 for a rightward background) and negligible motion was reported when the background was not moving (2).

To further examine the locus of these effects an analysis was carried out on the absolute values of the motion strength ratings. To determine whether the primer could at least reduce the motion experienced when there was a MAE, the motion strengths when the two illusions predicted motion in the same direction (left primer and left background, plus right primer and right background) were combined (the compatible condition), as were the ratings when the two illusions predicted conflicting results (the incompatible condition - left primer and right background, plus right primer plus left background). If the primer at least exerted an influence on the experienced motion, as would be expected if ILM and the MAE converged on the same locus, then the compatible strength ratings for the bar probe should be of a greater magnitude than the incompatible ratings.

Pure measures of ILM (the pure ILM condition) and the MAE (the pure MAE condition) were also derived in order to determine whether these exerted a qualitatively different effect on the subject's motion experience. The pure ILM rating was derived from the average absolute values of the motion strength ratings for the presentation of the illusion when there was no moving background (left and right primer conditions when there was no moving background). A measure of the pure MAE was derived when the background moved but no primers were presented before the probe (left and right background motion, but no primers presented).

Mean motion ratings for these four conditions were subjected to a 2 (probe type) X 4 (motion condition) repeated measures ANOVA. The analyzed cell means are graphed in Figure 51 along with the control condition of the presentation of a simple bar probe without a primer and without background motion.

The only significant effect was the main effect of probe item. Overall, motion was weaker when the probe was identical to the primer (9) compared to when it was a horizontal bar (53; $F_{(1,5)}=28.50$, $MS_e=831.01$, $p<.005$). Planned contrasts revealed no differences between the strengths of motion in the bar except for a difference between the compatible (64) and incompatible conditions (41; $F_{(1,20)}=15.66$, $MS_e=105.77$, $p<.005$). When the effects of ILM and MAE were in the same direction, greater motion was experienced than when they were in conflict. Clearly then, ILM and the MAE interact at a common locus at some level of processing.

When the probe was identical to the primer, motion was experienced most strongly in the pure MAE condition (21). Although the pure MAE strength rating was not different ($p$>.05) from the compatible motion condition (9), it was stronger than the incompatible condition (0; $F(1,20)=12.14$, $MS_e=105.77$, $p<.005$).

The only cells in the original design ignored by the above analysis were those corresponding to when the probe was presented alone on a stationary field. This condition was expected to not show an effect of motion (the stationary control condition), and was analyzed separately. The mean motion ratings (8 for the bar and 3 for the square probe) did not differ from zero as determined by one-sample t-tests, regardless of the probe used ($p$'s>.30).

The overall lower motion ratings observed with the apparent motion probe demonstrate yet another difference between ILM and apparent motion caused by the use of such a probe stimulus. Furthermore, the low strength of motion rated with this probe suggests that an attentional biasing in the direction of the moving dot field was not the source of the greater effect found with the horizontal bar probe. The current results clearly demonstrated that a simple MAE and ILM interact, suggesting that both involve the use of the same motion detection system.

## MORE THAN MEETS THE EYE

Several investigators have proposed that the illusory motion effect is a high-level cognitive phenomena involving the visual system's response to a world of objects in motion (Downing & Treisman, 1997; Tse & Cavanagh, 1995; Tse et al., 1998). Furthermore, several of the phenomena outlined in Chapter 1 seem not to be compatible with the gradient hypothesis. Perhaps as is historically the case in the majority of psychological debates, both accounts might be correct. That is, there might be a low level gradient sort of mechanism that contributes to higher-level mechanisms that parse the visual scene in terms of objects and object motion. There may even be backwards masking of motion experienced in light of object identification.

If there is a distinct set of object level processes then one might expect that the use of real objects or identical objects in motion would assist object matching processes. Experiments 1 and 2 failed to support the latter expectation because superior motion experiences were found when a bar probe was presented than when a probe identical in all respects to the primer was used. The current experiment re-examines the former expectation: Could the use of real objects result in a different motion experience than the use of more basic, less easily identifiable forms?

## EXPERIMENT 11

To examine this question, motion strength and direction resulting from the presentation of a primer and probe composed of identifiable objects were contrasted with similar measures from distorted control objects.

### *Method*

*Observers*. Twenty four undergraduates participated in a single 5 minute experimental session in exchange for partial course credit. All observers reported normal or corrected-to-normal vision.

*Apparatus and Stimuli*. The stimuli were presented on a ColorPlus display controlled by a Macintosh LC630 running Microsoft Powerpoint. In the identifiable object condition a baseball and bat were used from the clip art package that accompanied Corel WordPerfect 3.5 for Macintosh (see the lower items in Figure 52). As a control, these same objects were made less identifiable by randomly perturbing their pixels within a 3 pixel radius 50% of the time (see the upper items in Figure 52). That is, for each pixel in the picture there was a 50% chance that it would be exchanged randomly with one of its randomly selected neighbors 3 pixels away or closer.

*Procedure*. Subjects were run prior to their participation in another experiment. As in Experiment 4, participants were then shown a brief Microsoft Powerpoint demonstration of the exogenous version of the illusion so that they would know what was being referred to as 'motion' in the display. They were then shown a Powerpoint demonstration with 8 sequences of a fixation cross for 1 second followed by a primer item for approximately half a second. The probe item was presented next until they clicked the mouse button to continue. The primer item was presented on the left and right equally often, and the grip end of the bat (or perturbed probe) appeared equally often away from as nearby the primer. Participants were instructed that once they had observed a sequence they were to mark on a scale printed on a piece of paper, the direction and strength of motion that they experienced within the probe item. The scale was fashioned after those used in Experiment 1 and asked for a rating of motion within the second appearing item.

### *Results and Discussion*

The marks made by participants were measured and scaled to a value between -100 and 100, and converted to an absolute value indicating motion away from the primer. The values of each 2 (probe item) X 2 (bat grip side) X 2 (side of primer) sequence were subjected to a repeated measures ANOVA.

As expected if there were separable processes contributing to the perception of motion within the probe items, when the objects were identifiable items, motion was rated as being significantly weaker (29; $F(1,23)=9.19$, $MS_e=1548.66$, $p<.006$) than when the item was less identifiable (46). No interactions approached significance (all $p$'s>.60). The cell means appear in Appendix O.

This experiment demonstrates that although distinct motion ratings were made by observers when the objects presented were clearly identifiable, weaker motion was experienced. This finding suggests that a somewhat different set of processes is likely to govern the perception of motion in clearly identifiable objects than in simpler forms such as those generally presented in ILM experiments. This finding supports data reported from using simple forms (see Orlansky, 1940, and Kolers and Pomerantz, 1971), though the effect is clearly stronger here than has been previously found. Clearly, high level processes can override motion within a probe item. The circumstances under which such processes are applied is an avenue for future investigation.

# CHAPTER 9: GENERAL DISCUSSION

In the introductory chapters, ILM-related phenomena were presented followed by several proposed explanations of these effects. The gradient theory of ILM was put forward by Hikosaka et al. (1993a, 1993b, 1993c; and previously by Bartley, 1936, 1941) and has been informed by research since. Recall that the tenet here is that motion within the probe item is produced by the triggering of a motion detection system as successive signals arrive over time and space. A perceptually-based gradient (von Grünau et al., 1995; von Grünau et al., 1996) is hypothesized to facilitate the transmission of signals in the visual system by speeding their arrival and delaying their perceived offset (Schmidt & Klein, 1997). Attention is hypothesized to be able to modulate the gradient in a top-down fashion as demonstrated in Chapter 6, though exogenously elicited forms of the illusion are significantly stronger than, and may override (Klein & Christie, 1996), endogenous effects (Hikosaka et al., 1993b).

The assumption that a motion detection system is acting as the source of motion in ILM plays a strong role in the gradient explanation. In Experiment 10, evidence was presented that ILM and the MAE interact at some level of processing. The MAE was able to override ILM, as would be expected if the inputs to a motion system (either from real or illusory stimulation) were vetoed by prior stimulation of the motion system. In the same experiment when ILM and MAE were in a directional conflict, the magnitude of the motion response of the MAE was reduced. This effect would be expected if stimulation caused by the illusion were integrated by the same system responsible for the MAE.

The assumption that ILM affects the motion system is called upon to explain why the presentation of a bar at a large distance from a primer causes motion to be experienced toward rather than away from the priming item (Steinman et al, 1995). This effect is hypothesized to result from inhibited signal transmission in the surround compared to the center of vision, and is directly comparable to findings that motion detection systems exhibit an excitatory center, inhibitory surround organization (Loomis & Nakayama, 1973; Kim & Wilson, 1997; Murakami & Shimojo, 1995; Norman et al., 1996). Similarly, the hypothesis that ILM direction and strength can be predicted by the relative proportions and combinations of signals indicating motion in a given direction is based on the notion that a motion signal integrator is at work (Faubert, 1996; Mather, 1980; Mather & Moulden, 1980; Williams & Sekuler, 1984). The finding that motion away from concave contours is weaker than motion away from convex contours (Experiment 7) supports this assertion. Further support comes from the finding that as the area of the probe that is consistent with motion in a single direction increases over 50%, the frequency of motion experienced in the direction of the majority of signals increases (Experiment 9).

Two other factors play a role in the gradient account's ability to explain the phenomena of Chapter 1. One factor is the hypothesis that spatial gradients exist on multiple attribute dimensions that are integrated to produce a final input to the motion detection system. This is required to explain examples where color similarity between the primer and the probe cause motion to be experienced preferentially away from the most closely colored primer object (Faubert & von Grünau, 1992, 1995). The second factor is spatial contiguity of the primer and the probe. Spatial contiguity can override the effects of color suggesting that the final integration of motion signals is determined to be highly reliant on this factor (Kanizsa, 1951, 1979; Tse et al., 1998).

The extended gradient framework fails to be able to accommodate the stimulus configuration presented in Figures 18a and 21 (Tse et al., 1998). In these displays, a primer that smoothly continues with one end of the probe is pitted against a larger primer that does not smoothly continue the opposite end of the probe. In Figure 21 the probe abuts the large primer with concave T-junctions. Motion is experienced away from the smaller primer even though (in Figure 21) the majority of motion signals would be expected on the gradient account to be away from the larger primer. Although this finding does not impact the extended gradient account, it does demonstrate that processes exist which can override gradient input (Experiments 8 and 11). Further research is required to determine precisely under what circumstances high-level processes may begin to exert more control over perception. One possibility is that displays which are not geometrically balanced and in which gradients are set in opposition to one another operate under the principles supplied for TAM (Tse et al., 1998). A further case in which the gradient account is unlikely to provide predictive utility involves the presentation of real, identifiable, objects as in Experiment 11. Here, high-level cognition inhibits the motion experience within the probe.

Alternatives to the extended gradient model will now be critically examined in light of previously existing evidence and the results of experiments presented in the current document. Comments will be made on Baloch and Grossberg's (1997) formotion account, Tse et al.'s (1998) TAM account, and Downing and Treisman's (1997) apparent motion impletion account. Zanker's (1997) luminance centroid account will not be discussed further (see Chapter 4).

## FORMOTION

Baloch and Grossberg (1997) provide an impressive and rich set of mechanisms capable of reproducing a variety of ILM-related phenomena. In one sense their formotion account encapsulates gradient theory because one assumption they require is that there is a spatial gradient within the assembly of bipole cells that form contours within the BCS. It is this spatial gradient of signals that gives rise to the motion away from the most active bipole cells when a stimulus is first presented, and toward the most active bipole cells when a stimulus is removed. Through local facilitation and the BCS and FCS interaction, the most activated points along the gradient are modified as boundary contours are formed. The response of the FCS and surface filling-in is yoked to this boundary formation response. Input from these systems to the motion processing stream is detected as movement.

Subtle components of the formotion account can explain many of the observations outlined in Chapter 1, particularly those observations involving irregular shapes and complex forms (i.e., Figures 17, 18, and 21). The model's stipulation that bipole cells of dissimilar orientations inhibit mutual activation can act as an explanatory source for the slower formation of concave boundaries, and consequently, the lower probability that motion will occur away from concavities. The speeding of boundary formation when the visual input is similarly oriented to existing boundary representations can account for the finding that smoothly continuing contours are quickly and easily formed, resulting in motion in their direction. Combined, these aspects of the model allow it to correctly predict the direction of motion in displays such as that of Figure 21, where the gradient model requires the postulation of other processes.

The formotion account's assumption that color opponency cells input to the BCS, allows it to predict the facilitation or inhibition of boundary formation on the basis of the color between primer and probe objects. This is important for examples such as that presented in Figure 10. The extended gradient account requires the further postulation of multiple feature gradients that are later integrated to accommodate this example.

In addition to the mechanisms of the BCS and FCS, the formotion account is sensitive to transients and is supplemented by an independent motion processing stream. Attention can influence motion within this stream by affecting the long-range motion processor.

Perhaps the weaknesses of the formotion account come from some of the same qualities that give it strength. The large collection of contributing mechanisms makes explanations based on the account difficult, especially for the uninitiated. At times, various components of the model are in conflict and it is unclear how to resolve those conflicts. For instance, in the double-primer paradigm with an SOA manipulation (see Figure 9), the boundary completion wave is in the wrong direction while other model components are reportedly in the correct direction. Similarly, as discussed in Chapter 1, the example of Figure 19b is problematic because motion here is away from a location which should demonstrate slowed boundary formation because of the effects of inhibition due to T-junctions and color opponency between the rectangle on the right and the probe.

The examples of Figures 20b, 44b and 44c are also problematic because the formotion account claims that the rules of modal and amodal completion are followed. As demonstrated in Experiment 6, motion is experienced in the outlying bar that is not completed behind the rectangular object.

Experiment 7 demonstrated that even an application of the model by its creators who have expert knowledge of its workings, can turn out to be incorrect. Although it may be possible to accommodate the findings of Experiment 7 within the formotion framework, the account provided by Baloch and Grossberg (1997) cannot be correct based on their supplied explanation. As discussed earlier, if the model is so flexible that it can accommodate any finding then it cannot be falsified and is difficult to use as a predictive tool to put to empirical test. Clearly, future work should concentrate on determining when various components of the model contribute to the perception of a stimulus, and to determining how these various contributions are integrated in the final motion percept.

## TRANSFORMATIONAL APPARENT MOTION

As revealed in Chapter 1, Tse et al. (1998) have made some interesting contributions to the study of ILM-related phenomena and have identified a number of cases that challenge gradient accounts and other explanations. There are however, aspects of the theory behind TAM that are imprecise, or that do not quite fit with the phenomenology.

The claim that TAM applies to objects that overlap in time and space is questionable. This may be a sufficient condition, but it is certainly not necessary. Similar effects often occur regardless of whether two objects overlap spatially, including the simple form of ILM where there is a gap between the primer and the probe (see Figure 26). Similarly, as presented in Figure 53, the probe need not even be a continuous object, and can be more space than object.

Temporal overlap is also not required as demonstrated by the experiments discussed pertaining to Figure 2. Both of these examples (Figures 2 and 53 and there are many more) are claimed to be TAM, so it clearly cannot be that spatial and temporal overlap of objects are necessary components for achieving these effects. How TAM is to handle cases where the second shape does not overlap the first in space, but does so in time is unclear. Is the claim that the second, later-appearing item is a transformation, extension or growth of the first, even though the objects are spatially separated? Does the parsing and matching algorithm parse the two objects in the second presentation and match them as the same object? Perhaps completion mechanisms can play a role here, though as revealed in Experiment 6 it may not be the case that TAM strictly follows the rules of modal and amodal completion.

Even more devastating for the TAM account is the fact that one need not even require two presentations of an object in order to experience motion within it. Gamma motion can be experienced with the single presentation of a stimulus (Bartley, 1936, 1941), under which case a parsing and matching operation cannot be undertaken. Furthermore there is no need for the visual system to posit a transformation in the visual field. Another problem for TAM is the finding that gamma motion does not even require figures, but can occur in stimuli composing the ground (Bartley, 1936, 1941). Although the majority of the work reported here has concentrated on motion within figures in the visual scene, this is likely an artifact of the way in which researchers have approached the study of gamma motion.

Other inconsistencies exist with the TAM account as well. Recall that the claim is made that TAM is sensitive to color and shape information because the parser uses this information in order to determine which contours group with one another to form figures. However, as demonstrated in the examples from Figures 17c and 19b, color information is often ignored. Similarly, motion is away from a T-junction in Figure 19b, violating the "rule" that motion is not experienced away from deep concavities.

In the simple form of the illusion, motion is found to occur away from primers with deep concavities and when there is no smooth continuity between the primer and probe (e.g., Kanisza, 1979). Furthermore, attribute information is not important in evoking a motion experience (von Grünau & Faubert, 1994) even when such information suggests distinct objects that would not be expected to transform into one another or to be matched to one another.

Tse et al. (1998) note that under ambiguous object matchings from the primer display to the probe display, supplementary information about objects can be used to disambiguate the pairing of figures in the first presentation with figures in the second presentation. It is only under such ambiguous stimulus situations that the gradient account seems to be violated: when no supplementary disambiguating information exists, motion ensues as would be expected by gradient predictions. Hence, it may be reasonable to hypothesize that it is only when extra information is presented in an ambiguous display that higher-level processes act to over-ride or further interpret the output of lower-level perceptual mechanisms.

Rather than being general, the heuristics raised by Tse et al. (1998) apply when clear proximity information is unavailable and there is ambiguity in the stimulus configuration. Hence one might question whether "...line motion is in fact an example of the more general class of phenomena that we call Transformational Apparent Motion" (page 9) or whether a more appropriate taxonomy categorizes TAM and its rules as a special case of ILM (or gamma movement) produced when disambiguating information is available in an ambiguous motion situation.

Because the range of situations in which the rules associated with TAM are found to apply is more narrow than the range of situations under which those rules do not apply, it could be argued that TAM is a completely different class, or a subclass of gamma movements which is less general but inherits some of its mechanisms and properties (such as filling in). TAM occurs only when information is present in an image that can resolve parsing and matching ambiguities.

## DOWNING AND TREISMAN'S ANTI-GRADIENT ARGUMENTS

Downing and Treisman (1997) took several different approaches toward falsifying the simple gradient account of Hikosaka et al. (1993a, 1993b). Their first set of experiments was aimed at directly testing the gradient account of ILM while their second set of experiments was meant to demonstrate a dissociation between ILM and endogenous attention cueing as assessed using a discrimination RT task and judgments of ILM strength. Chapter 6 was devoted to re-examining whether endogenous attention could be found to affect ILM direction and strength, and an affirmative result was obtained. The discussion in that chapter addressed whether Downing and Treisman (1997) found a RT and ILM dissociation as they believed and demonstrated that what they had revealed was a difference between exogenous and endogenous elicitation of the illusion. Their former set of anti-gradient arguments will now be addressed.

A common method for producing ILM is to present a priming object followed shortly afterwards by a line with one end in the vicinity of the object. Experiment 1A of Downing and Treisman (1997) reported that if the order of presentation of the primer and the probe line is reversed, then motion is perceived within the line in a direction toward the primer -- the opposite of ILM (see Kanizsa, 1979; von Grünau & Faubert, 1992, 1994). This post-cueing illusion fits with Downing and Treisman's impletion account because in each case, the sequence of events could be said to be interpreted as the trajectory of a single object.

The post-cueing illusion is inconsistent with the simple gradient explanation proposed by Hikosaka et al. (1993a, 1993b) because such an account predicts that onset and offset signals will arrive at a motion detection system in identical sequences causing only the percept of motion away from the primer object. The post-cueing illusion is however, compatible with a spatial gradient account in which the primer not only speeds signal transmission in the visual system but also temporally extends the duration of such transmission along the gradient (Schmidt & Klein, 1997; Schmidt & Pylyshyn, 1994). As discussed in Chapter 2, this extended gradient model suggests that phenomenologically, signals near the primer location reach visual motion processing centers faster and remain active longer, than more distant signals that are presented for the same amount of time. The post-cueing illusion is explained by this account because removing the line while leaving the primer object present would cause offset signals distant from the primer to cease before those close to the primer, resulting in the percept of the bar shrinking back toward the primer.

In apparent contrast to this hypothesis, Downing and Treisman (1997) found using a simple RT detection paradigm, that attentional cueing facilitated the detection of offsets as much as the detection of onsets. This led them to conclude that the post-cue could not have had the effect of extending the transmission of signals within the line. However, this finding is not conclusive. First, the visual pathways mediating RT are unlikely to be identical with those mediating perception. Second, many researchers have found that offsets attract attention (Miller, 1989; Theeuwes, 1991; Hikosaka et al., 1993a), and if the above account is correct then one of the effects of that attraction could be the temporal extension of signals from where the object had been. The extended gradient account predicts that offsets attract attention and accelerate signal transmission, thereby predicting a fast detection of the offset transient (Hikosaka et al., 1993a). Although an offset could be detected quickly, this does not mean that the stimulus is no longer consciously accessible through some other route.

Enns, Brehaut and Shore (1996) found that an attended stimulus was perceived to be on view for a longer time than an unattended stimulus and this effect was completely independent of temporal order judgments made regarding the onset of the stimuli. Hence attention not only speeded signals, but kept them on view for longer. Enns et al. (1996)

interpretted this finding of independence between duration perception and onset perception in terms of the activities within transient and sustained visual channels (Breitmeyer, 1984; Breitmeyer & Ganz, 1976; Todd & van Gelder, 1979). Transient channels speed conscious access to stimulus signals, while sustained channels prolong access to the signals from those stimuli. An anatomical distinction along these lines is present even at the level of retinal ganglia, with slower-conducting parvocellular ganglia contributing to the sustained channel, while fast acting transient cells contribute critical timing information to the magnocellular route. Although the findings of Enns et al. (1996) concerns onsets, the fact that offsets trigger the transient system and have repeatedly been found to act like onsets (Downing & Treisman, 1997; Miller, 1989; Theeuwes, 1991; Hikosaka et al., 1993a), suggests that offsets would be expected to be independent of duration as well.

One might question, based on the above information, whether RTs collected in conjunction with ILM (or TOJ) tasks should be expected to show similar results. If RT is a product of the magnocellular system while judgments of perception arise from a combination of magnocellular and parvocellular processing, then one would not expect the two measures to yield directly comparable results. Schmidt (1996) examined the time course of 'inhibition or return' (the inhibited processing of information presented at a recently processed location) using an ILM and RT task and found that while this effect was present with RT, it was not detectable by ILM. Similar results have been found using TOJs (Maylor, 1985; Gibson & Egeth, 1994). Gibson and Egeth (1994) even collected TOJs and RT data on the same trials in the same experiment and found a dissociation (see Klein, Schmidt & Müller, 1998). Interpreting these findings strictly within the framework that RT is sensitive to attentional measures while ILM is not, ignores what is important about this dissociation.

Further support for the hypothesis about the temporal extension of perceptual signals arising from an attentional cueing manipulation is emerging. In a masking paradigm, Enns and DiLollo (1996) have found that the effects of a mask are weakened with the allocation of attention, suggesting that attention helped to overcome the mask's effect. Elsewhere, using a perceived duration task, Mattes and Ulrich (1998) too have found evidence that attended visual stimuli are perceived for longer durations than unattended stimuli. All of these effects support Thomas and Weaver's (1975) attenuation hypothesis which proposes that one of the effects of attention is to increase perceived duration.

## THE IMPLETION ACCOUNT - THE EFFECT OF A FLANKER

Downing and Treisman's (1997) second experiment, Experiment 1B, extended their argument against gradient accounts. They note that according to the gradient model, a display in which both ends of the line are preceded by primers (a double-cued, or double-primer display) should create a sensation of motion from either end, colliding in the middle (see Figure 8). Similarly, if one presents flanking bar probes on either side of the primers then not only should a collision be experienced within the central bar but motion should be away from the primers in each of the flanking bars (see Figure 12). As predicted by the gradient account, this is what is found (Faubert & von Grünau, 1992a, 1992b, 1995).

Accepting these results, Downing and Treisman claim: "This result, however, is also consistent with an impletion account. It is known that apparent motion is readily seen to split or converge in displays for which there is no strict one-to-one mapping between successive stimuli (e.g., Kolers, 1972)" (page 770). Although apparent motion does this, one might question what reason there is for impletion to infer that the probe objects transform in the way that they do? What likely real world situation exists which would cause a retinal projection of these sorts?

Consider the displays shown in Figures 27 and 28. Note that in these displays the primers are some distance from the location where the central probe line will appear. A motion collision is experienced within the probe. It cannot be claimed that impletion inferred that the primers jumped the short distance to the probe and then grew in length from there because the primers are present throughout the probe's presentation. For Figure

27 the impletion account must invoke an argument similar to that used by Downing and Treisman (1997) for the simpler illusion presented with a gap between the primer and probe as in Figure 54: the impletion system automatically interprets this as if two objects (which later appear as the ends of the central bar) were occluding identical objects (the primers) that were revealed when the objects in the forefront jumped toward the center and then grew in length from there, colliding and merging into a single object (the probe). This seems a bit awkward because it does not often happen in the real world. In daily experience, multiple objects (and this effect need not be limited to simply two primers -- see Schmidt et al., 1998) do not often merge into a single object. Items do not often jump revealing identical items beneath them. Arguably, the simplest real world interpretation would be that a new object appeared between two existing objects, but then there is no reason for the impletion hypothesis to posit a transformation within the probe. An even more complicated situation arises for Figure 28. Here even more objects are overlaid, jumping, growing and colliding. The percepts resulting from these displays are much more easily and plausibly explained by the gradient account (see Chapter 1) or the formotion account (see Chapter 4).

Ignoring the role of impletion in these cases, Downing and Treisman (1997) questioned naive observers on their motion percepts in the situation where two primers appear followed by two probe lines: one between the primers and the other flanking one of the primers, either off to the left or to the right (see Figure 11). In this situation there is commonly a general percept of motion in a single direction consistent with motion away from the primer in the flanking bar (or *flanker*). That is, a collision is infrequently reported in the central line (Faubert & von Grünau, 1992, 1995). Downing and Treisman interpretted this finding as evidence against a gradient account because such an account should predict motion away from the primer in the flanker while at the same time a motion collision should occur in the line between the primers, just as is the case when the flanking bar is absent.

This stimulus configuration, which appears to present problems for the gradient account was studied further in Chapter 7. Like Downing and Treisman (1997) the current work revealed that observers do experience a collision within the central bar on some trials (10% in Experiment 8, with one naive observer in Experiment 9 reporting collisions on 100% of trials). These collisions can be explained by gradient theory, but it is unclear how they are explained by the impletion account. Although on the majority of trials, motion was reported in only a single direction away from the priming dots, Experiment 8 showed that the presentation of the central bar over space and time could not be detected in the flanker paradigm. The finding that real motion is masked by the flanker invalidates Downing and Treisman's (1997) conclusion that there is no gradient of arrival times. This led us to conclude that processes other than the spatial gradient are influencing the illusory motion in this case.

In Experiment 9 one plausible account of the flanker result was provided in terms of motion signal integration. When motion direction signals are in conflict and one set of signals is more populous than another, then that direction is detected as the dominant motion direction. The data from Experiment 9 supported this notion, as do the findings of Faubert (1996) who demonstrated that conflicting motion direction signals produced by the illusion are integrated in a fashion similar to signals arising from motion coherence displays. An inhibitory motion surround (Steinman et al., 1995) may have also played a role in the flanker outcome. If signals far from the primer are inhibited, the presentation of a bar with one end far out in the periphery might be expected to have an enhanced motion effect away from its uninhibited central portion (see Bartley, 1936 for a demonstration of such an effect).

## ILM AND APPARENT MOTION EQUIVALENCY

In a final experiment directly challenging the gradient hypothesis of ILM, Downing and Treisman's (1997) Experiment 1C showed that following a primer, the presentation of either a line probe or a similarly positioned probe that was identical to the primer, can elicit similar motion ratings within certain ranges of SOA (Stimulus-Onset Asynchrony) and distance. The similarity of subjects' motion judgments for these two probe stimuli was interpreted as evidence that ILM (using the line probe) is classical apparent motion supplemented by an apparent motion impletion process. Downing and Treisman claim that: "If our account is correct, apparent motion and the line-motion illusion should show the same effects of temporal and spatial separation of the two stimuli. This prediction was tested by having participants make ratings both on line-illusion displays and on comparable apparent motion displays, in which the line was replaced by a dot identical to the cue, located where the nearest end of the line would appear on equivalent line trials" (page 771).

An alternative interpretation of their data is that both the line probe and the dot probe displays were tapping the same underlying mechanism: a spatial gradient. With respect to a later experiment Downing and Treisman claimed "...that there is no ready explanation for why a gradient of attention should affect apparent motion the way it did in this experiment. The central target had negligible spatial extent, and was equidistant from the attended spot and the spot diagonally opposite" (page 775). First, with regard to the notion of presenting the probe at equal distances between the attended and unattended objects, it is one of the gradient account's principle assumptions that attention speeds signal transmission near its locus. Consequently, it is difficult to see why Downing and Treisman (1997) claimed that the gradient account did *not* predict an effect of prior entry for the attended item (e.g., Hikosaka et al., 1993a; Stelmach & Herdman, 1991). Second, the motion detection system is part of the gradient hypothesis' apparatus and as such is hypothesized to be involved in motion judgments regardless of the spatial extent of the probe. The gradient account entails that the dot probe and the line probe both rely on the same mechanism of prior entry (Stelmach & Herdman, 1991; Stelmach, Herdman, & MacNeil, 1994). They differ qualitatively because the probe item lacks spatial extent.

Data presented in Experiments 1 and 2 demonstrated that ILM and apparent motion (as defined by using a simple probe identical to the primer) do not behave identically. They may behave qualitatively similar under certain temporal and spatial parameters, but differences are revealed when a comprehensive comparison is undertaken. A dissociation between the motion effects from an extended probe and one similar in nature to the primer was again observed in Experiment 10.

## GRADIENTS AND ATTENTION

In the second part of their paper Downing and Treisman (1997) argued that ILM cannot be an attentional effect. When they augmented the ILM studies of Hikosaka et al. (1993b) that involved endogenous attentional manipulations with a RT discrimination task they found a dissociation between their RT measure and judgments of ILM strength. Further investigation and discussion of these experiments and findings were presented in Chapter 6. Here it was demonstrated that no real basis for claiming that such a dissociation exits. Even if a dissociation did exist, one could not conclude that one measure was sensitive to attention while the other was not. Response time measures encompass much more than simply estimates of perception. They include response components and tertiary effects of perception as well as attention. Similarly, as demonstrated in Experiments 3-5, ILM is extremely sensitive to low-level perceptual, or bottom up factors, but can be influenced by endogenous attentional contributions. To treat the two measures as objective measures of a single process is misguided. There are likely to be multiple processing sources contributing to attentional effects and no two measures of attention should be expected to covary with all of them.

In closing, Downing and Treisman (1997) state that "We believe that the line-motion illusion, which has previously been attributed to attention, may be better explained through this process of implicit inference" (page 778). Whether cognizing perception is a better mode of explaining, or even an acceptable mode of explaining is a matter of some debate (Kanizsa, 1982, 1985; Pylyshyn, 1998). Until impletion is made explicit and testable, there is little reason to expect that this approach will generate any new information about ILM or the processes contributing to it. Perhaps impletion is a useful heuristic for describing what visual displays may look like, but it yields no insight into why or how these effects are occurring. As revealed by attempting to apply the impletion hypothesis to the basic phenomena outlined in Chapter 1, impletion lacks precision in its predictions. Impletion is incapable of providing an adequate account of many ILM data, and for many others it requires postulating *post hoc* assumptions about the way that the impletion inferencing operates.

## RATIOMORPHIC THEORIES OF ILM

The theories of ILM outlined in Chapter 3, the Apparent Motion Impletion account and the Transformational Apparent Motion account, are cognitive in their orientation. They both suggest that the visual system embodies rules and makes unconscious inferences. They are 'interpretive' or 'ratiomorphic' hypotheses - hypotheses which involve unconscious inferences drawn in the early stages of vision (Kanizsa, 1985).

Kanizsa (1985, page 26) addresses "ratiomorphic" hypotheses and says: "...we may also ask what advantages would be gained from this formulation ... compared with the view which holds that the visual system does not know or apply any rule but simply functions lawfully according to principles on the basis of which it is programmed." He continues (page 27): "To say that the perception ... is the result of an unconscious process of problem solving does not contribute at all to understanding the phenomenon. Our knowledge of the laws determining the phenomenon, of the conditions which facilitate it and of those which hinder or make it impossible, remains as it was before. A metaphor is no substitute for an explanation. Such an 'explanation', moreover, would have the disadvantage of applying only to positive cases." To underscore this last point, recall the earlier argument demonstrating that TAM's rules and principles apply only under a restricted range of situations. These rules do not apply under normal conditions. Similarly, recall the difficulty that impletion has accounting for stimulus configurations in which the primers remain as the probe is presented.

On the topic of ratiomorphic hypotheses and implicit inferences, Pylyshyn (1998) adds: "Early vision does not respond to any other kind of knowledge or new information related to these constraints (e.g., the constraints show up even if the observer knows that there are conditions in a certain scene that render them invalid in that particular case). What this means is that no additional regularities are captured by the hypothesis that the system has knowledge of certain natural laws and takes them into account through "unconscious inference". Even though in these examples the visual process appears to be intelligent the intelligence is compatible with it being carried out by neural circuitry that does not manipulate encoded knowledge. Terms such as "knowledge", "belief", "goal" and "inference" give us an explanatory advantage when it allows generalizations to be captured under common principles such as rationality or even something roughly like semantic coherence (Pylyshyn, 1984). In the absence of such overarching principles, Occam's Razor or Lloyd Morgan's Canon dictates that the simpler or lower-level hypothesis (and the less powerful mechanism) is preferred" (page 27). To apply Pylyshyn's point to the current phenomena, note that a motion collision occurs in the double-primer display even though it does not follow any natural constraints. Rather than being a product of implicit inference sensitive to the most likely real world state of affairs, the collision reflects the way that the visual system is programmed to respond. Researchers shouldn't expect the system to always produce cognitively meaningful results (i.e., Experiments 6 and 7).

One further point regarding the theories outlined in Chapter 3 is that they fail to be able to make predictions regarding anything except the direction of the illusory motion to expect. As demonstrated by the majority of the experiments in the current document, motion strength and frequency are the principle dependent measures used, and these are very useful measures for distinguishing hypotheses. In addition to motion direction predictions the gradient account makes predictions about strength and relative likelihood based on primer-probe distance and time (Experiments 1 and 2), motion direction conflicts at the motion integration stage (Experiments 7 and 9), motion detector usage (Experiment 10) and attentional contributions (Experiments 3-5).

## CONCLUSION

Marr recognized that rarely can a complex system be understood merely by extrapolating from the properties of its elementary components. To investigate complex systems, Marr (1982) stressed that researchers must be prepared to adopt different kinds of explanations at different levels of description to account for the system viewed as a whole. The three levels of interest that Marr specified are the computational theory, the representation and algorithm, and the hardware implementation. The most abstract level of understanding, the level of computational theory, is the level of *what* the system does and *why* it does it. The computational theory is realized, still abstractly, at the level of representation and algorithm with a specific representational format that has algorithms compatible with such representations. The most basic of Marr's descriptive levels concerns how the system is physically accomplished, or in what medium and form the higher levels of description are realized.

Applying Marr's framework to the domain of ILM, suggests that the various theories presented may appear to be in conflict primarily by virtue of their addressing of different aspects of this explanation hierarchy. The apparent motion impletion account is a computational theory of the ILM effect. It is concerned with what the system is doing at an abstract level (treating visual stimulation as objects) and why the system is doing it (because we interact with a world of objects and make sense of the world in terms of the objects that are in our environment). Yet the impletion account ignores the other levels of explanation. It does not address issues of representation and algorithm (except to specify what is represented - objects in motion) and it is independent of this level of explanation and of the level of implementation.

The TAM account of ILM phenomena addresses the computational theory of ILM by appealing to the idea that the illusory motion effects are artifacts of a visual scene parser that is attempting to link the probe item with the primer that it is most likely to extend. It is doing this to make sense of the world, and the transformational motion provides a smooth transition of one view to the next. Specifically how this is represented or the algorithms used to accomplish it go unspecified, as does the implementation.

The formotion account operates at the level of the implementation and provides some plausible representations and algorithms that may be acting in ILM. The implementation is claimed to be neural and the representations are in the form of the various sorts of cells and interconnections present in the BCS, FCS, and short and long-range motion systems. The formotion account does not specifically target the computational theory, but it can supply an explanation for it. Because the formotion is a lower-level explanation, it can explain the resulting phenomena with greater detail and precision than the accounts that provide just a computational theory. Furthermore, it can supply an explanation of effects that don't quite fit with the computational theory (such as the divergence and merging of discrete objects) because they are artifacts of the representations and algorithms used.

Gradient theories target the intermediate level of representation and algorithm. The spatial gradient is the representational format hypothesized to operate and to give rise to the effects of the computational level. Gradient theories do not provide a comprehensive account of their implementation in neural structures (nor do they attempt to).

From the perspective of Marr's (1982) organizational framework, the explanations supplied at differing levels are not necessarily in conflict. However, they are in conflict when lower-level phenomena predict that an effect should occur which is not consistent with higher-level explanations, such as the divergence and merging of single objects (see discussion above), or the motion within portions of a probe that are on the higher-level account, not completed (see Experiment 6). Such inconsistencies do not indicate that the computational theory should be abandoned, but merely that it is incomplete. Researchers must keep in mind that artifacts of the representation and algorithms employed may introduce subtle effects that their computational theories cannot accommodate.

Low-level accounts can supply more precision in their explanations than the high level accounts. As mentioned above, the high-level accounts supply only predictions of motion direction and do not supply information regarding motion strength. Predictions from the gradient accounts have triggered a wide variety of research that precisely investigate the parameters surrounding ILM effects (Miyauchi et al., 1992; Schmidt & Klein, 1997; Steinman et al., 1995; von Grünau et al., 1995, 1996), while high-level accounts have yet to stimulate such work. Although high level accounts do motivate the discovery of new stimulus configurations (Tse et al., 1995, 1998), so do low-level accounts (Baloch & Grossberg, 1997; Faubert & von Grünau, 1992, 1995; Schmidt & Klein, 1997; Schmidt et al., 1998).

The current paper has presented a range of explanations for ILM and ILM-related (gamma movement) phenomena. As illustrated in Chapters 2-4 (and in the empirical work), no theory of the effect has proven to be comprehensive, which usually indicates the contribution of multiple processes. Although the formotion account most closely takes a multiple process approach to explaining the phenomena, it is not always clear how it applies to a given stimulus or whether it correctly explains certain stimulus configurations (i.e., Experiment 7). I adopt the gradient explanation as the currently preferred explanation of ILM effects for reasons of completeness (it explains more), accuracy (it affords accurate predictions), and simplicity (predictions are easily derived). This document stands as a testament that there is yet to be a theory presented that deserves to supplant the gradient explanation.

# ENDNOTES

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[1] It should be noted however, that as discussed in the Introduction, temporal and spatial overlap are not necessary components of eliciting the illusion exogenously. Motion within the probe is often experienced when there is an intervening space between the primer and the probe, though the strength of such a percept varies with distance (Miyauchi, Hikosaka & Shimojo, 1992; Steinman, Steinman, & Lehmkuhle, 1995; von Grünau, Racette & Kwas, 1996). In the temporal domain, though the percept weakens over time, ILM can be experienced within a probe appearing even as long as 900 msec after the primer is extinguished (Hikosaka et al., 1993a; Schmidt, 1996).

[2] This is not apparent from Hikosaka et al.'s (1993b) written presentation of their work, but is presented in their Figure 2.

[3] Due to participant time constraints, two participants were run only in Phase 3.

[4] The saccade detection method used in Experiment 4 involved rejecting trials in which there was a change in fixation position after the subject indicated that they were attending, rather than relying on the absolute position foveated. Hence there was a remote possibility that the 7 of 8 subjects who showed an endogenous cueing effect disobeyed explicit instructions to fixate the cross and instead actually foveated the stimulus they were instructed to attend, thereby resulting in the experience of motion away from the endogenously cued location. To check against this unlikely event, a separate experiment not reported here for reasons of simplicity, replicated this paradigm using the SR Research Ltd. (Toronto, Canada) eye monitoring system. In this experiment, at no time did observers' gaze leave a two degree box centered around the fixation cross. The pattern of results, based on 10 subjects was identical to that found in Experiment 3-5.

[5] As discussed in Chapter 1 and elsewhere, ILM is associated not only with the locus of attention, but is also influenced by perceptual factors such as luminance. As a result, attempting to measure the effects of endogenous attention while at the same time presenting

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the probe line across a luminant fixation point would be expected, on the gradient account, to result in a weakened motion percept. Perceptually-based gradients surrounding each of these display elements may cause the motion signals derived to counteract one another, yielding a weaker percept. Other implementation-based reasons exist for a weak percept as well . As in Downing and Treisman's (1997) Experiment 3, there was a substantial gap between the primer and the probe ( 0.6°, 170% the size of the primer), the area which the gradient account proposes speeds signals most strongly. In addition, the probe object appeared for only 60 msec, a brief enough duration that one might expect an ambiguous motion experience to result.

[6] Preliminary support for the hypothesis that the flanker acts to distract subjects from reporting on collision within the central line emerged from a pilot study in which subjects reported only leftwards or rightwards motion in flanker trials (with or without physically drawn collisions), but upon debriefing, offered that they had experienced a collision in the central bar on many of the trials. Further, in Experiment 9 one subject reported experiencing a collision in the central bar on 100% of the trials regardless of the presence of a flanker. For this reason, observers were asked only to report on motion perceived within the line joining the primers (the central bar). It is this aspect of the display that is of interest when testing the gradient model, and not asking subjects specifically about it may encourage them to ignore it. Even with these specific instructions, during debriefing many subjects admitted entering rightward or leftward motion judgments even though they had detected some motion in the opposite direction within the central line, an observation that casts doubt on this paradigm as an appropriate test of the gradient model's competence.

# APPENDIX A: EXPERIMENT 2 WITHIN-PROBE MOTION RATINGS

Mean within-probe motion ratings in Experiment 1

| primer status | SOA | probe type | distance in degrees | | | |
|---|---|---|---|---|---|---|
| | | | minimal | half | one | six |
| remains | 150 msec | identical | 15.611 | 16.759 | 17.538 | 19.199 |
| | | square | 35.925 | 37.013 | 32.733 | 36.385 |
| | | bar | 68.204 | 61.683 | 61.168 | 56.120 |
| | 750 msec | identical | 16.607 | 14.588 | 15.027 | 21.520 |
| | | square | 35.130 | 28.533 | 31.785 | 39.399 |
| | | bar | 61.878 | 63.041 | 64.285 | 61.488 |
| disappears | 150 msec | identical | 11.861 | 15.048 | 16.569 | 23.652 |
| | | square | 32.007 | 33.550 | 34.415 | 37.089 |
| | | bar | 69.005 | 64.984 | 68.804 | 61.152 |
| | 750 msec | identical | 13.717 | 13.398 | 18.198 | 22.932 |
| | | square | 33.338 | 32.841 | 32.316 | 39.946 |
| | | bar | 66.959 | 61.120 | 58.788 | 58.902 |

# APPENDIX B: EXPERIMENT 2 BETWEEN-OBJECT MOTION RATINGS

Mean between-object motion ratings in Experiment 1

| primer status | SOA | probe type | distance in degrees | | | |
|---|---|---|---|---|---|---|
| | | | minimal | half | one | six |
| remains | 150 msec | identical | 27.868 | 36.942 | 40.806 | 54.215 |
| | | square | 33.290 | 39.448 | 41.331 | 52.300 |
| | | bar | 34.075 | 40.557 | 42.879 | 48.734 |
| | 750 msec | identical | 25.227 | 34.210 | 35.617 | 47.570 |
| | | square | 28.436 | 33.717 | 38.392 | 48.473 |
| | | bar | 35.200 | 35.292 | 38.317 | 49.118 |
| disappears | 150 msec | identical | 24.583 | 36.824 | 39.730 | 52.630 |
| | | square | 27.532 | 33.864 | 42.175 | 46.326 |
| | | bar | 32.002 | 37.776 | 38.144 | 48.295 |
| | 750 msec | identical | 22.608 | 33.885 | 36.591 | 48.427 |
| | | square | 24.746 | 29.118 | 35.758 | 45.205 |
| | | bar | 33.582 | 29.886 | 31.174 | 48.399 |

# APPENDIX C: EXPERIMENT 1 OVERALL MOTION RATINGS

Mean overall motion ratings in Experiment 1

| primer status | SOA | probe type | distance in degrees | | | |
|---|---|---|---|---|---|---|
| | | | minimal | half | one | six |
| remains | 150 msec | identical | 30.812 | 43.636 | 46.369 | 58.577 |
| | | square | 40.606 | 39.935 | 44.659 | 57.777 |
| | | bar | 63.750 | 65.904 | 61.006 | 60.779 |
| | 750 msec | identical | 28.777 | 38.918 | 41.315 | 52.202 |
| | | square | 38.458 | 40.373 | 43.296 | 54.335 |
| | | bar | 63.636 | 58.793 | 63.923 | 64.367 |
| disappears | 150 msec | identical | 23.371 | 42.110 | 42.911 | 61.488 |
| | | square | 36.895 | 38.171 | 47.348 | 56.472 |
| | | bar | 65.871 | 63.653 | 62.137 | 59.026 |
| | 750 msec | identical | 25.065 | 36.818 | 42.814 | 52.673 |
| | | square | 31.488 | 37.868 | 41.131 | 54.400 |
| | | bar | 62.164 | 60.455 | 56.380 | 60.731 |

# APPENDIX D: EXPERIMENT 2 WITHIN-PROBE MOTION RATINGS

Mean within-probe motion ratings in Experiment 2

| primer status | probe type | SOA | distance in degrees | | | |
|---|---|---|---|---|---|---|
| | | | minimal | half | one | six |
| remains | identical | 150 msec | 10.237 | 14.164 | 12.306 | 17.200 |
| | | 450 msec | 8.007 | 10.462 | 11.512 | 15.270 |
| | | 750 msec | 9.174 | 10.585 | 12.934 | 14.894 |
| | bar | 150 msec | 59.502 | 57.123 | 55.136 | 49.944 |
| | | 450 msec | 52.726 | 51.654 | 54.483 | 49.421 |
| | | 750 msec | 56.684 | 51.267 | 51.712 | 46.017 |
| disappears | identical | 150 msec | 6.779 | 10.037 | 13.870 | 16.360 |
| | | 450 msec | 7.951 | 10.958 | 13.318 | 15.903 |
| | | 750 msec | 8.208 | 11.410 | 11.919 | 16.225 |
| | bar | 150 msec | 56.287 | 58.110 | 53.562 | 52.984 |
| | | 450 msec | 47.013 | 50.833 | 49.462 | 48.448 |
| | | 750 msec | 47.035 | 46.840 | 47.132 | 44.395 |

# APPENDIX E: EXPERIMENT 2 BETWEEN-OBJECT MOTION RATINGS

Mean between-object motion ratings in Experiment 2

| primer status | probe type | SOA | distance in degrees | | | |
|---|---|---|---|---|---|---|
| | | | minimal | half | one | six |
| remains | identical | 150 msec | 23.959 | 36.100 | 36.973 | 47.541 |
| | | 450 msec | 27.229 | 32.649 | 35.841 | 47.247 |
| | | 750 msec | 27.444 | 33.343 | 35.031 | 47.194 |
| | bar | 150 msec | 37.244 | 39.126 | 38.844 | 39.666 |
| | | 450 msec | 36.599 | 39.422 | 37.964 | 43.803 |
| | | 750 msec | 36.929 | 35.899 | 36.949 | 43.998 |
| disappears | identical | 150 msec | 13.686 | 23.697 | 34.664 | 43.301 |
| | | 450 msec | 14.785 | 24.983 | 32.657 | 39.230 |
| | | 750 msec | 12.064 | 18.285 | 27.749 | 36.715 |
| | bar | 150 msec | 31.670 | 37.160 | 38.598 | 41.605 |
| | | 450 msec | 33.892 | 35.353 | 36.876 | 41.011 |
| | | 750 msec | 30.852 | 34.070 | 36.737 | 38.239 |

# APPENDIX F: EXPERIMENT 2 OVERALL MOTION RATINGS

Mean overall motion ratings in Experiment 2

| primer status | probe type | SOA | distance in degrees | | | |
|---|---|---|---|---|---|---|
| | | | minimal | half | one | six |
| remains | identical | 150 msec | 29.455 | 43.479 | 44.887 | 61.572 |
| | | 450 msec | 34.251 | 43.160 | 44.095 | 59.296 |
| | | 750 msec | 32.941 | 41.814 | 45.289 | 57.661 |
| | bar | 150 msec | 63.408 | 61.423 | 61.096 | 61.326 |
| | | 450 msec | 59.860 | 59.677 | 59.502 | 62.480 |
| | | 750 msec | 60.803 | 57.677 | 57.598 | 63.019 |
| disappears | identical | 150 msec | 15.702 | 28.613 | 40.890 | 60.651 |
| | | 450 msec | 20.400 | 34.278 | 43.174 | 59.501 |
| | | 750 msec | 14.193 | 25.524 | 35.755 | 56.029 |
| | bar | 150 msec | 58.604 | 61.299 | 59.633 | 62.627 |
| | | 450 msec | 55.896 | 58.466 | 55.878 | 60.966 |
| | | 750 msec | 52.181 | 56.206 | 57.285 | 59.679 |

## APPENDIX G: EXPERIMENT 3 PHASE 1 CELL MEANS

Discrimination RT in msec as a Function of Validity and Color Attended

| | attend red | attend green |
|---|---|---|
| valid | 648.547 | 657.820 |
| invalid | 731.773 | 799.104 |

Discrimination RT in msec as a Function of Target Identity and Color Attended

| | attend red | attend green |
|---|---|---|
| T | 661.818 | 677.359 |
| X | 673.695 | 706.183 |

Errors as a Function of Validity and Color Attended

| | attend red | attend green |
|---|---|---|
| valid | 2.143 | 1.000 |
| invalid | 1.429 | 1.000 |

# APPENDIX H: EXPERIMENT 3 PHASE 2 CELL MEANS

Frequency and Strength of Motion for Motion Direction Classifications Relative to the Attended Item:

Frequency of Motion Direction (% of total trials)

| attended item | away | toward | collision | no motion | away via collision | toward via collision |
|---|---|---|---|---|---|---|
| red | 34.285 | 31.427 | 18.928 | 10.715 | 2.500 | 2.142 |
| green | 26.427 | 33.215 | 12.500 | 15.715 | 10.358 | 1.785 |

Motion Strength Dependent Measure

| attended item | away | toward | collision | away via collision | toward via collision |
|---|---|---|---|---|---|
| red | 5.718 | 6.205 | 5.387 | 2.357 | 3.786 |
| green | 5.837 | 5.409 | 3.833 | 2.366 | 1.371 |

## Appendix I: Experiment 3 Phase 3 Cell Means

Discrimination RT in msec as a Function of Validity and Color Attended

| | attend red | attend green |
|---|---|---|
| valid | 661.856 | 651.404 |
| invalid | 731.469 | 792.034 |

Discrimination RT in msec as a Function of Validity and Color Attended

| | attend red | attend green |
|---|---|---|
| T | 676.544 | 672.492 |
| X | 680.389 | 696.132 |

Errors as a Function of Validity and Color Attended

| | attend red | attend green |
|---|---|---|
| valid | 2.000 | 0.875 |
| invalid | 1.250 | 0.750 |

Frequency and Strength of Motion for Motion Direction Classifications Relative to the Attended Item

Frequency of Motion Direction (% of total trials)

| attended item | away | toward | collision | no motion | away via collision | toward via collision |
|---|---|---|---|---|---|---|
| red | 39.688 | 16.250 | 28.125 | 8.438 | 5.312 | 2.188 |
| green | 25.313 | 19.375 | 29.688 | 10.625 | 10.938 | 4.062 |

Motion Strength Dependent Measure

| attended item | away | toward | collision | away via collision | toward via collision |
|---|---|---|---|---|---|
| red | 5.815 | 5.707 | 5.748 | 3.253 | 3.062 |
| green | 5.278 | 3.773 | 5.127 | 2.902 | 2.963 |

## APPENDIX J: EXPERIMENT 4 AND 5 INSTRUCTIONS

### Participant Instructions

This experiment consists of a couple of tasks together. There are two identical phases. You will do a "letter discrimination task" and a "motion judgment task" combined.

At the beginning of the experiment, attend (without moving your eyes) to the location of the instructed object (i.e., "attend to the circle", or "attend to the triangle"). What does attend mean? Here's an example: you can look at a face and determine the number of fingers that a person is holding up some distance away without moving your eyes from their face. This is referred to as the ability to attend to a location in space independently from where your eye position is. This is the type of attending that will be done in the current experiment.

On each trial, a fixation cross will appear in the center of the screen. You must fixate this without moving your eyes from it (you will be wearing an eye movement monitor that guarantees that you do not move your eyes -- if you do move your eyes, or if you blink, you will have to do the trial over again). Shortly afterwards, a circle and a triangle will appear above and on either side of the fixation cross. You must attend one of these.

Letter Discrimination

On letter discrimination trials, shortly after the fixation cross appears, a circle and a triangle will be presented, and you are to attend to the instructed item. The shapes will be replaced briefly by letters. You must signal as quickly as possible whether a 'T' or an 'X' was present in the display. Pressing the left arrow means that a 'T' was present, while pressing the right arrow key means that an 'X' was present. 75% of the time, the T' or the 'X' will be presented at the location of the shape you were instructed to attend.

Line Motion Judgment

On line motion trials, shortly after the fixation cross appears, a circle and a triangle will be presented, and you are to attend to the instructed item. Next, however, no letters will appear. Instead, a horizontal bar will be drawn in the space between the shapes, and you are asked to report, by clicking a point along a scale, whether you perceived it to be drawn leftwards (from right to left), rightwards (from left to right) or with no motion -- that is, to have appeared all at once with no motion. The degree to which you click toward one or the other end of this scale indicates the strength of your motion experience. You will be shown an example of the type of motion to expect, which is an example of 100% strength. Please use the full length of the scale.

So to recap, you are to attend the specified shape (without moving your eyes from fixation) while being prepared to press one of the indicated buttons if either an 'X' or a 'T' appears. If a letter appears, indicate whether an X or a T was presented. If instead, a "bar" is drawn joining the circle and triangle, then classify your motion experience using the mouse.

You will be run in the experiment twice -- the first time is to familiarize you with the task. The second time is for keeps -- so, wasting some data at the beginning of the first session is okay.

Thanks!

# APPENDIX K: EXPERIMENT 4 CELL MEANS

Discrimination RT in msec as a Function of Validity and Object Attended

| validity | target | attend triangle | attend circle |
|---|---|---|---|
| valid | T | 652.245 | 877.219 |
| | X | 630.177 | 854.906 |
| invalid | T | 784.153 | 1051.188 |
| | X | 724.036 | 1156.053 |

Discrimination Errors as a Function of Validity and Object Attended

| validity | target | attend triangle | attend circle |
|---|---|---|---|
| valid | T | 2.000 | 0.000 |
| | X | 2.500 | 0.000 |
| invalid | T | 0.750 | 0.000 |
| | X | 1.250 | 1.250 |

Frequency and Strength of Motion for Motion Direction Classifications Relative to the Attended Item

Frequency of Motion Direction (% of total trials)

| attended item | away | toward | no motion |
|---|---|---|---|
| triangle | 63.426 | 33.800 | 2.778 |
| circle | 60.648 | 26.852 | 12.500 |

Motion Strength Dependent Measure

| attended item | away | toward | no motion |
|---|---|---|---|
| triangle | 63.913 | 65.575 | 1.956 |
| circle | 48.108 | 50.333 | 4.005 |

# APPENDIX L: EXPERIMENT 5 CELL MEANS

Discrimination RT in msec as a Function of Validity and Object Attended

| validity | target | attend triangle | attend circle |
|---|---|---|---|
| valid | T | 796.424 | 1063.164 |
| | X | 839.569 | 979.480 |
| invalid | T | 972.523 | 1071.936 |
| | X | 958.416 | 1007.432 |

Discrimination Errors as a Function of Validity and Object Attended

| validity | target | attend triangle | attend circle |
|---|---|---|---|
| valid | T | 0.500 | 6.400 |
| | X | 0.750 | 5.200 |
| invalid | T | 1.250 | 0.200 |
| | X | 3.000 | 1.000 |

Frequency and Strength of Motion for Motion Direction Classifications Relative to the Attended Item

Frequency of Motion Direction (% of total trials)

| attended item | away | toward | no motion |
|---|---|---|---|
| Endogenous | | | |
| circle | 45.000 | 13.846 | 41.154 |
| triangle | 26.442 | 23.558 | 41.935 |
| Exogenous | | | |
| circle | 76.154 | 21.538 | 2.308 |
| triangle | 93.750 | 5.288 | 0.960 |

Motion Strength Dependent Measure

| attended item | away | toward | no motion |
|---|---|---|---|
| Endogenous | | | |
| circle | 38.675 | 36.039 | 3.452 |
| triangle | 38.614 | 40.055 | 3.223 |
| Exogenous | | | |
| circle | 39.413 | 20.290 | 2.100 |
| triangle | 52.361 | 2.956 | 1.606 |

# APPENDIX M: EXPERIMENT 6 MOTION RATINGS

Mean Motion Strength Within the Probe Item Opposite the Primer in Experiment 6

| SOA | rectangle | | kanizsa triangle | | |
|---|---|---|---|---|---|
| | occluded (Figure 20a) | non-occluded (Figure 20b) | occluded (Figure 44a) | non-occluded (Figure 44b) | non-occluded (Figure 44c) |
| 45 msec | 49.757 | 35.286 | 28.814 | 38.086 | 19.743 |
| 255 msec | 48.671 | 41.100 | 34.100 | 36.886 | 19.214 |
| 750 msec | 46.157 | 38.743 | 36.014 | 34.086 | 32.114 |
| 1245 msec | 43.257 | 41.986 | 38.100 | 30.900 | 32.557 |

# APPENDIX N: EXPERIMENT 7 MOTION RATINGS

Mean Motion Strength Ratings Within the Probe Item in Experiment 7

| SOA | arrowhead pointing away from shaft | arrowhead pointing toward shaft |
|---|---|---|
| 105 msec | 62.325 | 49.620 |
| 1005 msec | 42.290 | 35.025 |

Motion Frequency Ratings in Experiment 7 (Percentage)

| Display and SOA | away from arrowhead | toward arrowhead | no motion |
|---|---|---|---|
| arrowhead away from shaft | | | |
| 105 msec | 81.5 | 9.0 | 9.5 |
| 1005 msec | 59.0 | 10.0 | 31.0 |
| arrowhead toward shaft | | | |
| 105 msec | 91.0 | 3.5 | 5.5 |
| 1005 msec | 67.5 | 3.5 | 29.0 |

## APPENDIX O: EXPERIMENT 11 MOTION STRENGTH RATINGS

Mean Motion Strength Ratings Within the Probe Item in Experiment 11

Positive values indicate rightward motion while negative values indicate leftward motion.

| probe item | primer side | grip side |  |
|---|---|---|---|
|  |  | left | right |
| bar | left | 52.562 | 41.385 |
|  | right | -41.667 | -47.438 |
| bat | left | 33.384 | 26.267 |
|  | right | -28.153 | -26.380 |

## APPENDIX P: FIGURES

Figure 1. Simple Illusory Line Motion. A primer appears in frame 1 followed shortly afterwards by a line probe. Motion is experienced within the line, as if it were drawn on over time. In this and all subsequent figures, the thin arrow represent the direction of reported motion within the probe.

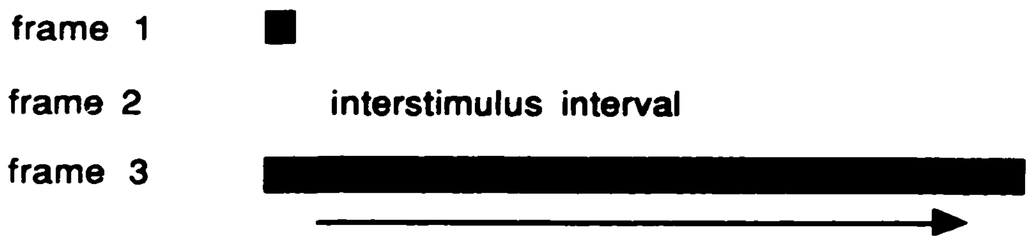

Figure 2. The illusion appears to be robust over a long blank interstimulus interval (ISI). Hikosaka et al. (1993a) presented a primer for 2 msec followed by a long ISI and found the illusion to still produce a robust motion experience. Simple ILM has been found to frequently occur even as long as 2176 msec after the removal of the primer (Kawahara et al., 1997).

Figure 3. Immediately after a stimulus disappears, motion is reported away from the former stimulus location (Hikosaka et al., 1993b).

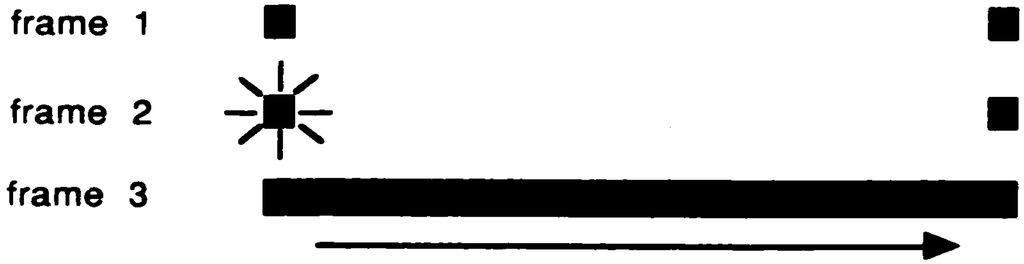

Figure 4. Transient changes in the visual scene reportedly cause ILM to be experienced away from the location of the transient. Hikosaka et al. (1993a) claimed that this demonstrates ILM sensitivity to stimulus-induced, or stimulus-driven attention.

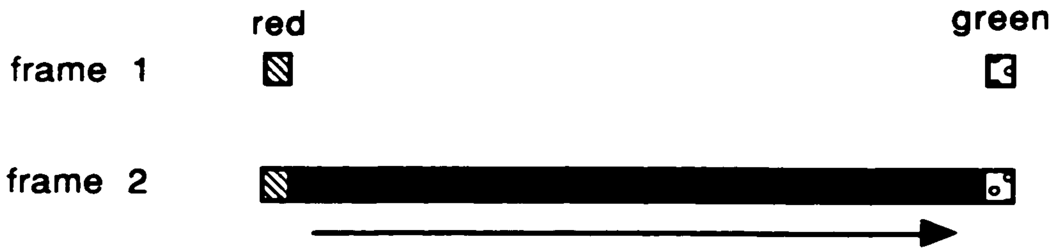

Figure 5. When a green and a red primer are put into conflict motion is reportedly away from the primer that observers are instructed to attend. This figure represents the experience of observers who are attending the red primer (Hikosaka et al., 1993b).

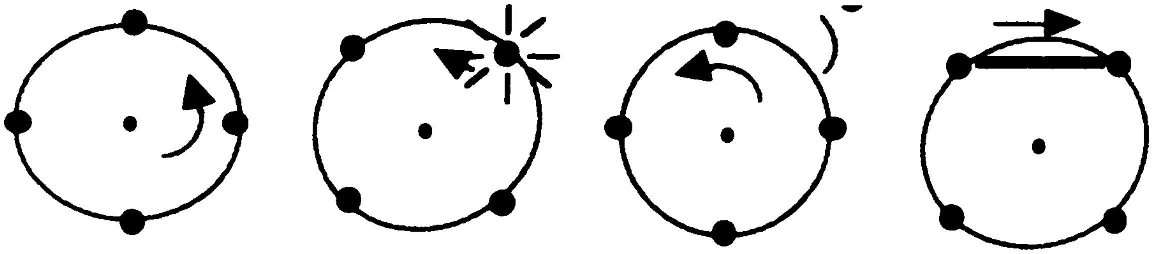

Figure 6. If several objects are moving and one of them is cued, with instructions to the observer to continue tracking the objects that was cued, motion is experienced away from the tracked object more of than an untracked object even though the location of the object has changed (Hikosaka et al., 1993b).

Figure 7. The removal of the probe line leaving only the primer object causes motion within the probe toward the primer.

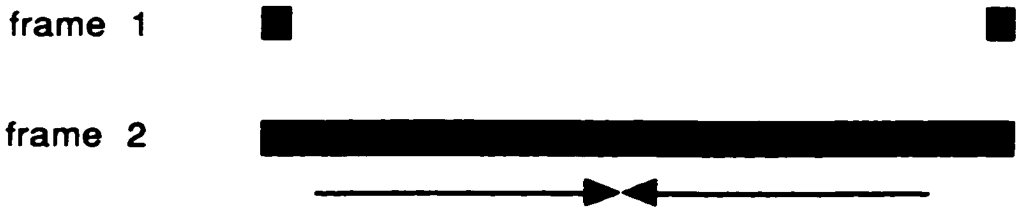

Figure 8. In the double-primer paradigm, motion from either primer colliding in the center is experienced with the presentation of a probe line between them (Faubert and von Grünau, 1992, 1995).

Figure 9. When one primer precedes the other in a double-priming paradigm, the motion collision point is experienced further away from the later-appearing primer with increasing temporal asynchrony between the presentation of the primers (Faubert and von Grünau, 1992, 1995).

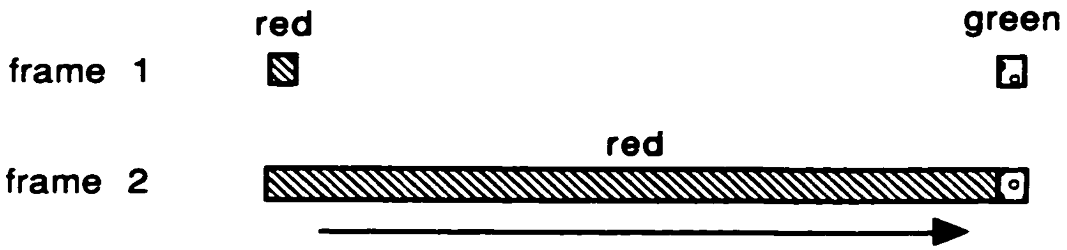

Figure 10. If the probe matches the color of one of the primers in a double-primer paradigm, motion is experienced exclusively away from that primer (Faubert and von Grünau, 1992, 1995).

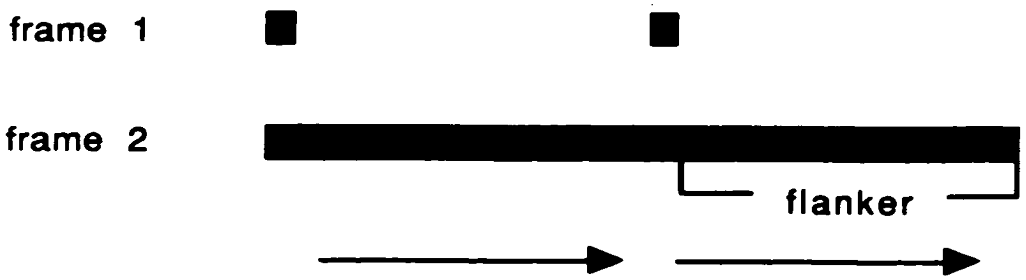

Figure 11. The addition of a flanking bar (as indicated above by the term "flanker") to the double-primer display of Figure 8 frequently causes a global experience of motion in a single direction away from the priming items (Faubert and von Grünau, 1992, 1995).

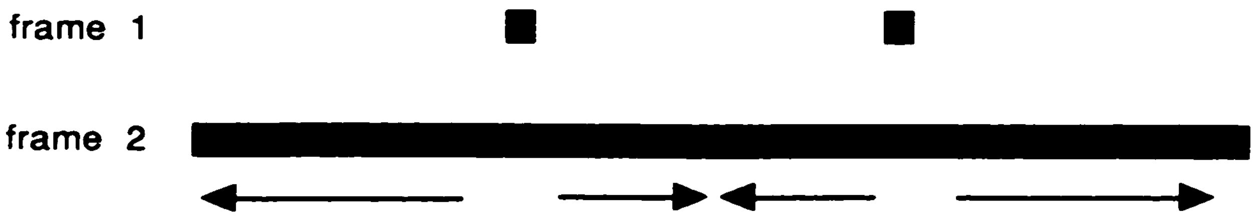

Figure 12. Adding two flanking bars, one on either side of a double-primer pair, causes motion away from each of the primers (Faubert and von Grünau, 1992, 1995).

Figure 13. Separating the primer and the probe bar by a large distance causes the direction of motion within the probe to reverse (Steinman et al., 1995).

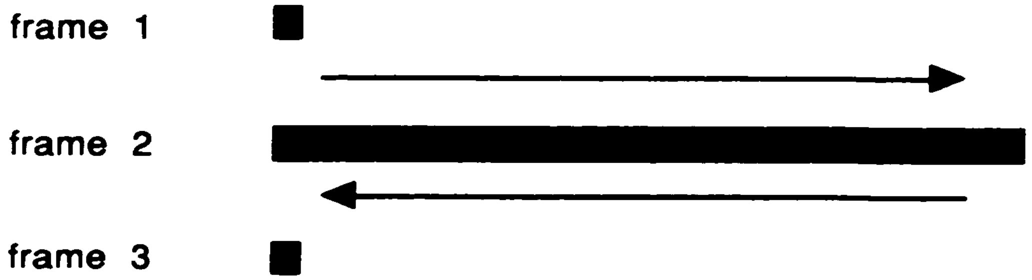

Figure 14. Presenting the primer both before and after a probe line causes the probe to expand away from the primer when it comes on and to shrink back toward the primer as it disappears.

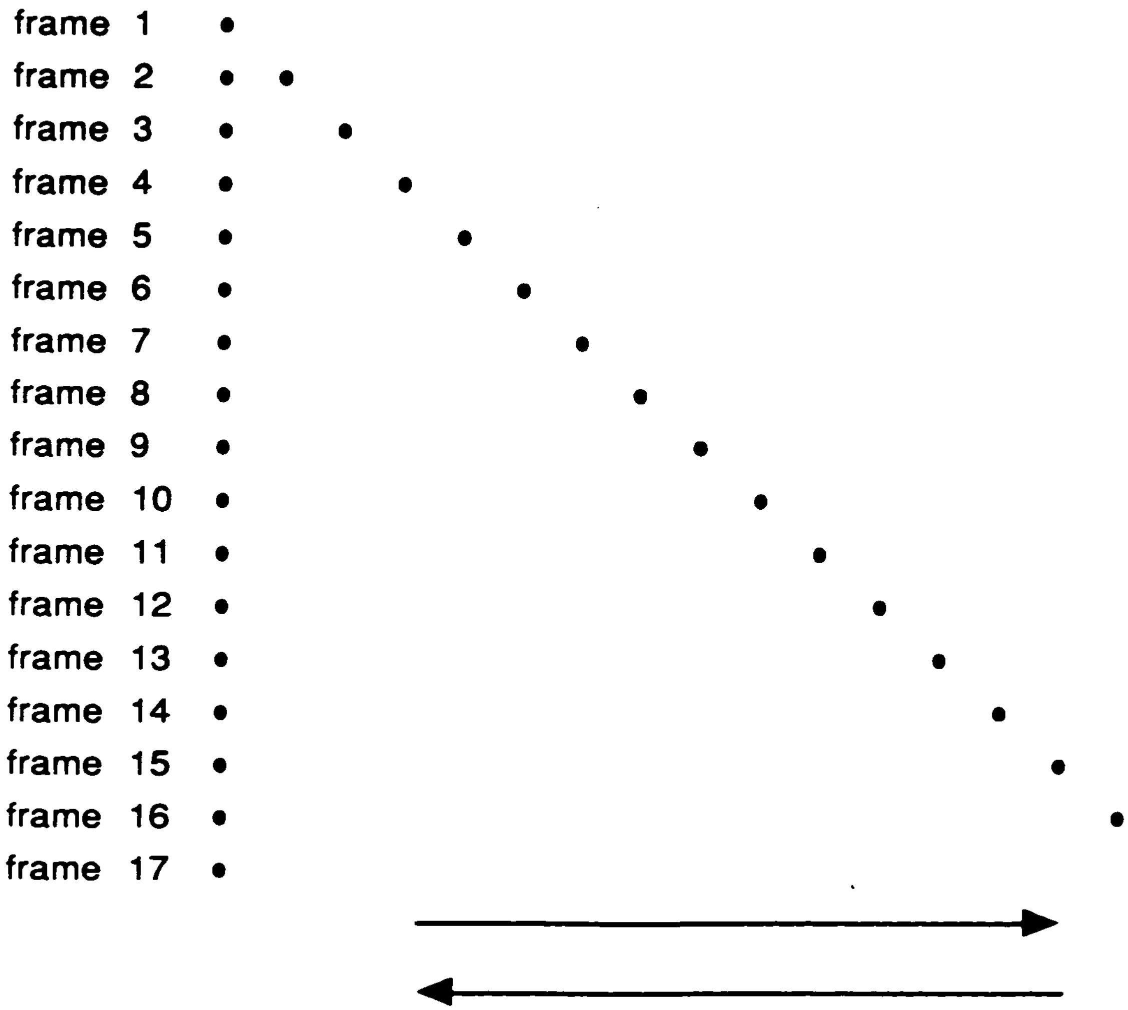

Figure 15. Two Motion Percepts are caused by the presentation of a quickly moving dot displaced away from a primer. Motion is first experienced away from the primer and then it is back toward the primer (Schmidt & Klein, 1997).

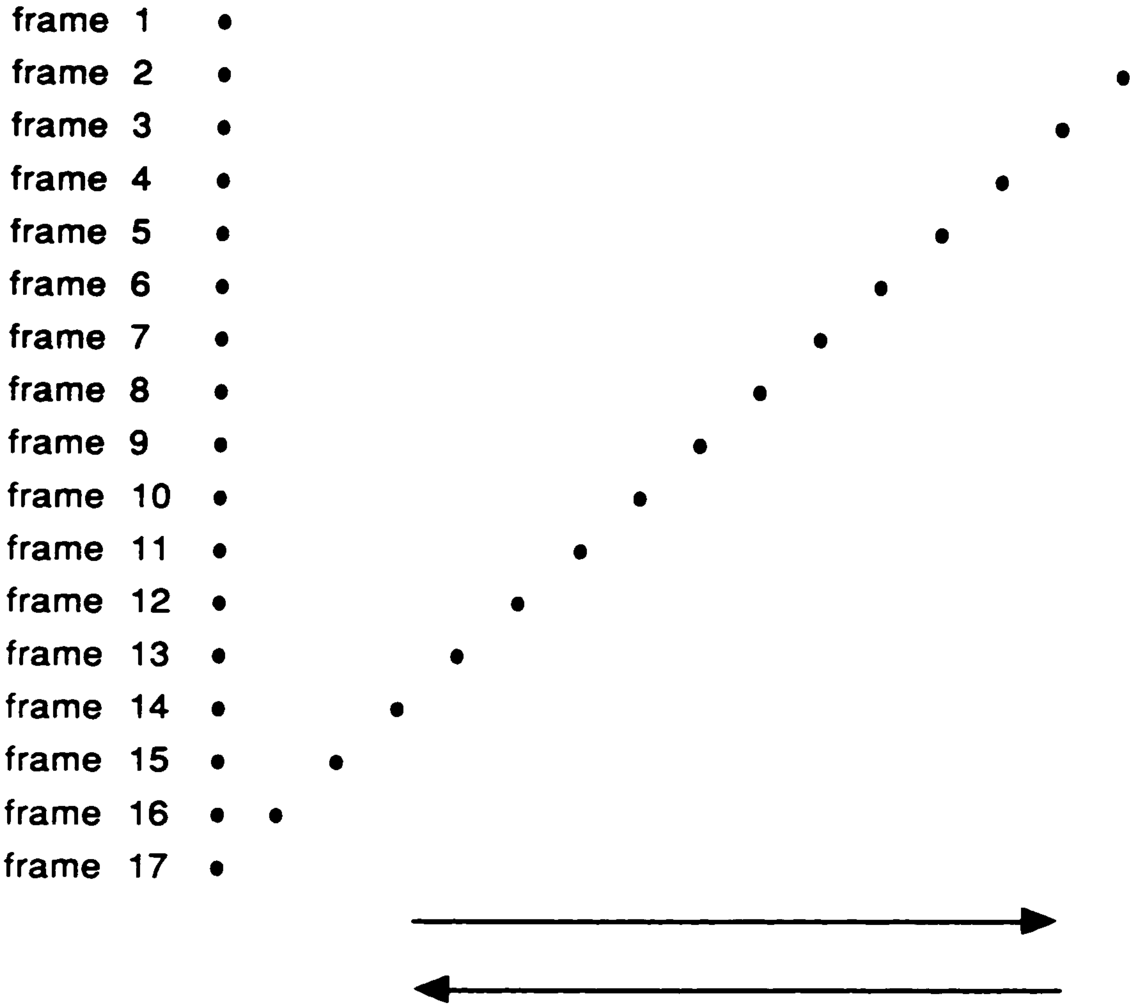

Figure 16. Two Motion Percepts are also caused by the presentation of a quickly moving dot displaced toward a primer. As in the previous example, motion is first experienced away from the primer and then it is back toward the primer (Schmidt & Klein, 1997).

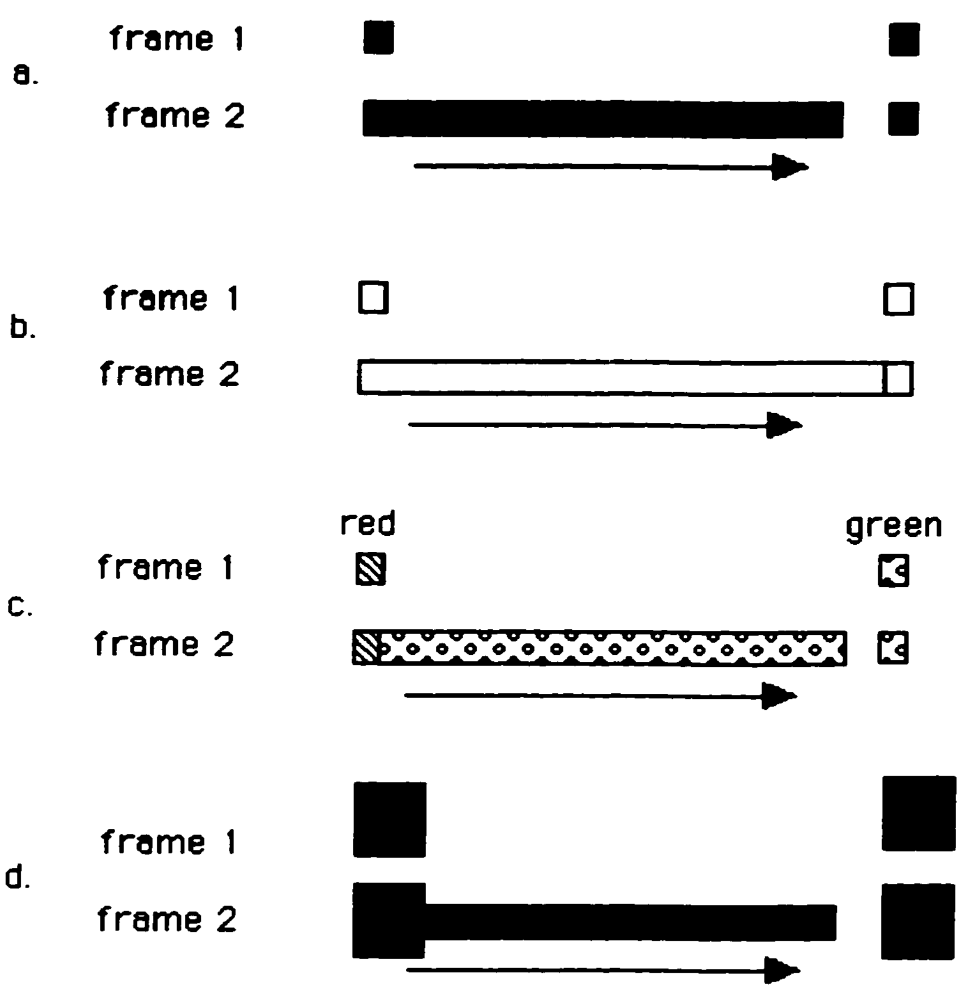

Figure 17. Stimulus contiguity between primer and probe items overrides color matches for determining the direction of motion in double-primer displays (see text for details, Tse et al., 1998).

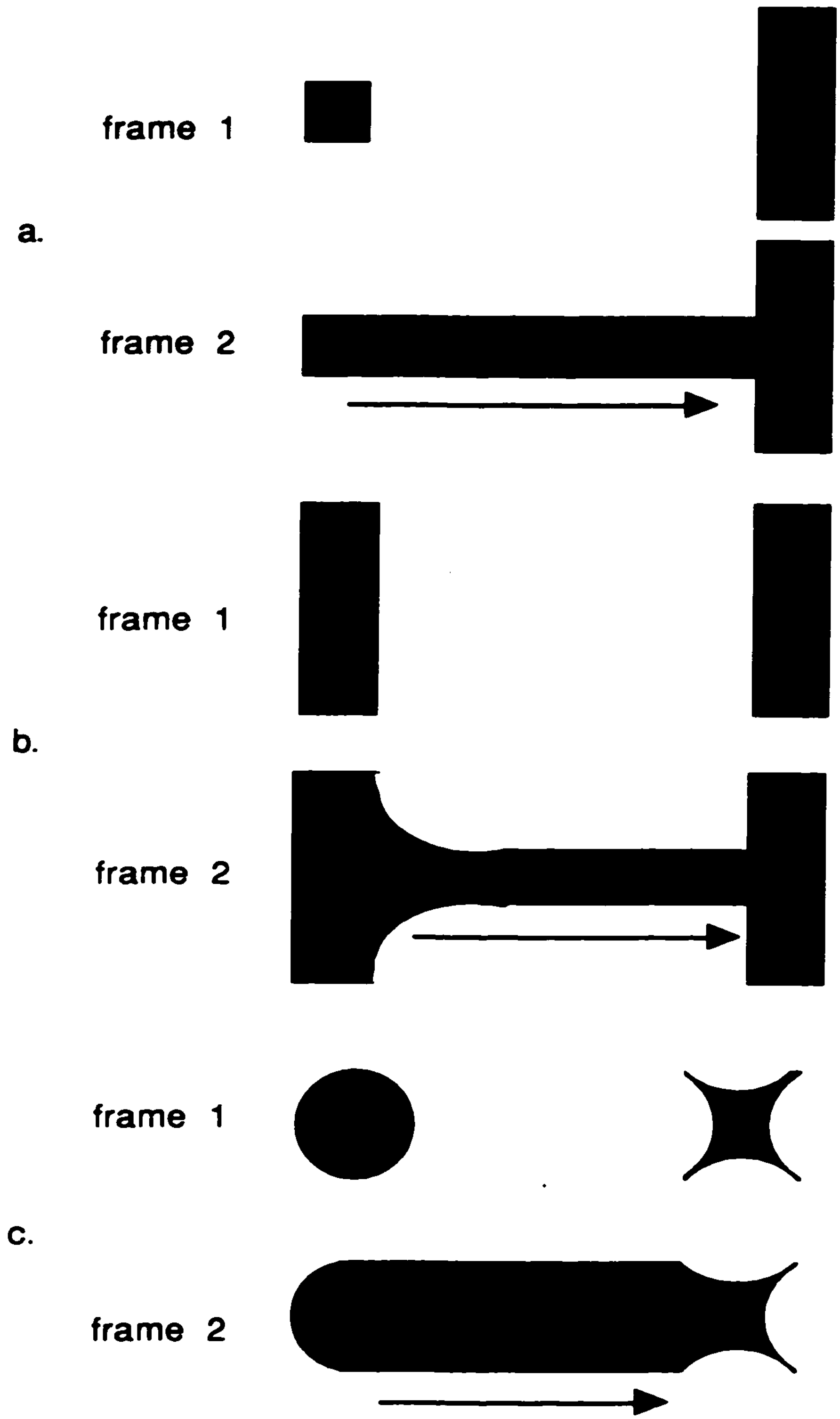

Figure 18. Smooth contours between primer and probe facilitate the direction of motion in double-primer displays, while deep concavities inhibit motion (see text for details, Tse et al., 1998).

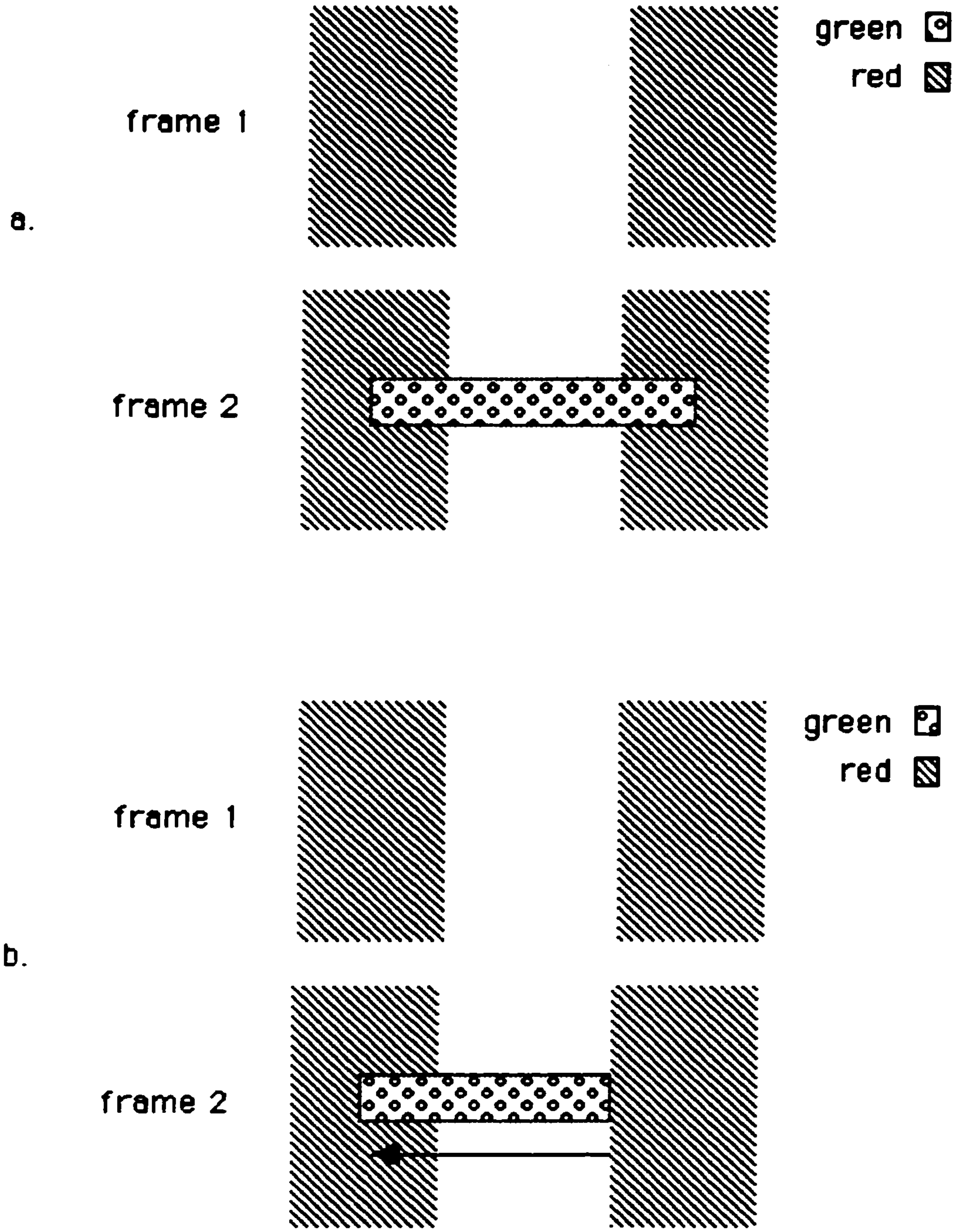

Figure 19. Transformational Apparent Motion is figure-centered rather than image centered (see text for details, Tse et al., 1998).

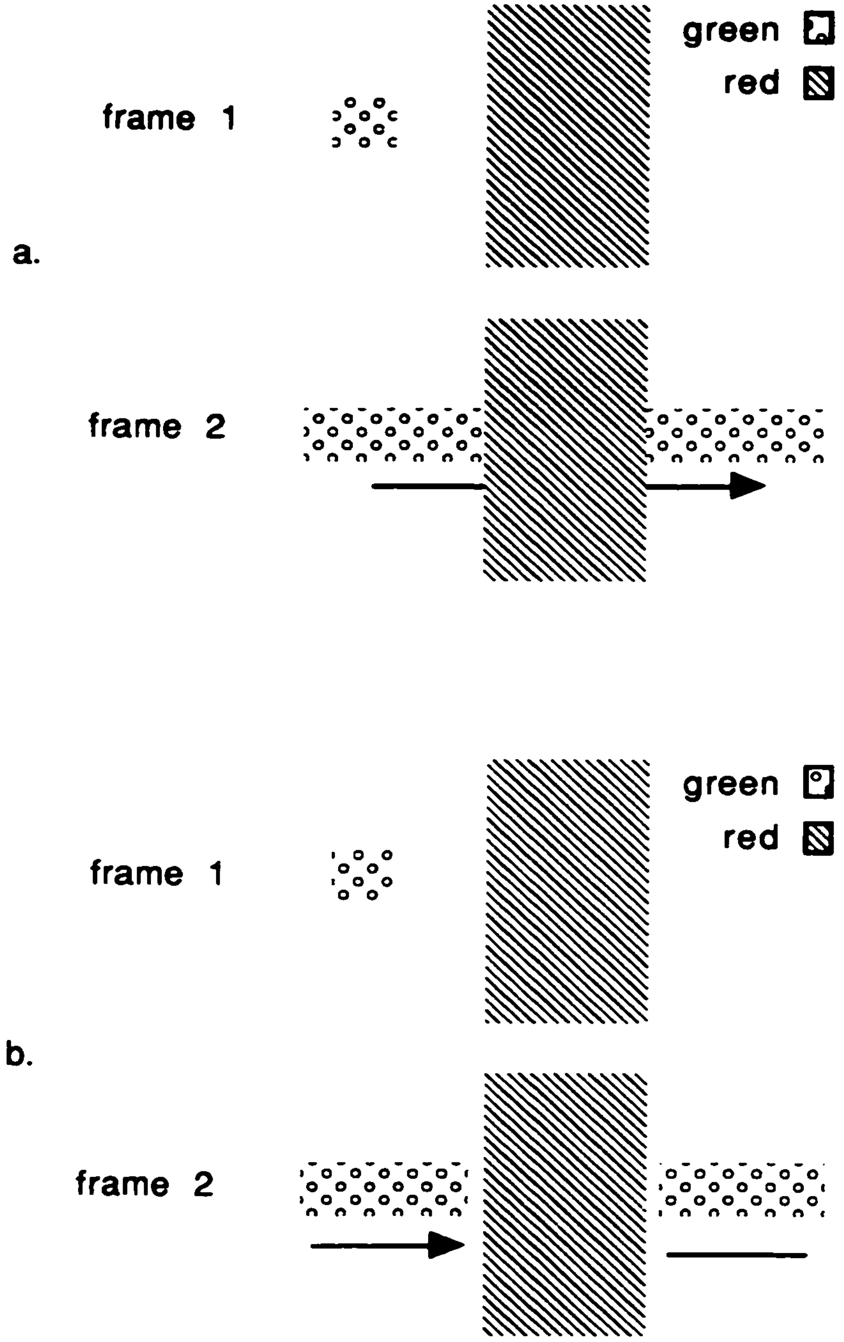

Figure 20. Transformational Apparent Motion occurs after amodal completion (see text for details, Tse et al., 1998).

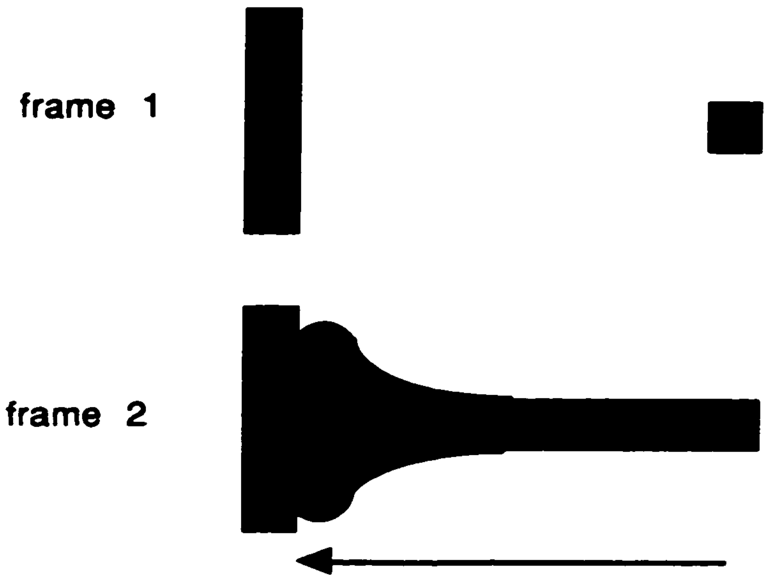

Figure 21. Motion is experienced away from the primer that shares smooth contours with the probe item. Stimulus energy models, and the gradient account, predict motion in the opposite direction (Tse et al., 1998).

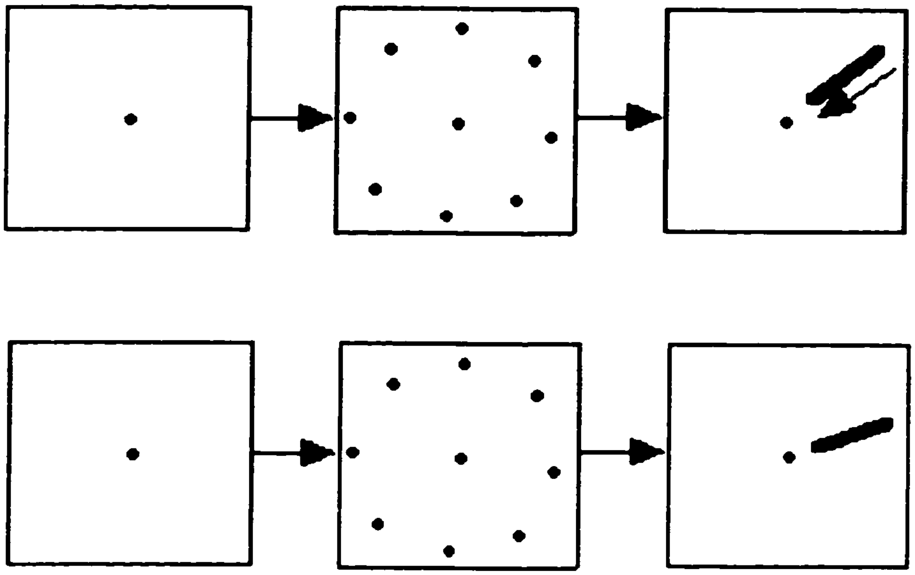

Figure 22. In a multiple primer display in which observers are to report the motion direction of a probe bar, motion is experienced inwards for approximately 5-7 items in the display when the probe abuts a primer location (top). When the probe bar falls in the empty space between two primers, motion is seldom experienced (bottom; Schmidt et al., 1998).

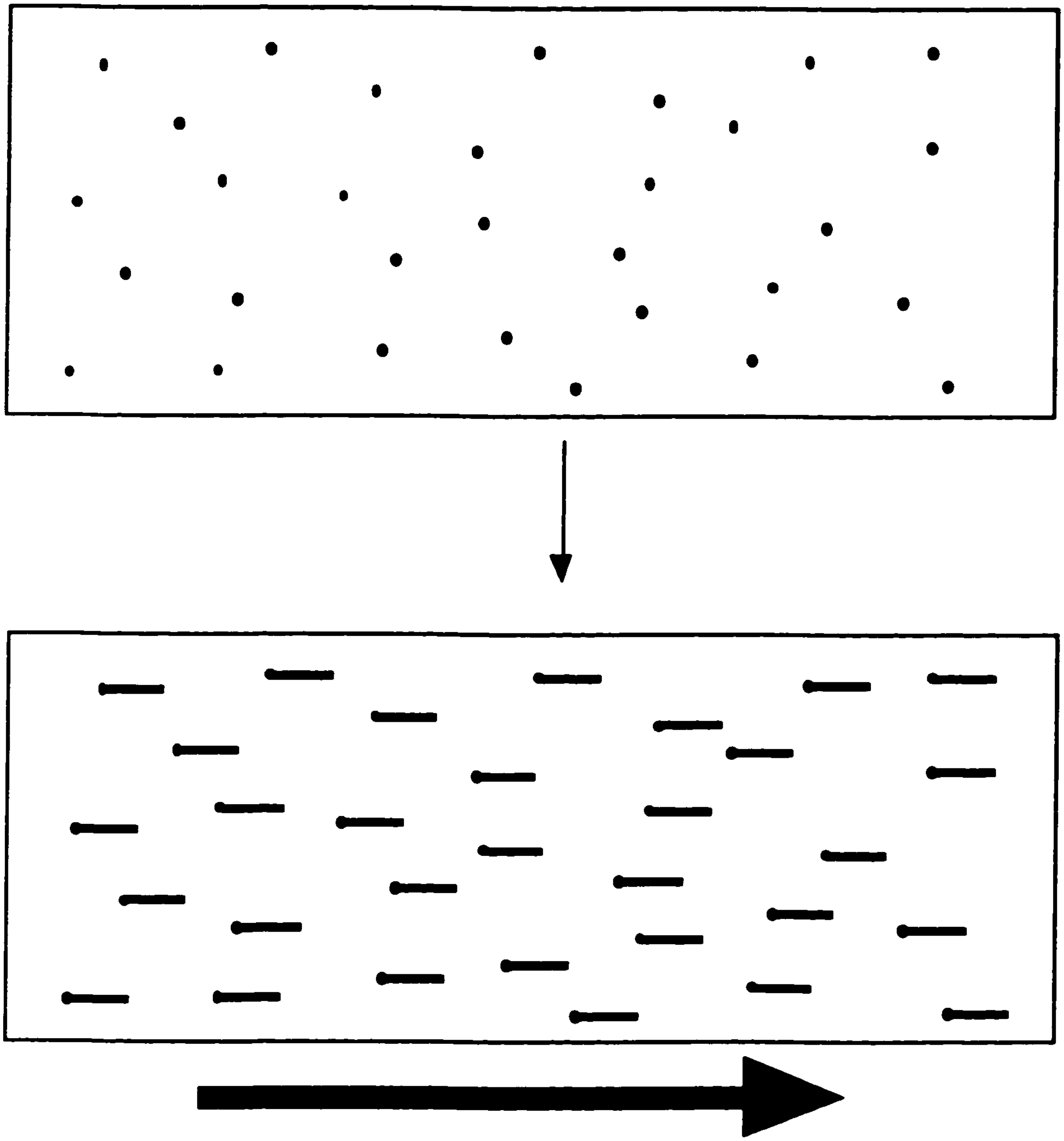

Figure 23. When a large number of simple ILM signals are presented they are integrated to produce an overall global motion percept in the majority direction of the individual presentations (Faubert, 1996).

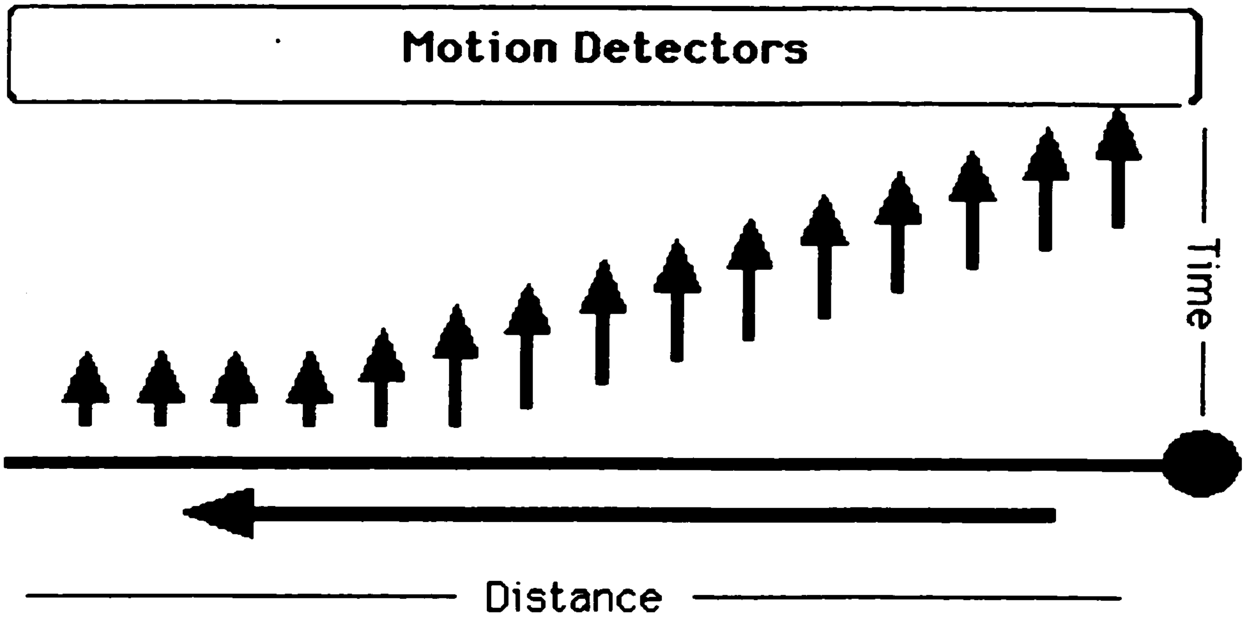

Figure 24. Hikosaka et al. (1991, 1993a, 1993b, 1993c) hypothesized that the mechanism underlying ILM is a spatial gradient that speeds signals arising nearby the primer location (round object on the right) toward a motion detection system. The degree of signal acceleration is purported to decrease with distance from the primer.

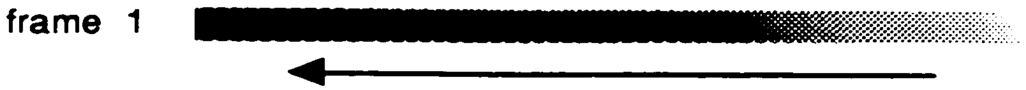

Figure 25. The presentation of a luminance gradient bar causes motion from its brightest to darkest end (von Grünau et al., 1995).

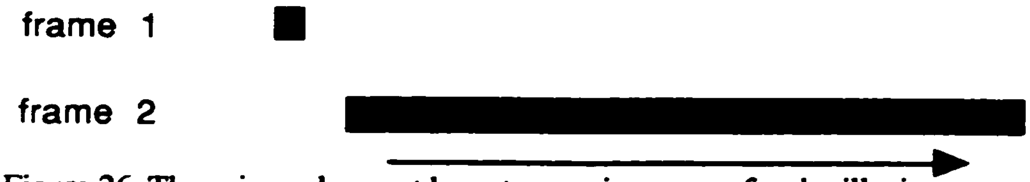

Figure 26. The primer does not have to remain present for the illusion to occur, and there can be a gap between the primer and probe positions.

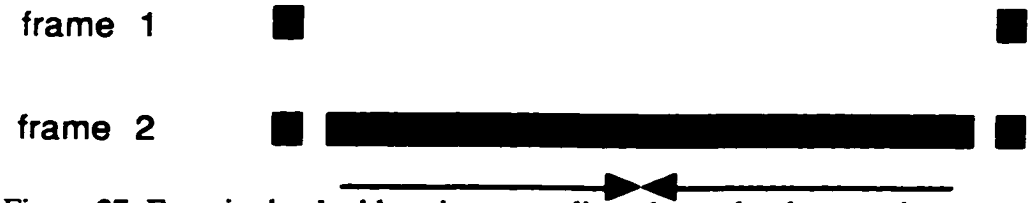

Figure 27. Even in the double-primer paradigm the probe does not have to spatially overlap the primers in order for the illusion to occur.

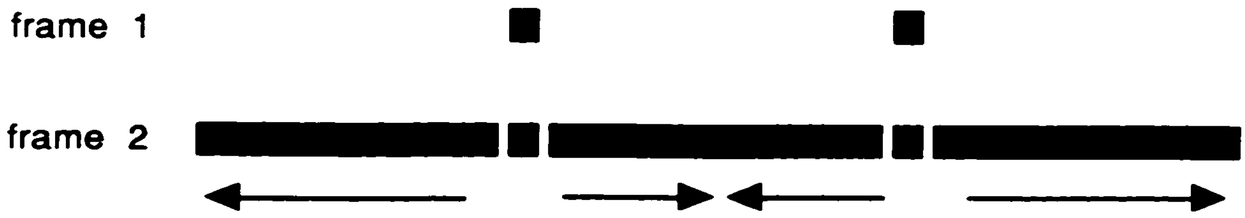

Figure 28. Adding flanking bars on either side of the primers of a double-primer display restores a collision within the central bar. Gaps between the primers, which remain present, and the probe, should prevent observers from experiencing the flanking bars as simple extensions of the primers.

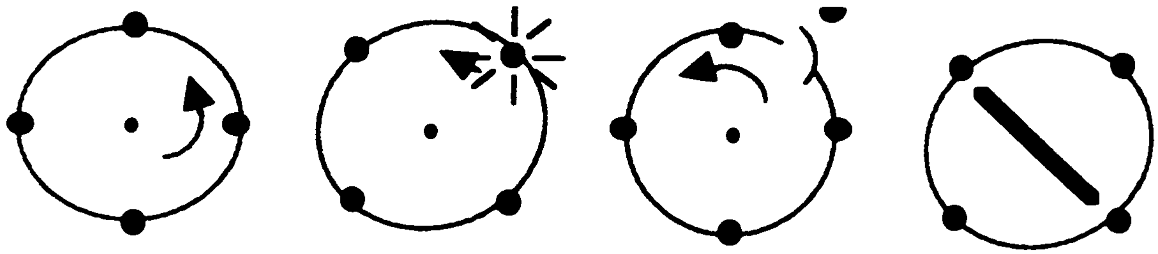

Figure 29. The stimulus configuration used in Downing and Treisman's (1997) Experiment 2A. The probe bar is presented superimposed on a visible fixation point. The probe is not contiguous with any of the other display objects.

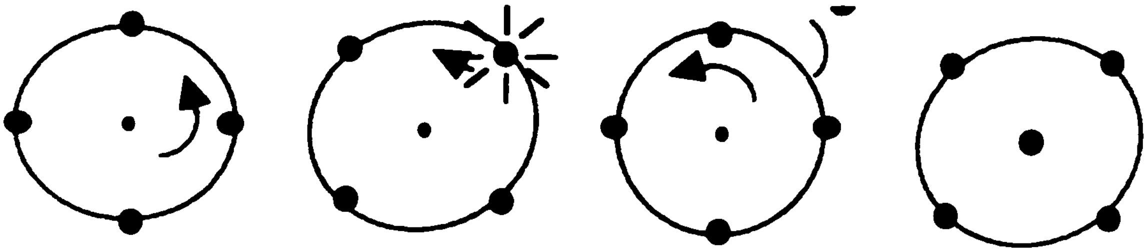

Figure 30. The stimulus configuration used in Downing and Treisman's (1997) Experiment 2B. The probe is a small circle identical to the other display objects, and is superimposed on a visible fixation circle with which it is spatially contiguous. The probe is not contiguous with the any of the other display objects. Yet impletion, it is claimed, infers the probe onset as a transformation of the previously cued primer that is distant, rather than the simple expansion of the fixation object.

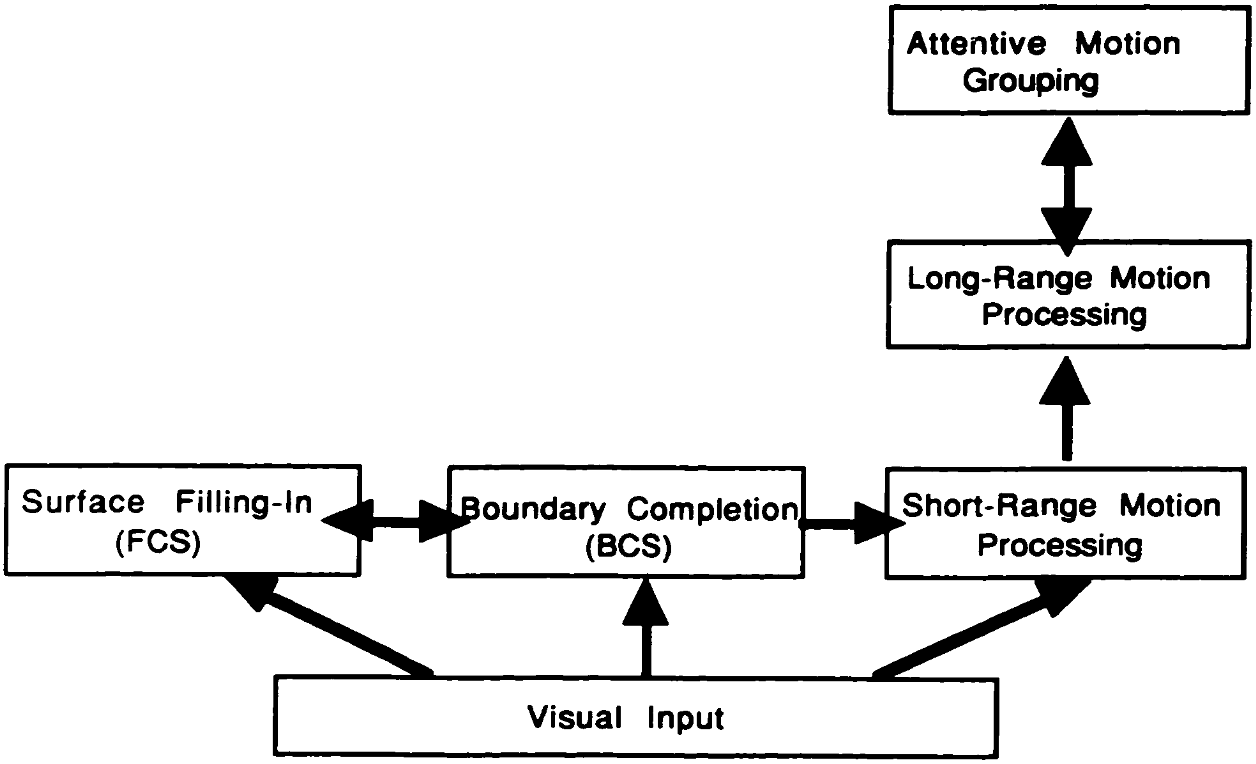

Figure 31. Proposed processing streams and their interactions, as presented in Baloch and Grossberg (1997). The Boundary Contour System (BCS) is responsible for generating boundaries of forms while the Feature Contour System (FCS) fills-in surfaces used in those forms. These systems feed into a parallel motion processing system represented by the three boxes on the right. Visual attention influences long-range motion processes used to track or group objects. Adapted from Baloch and Grossberg (1997).

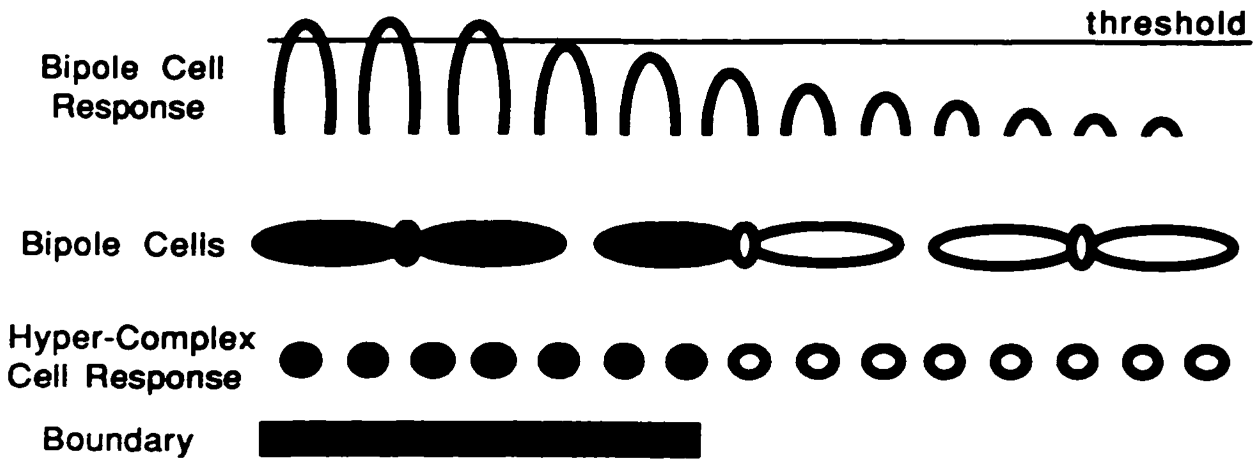

Figure 32. If the entire bipole cell, or the cell body and one lobe are activated then the cell fires (two leftmost bipole cells above). Otherwise the cell does not fire (rightmost bipole cell above). There is a graded level of activation from in inactivated bipole cells as a function of the boundary surface. Adapted from Baloch and Grossberg (1997).

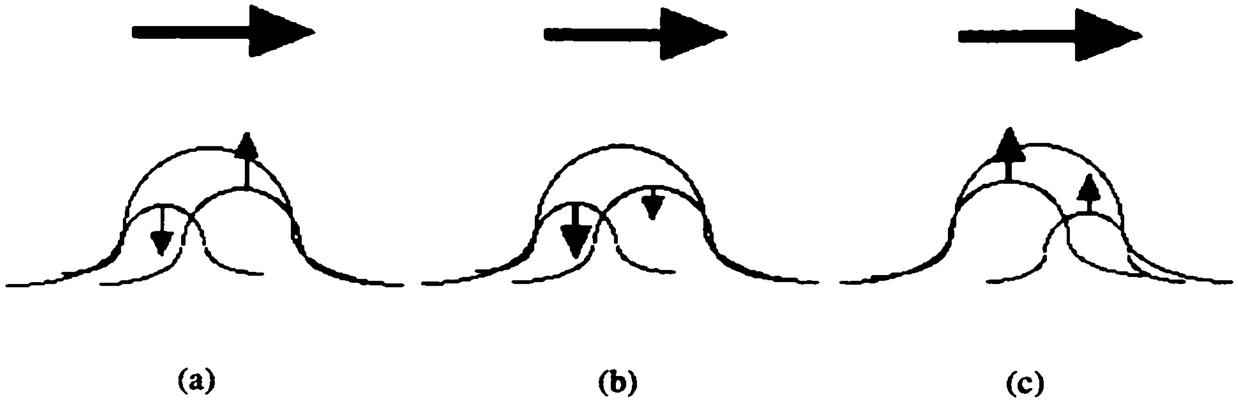

Figure 33. Conditions that lead to a continuous motion G-wave are presented. In (a), the first mound decays as the second grows. In (b), the first mound is decaying more quickly than the second. In (c) the first mound grows faster than the second. Adapted from Baloch and Grossberg (1997).

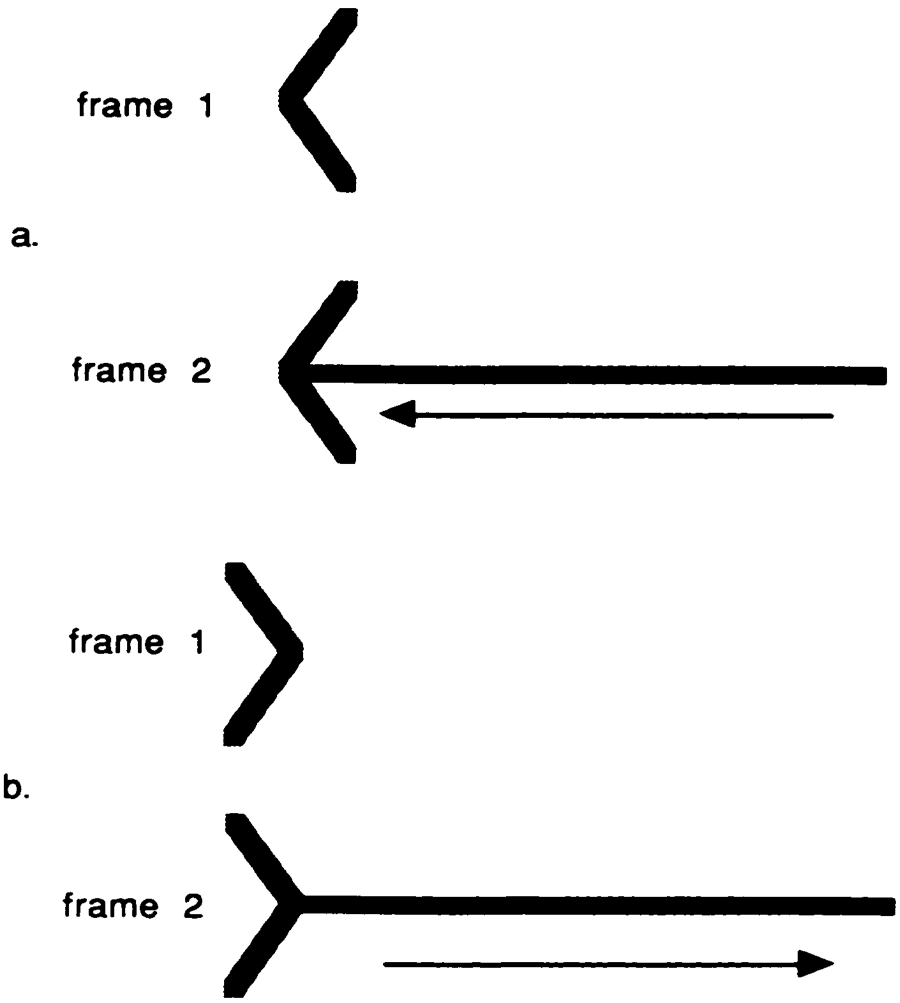

Figure 34. Baloch and Grossberg (1997) claim that when the primer and the probe make up and arrows as in (a), motion in the probe bar is toward the arrowhead because local orientation inhibition causes the far end of the probe's boundary to form earlier than the close end. In (b) orientation facilitation is active resulting in the reverse situation.

Figure 35. The primer for Experiments 1 and 2 were vertical lines. The probes were either a vertical line (apparent motion condition), a square (Experiment 1 only), or a long horizontal bar (illusory line motion condition).

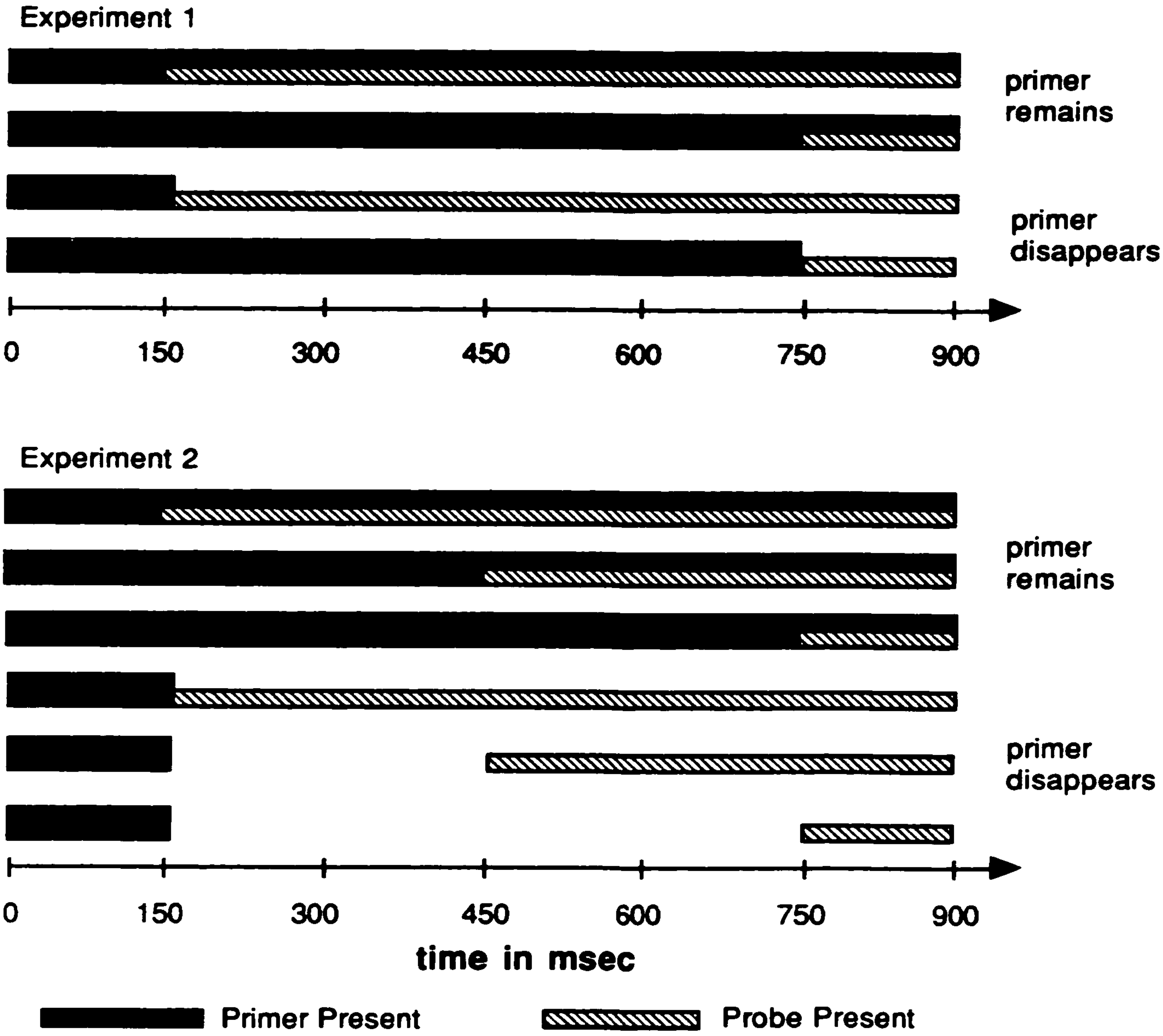

Figure 36. Time-line representing stimulus presentations in Experiment 1 (top) and 2 (bottom). Each row represents a condition of the experiment, with the times that the primer is present indicated in solid black, and the time that the probe is present indicated by hatch marks. SOA was manipulated in Experiment 1, while SOA and ISI was manipulated in Experiment 2.

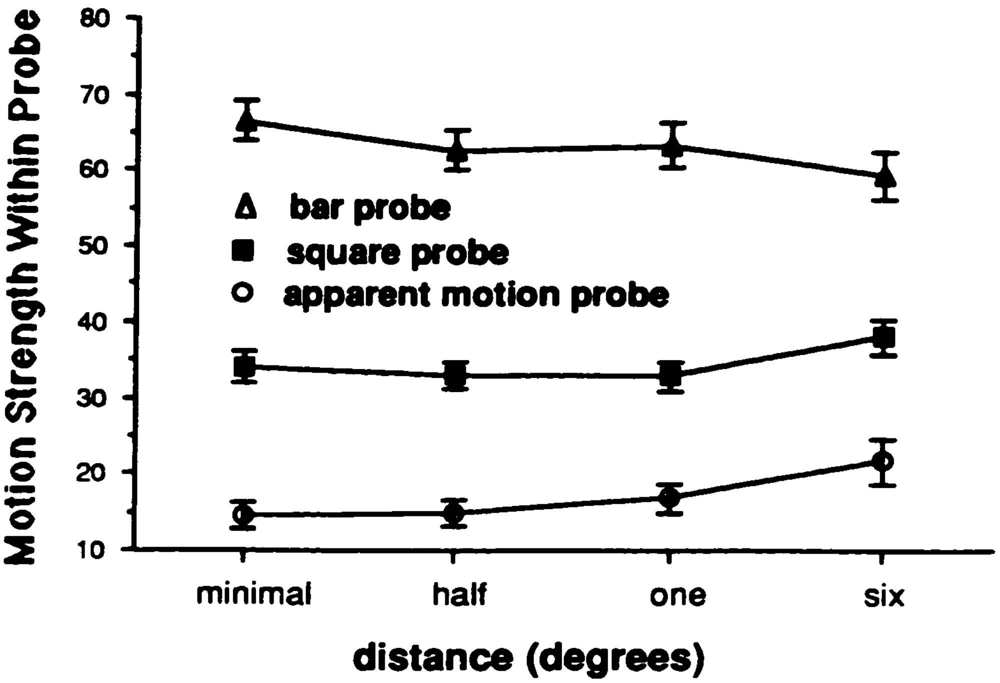

Figure 37. Probe type by distance interaction means for judgments of motion within the probe for Experiment 1. The apparent motion condition is clearly dissociated from ILM. While ILM weakened with distance, the other probes strengthened. Motion strength was a function of the probe object's area. The error bars represent the standard error.

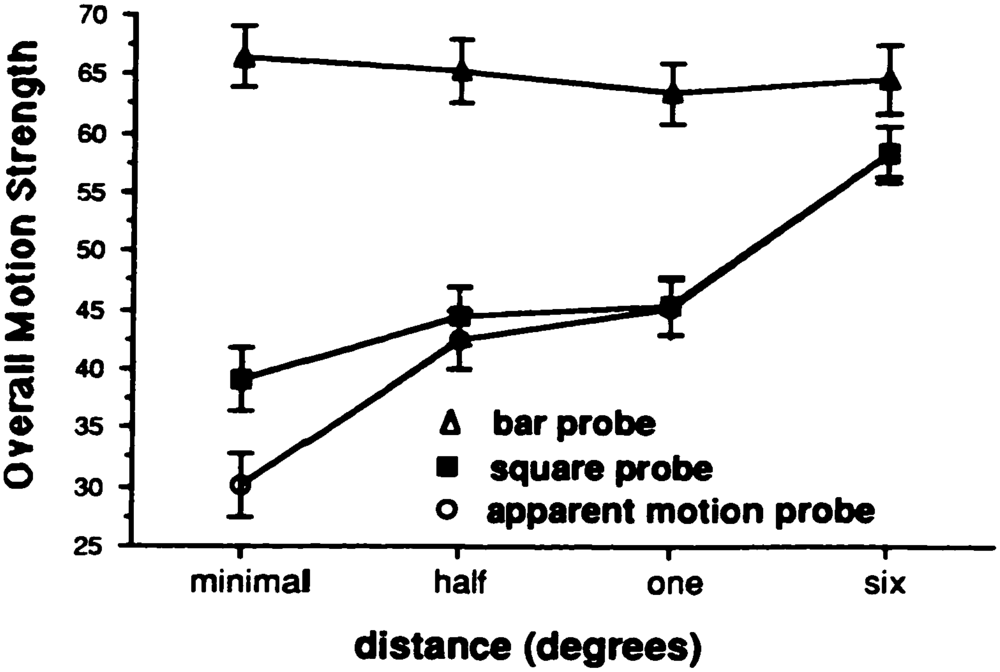

Figure 38. Probe type by distance interaction means for judgments of overall motion in Experiment 1. Apparent motion is clearly dissociable from ILM, especially at small primer-probe separations. The error bars represent the standard error.

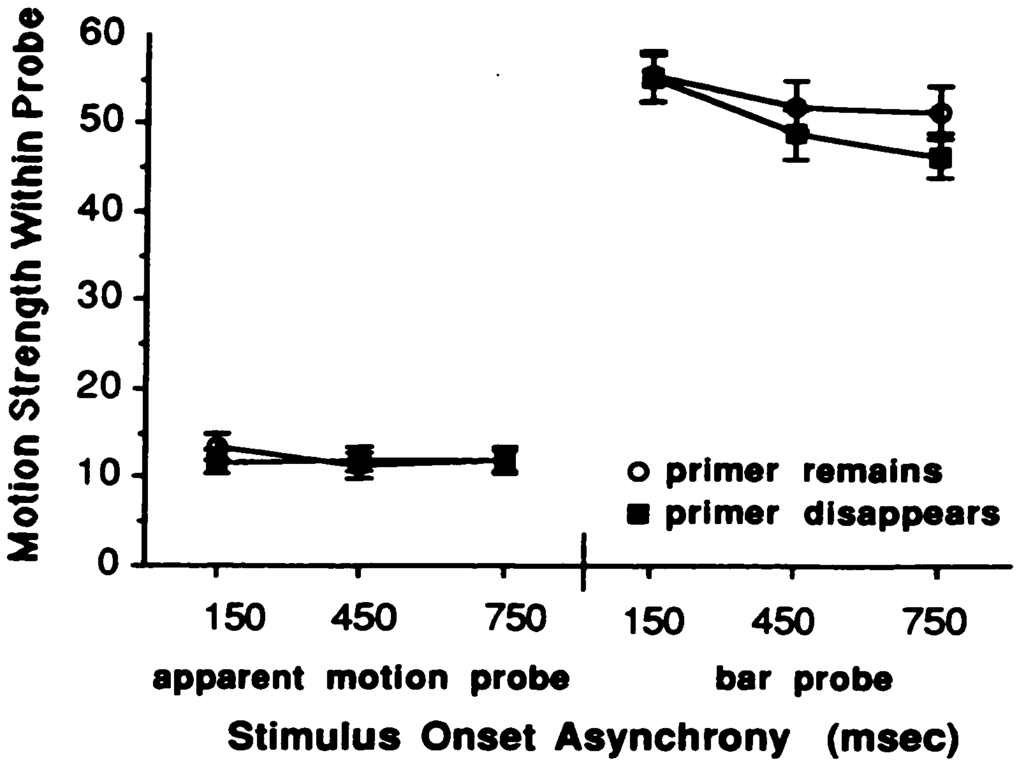

Figure 39. Probe type, primer status and SOA interaction means for judgments of motion within the probe for Experiment 2. ILM was always stronger than apparent motion. While there were no effects of removing the primer on within motion judgments for apparent motion, ILM weakened slightly with increasing ISI and with the removal of the primer during this interval. The error bars represent the standard error.

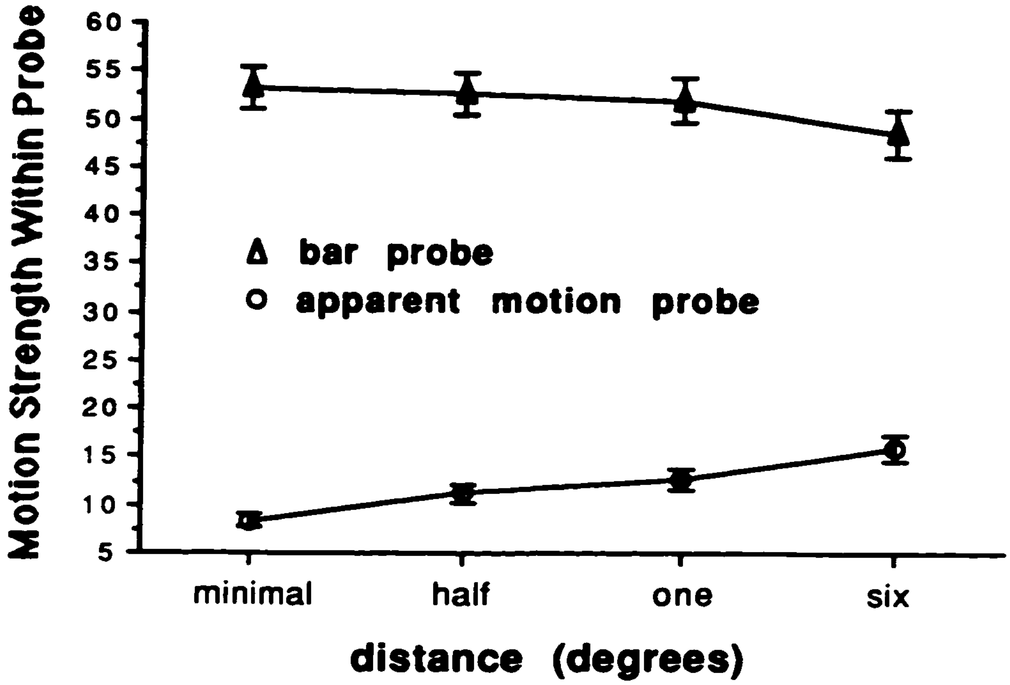

Figure 40. Probe type by distance interaction means for judgments of motion within the probe for Experiment 2. Again, the apparent motion condition is clearly dissociated from ILM. While ILM weakened with distance, the apparent motion probe was rated more strongly. The error bars represent the standard error.

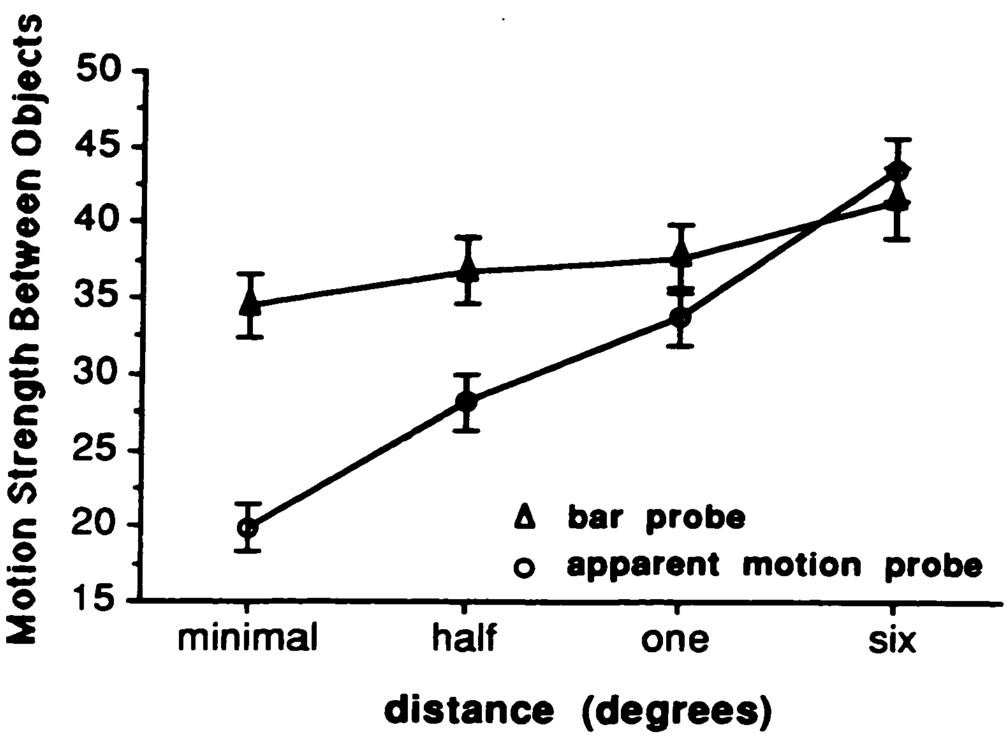

Figure 41. Probe type by distance interaction means for judgments of between object motion in Experiment 2. As before, at small primer-probe separations apparent motion is dissociated from ILM. The error bars represent the standard error.

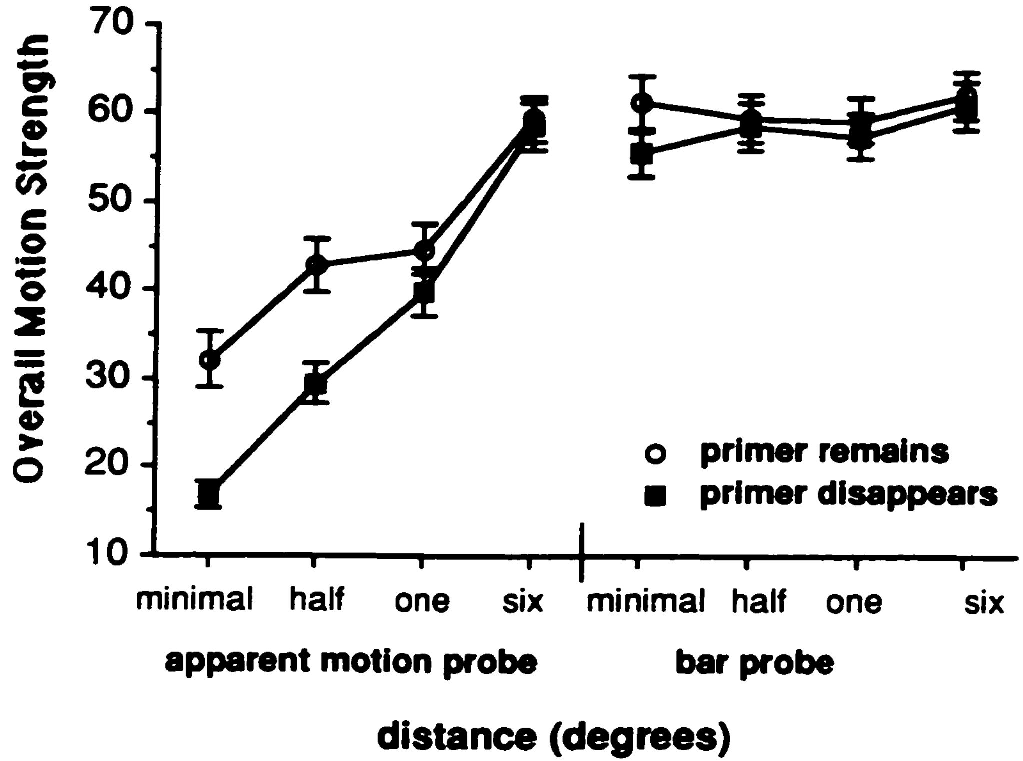

Figure 42. Probe type, primer status and distance interaction means for judgments of overall motion in Experiment 2. ILM was strong regardless of the distance between the primer and probe, and regardless of whether or not the primer remained present throughout the trial. Apparent motion however, was weak at small primer-probe separations, was stronger when the primer remained throughout the trial, and increased in strength as a function of primer-probe distance. The error bars represent the standard error.

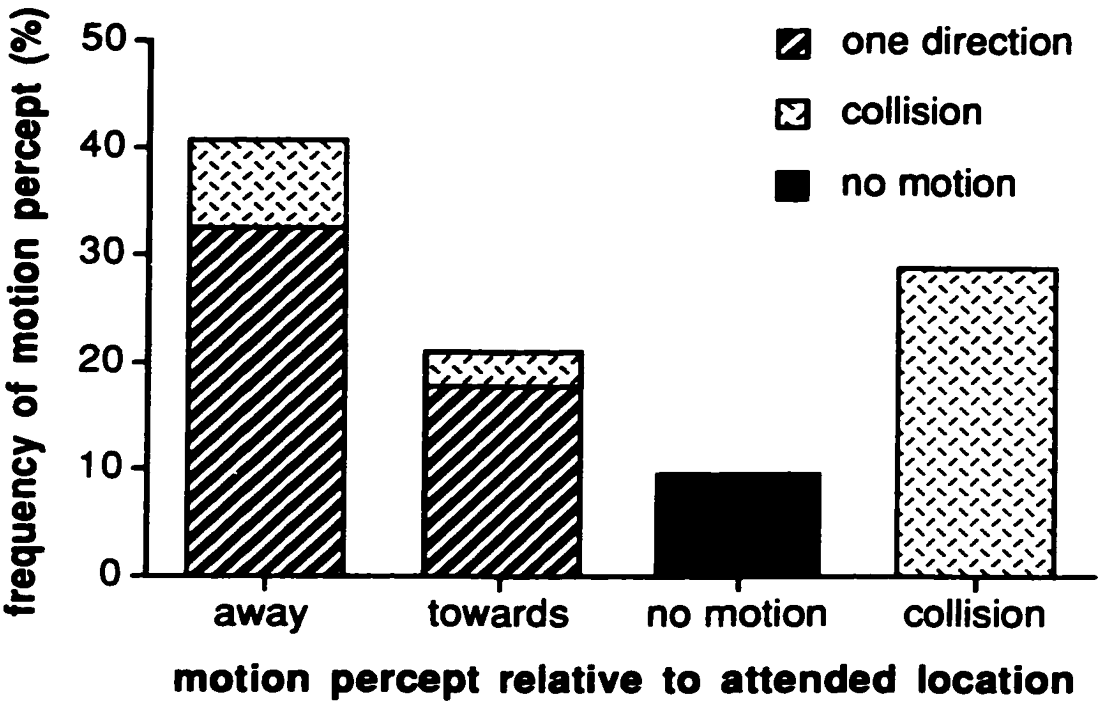

Figure 43. Illusory line motion results from Experiment 3, Phase 3, collapsed across the color of the attended box.

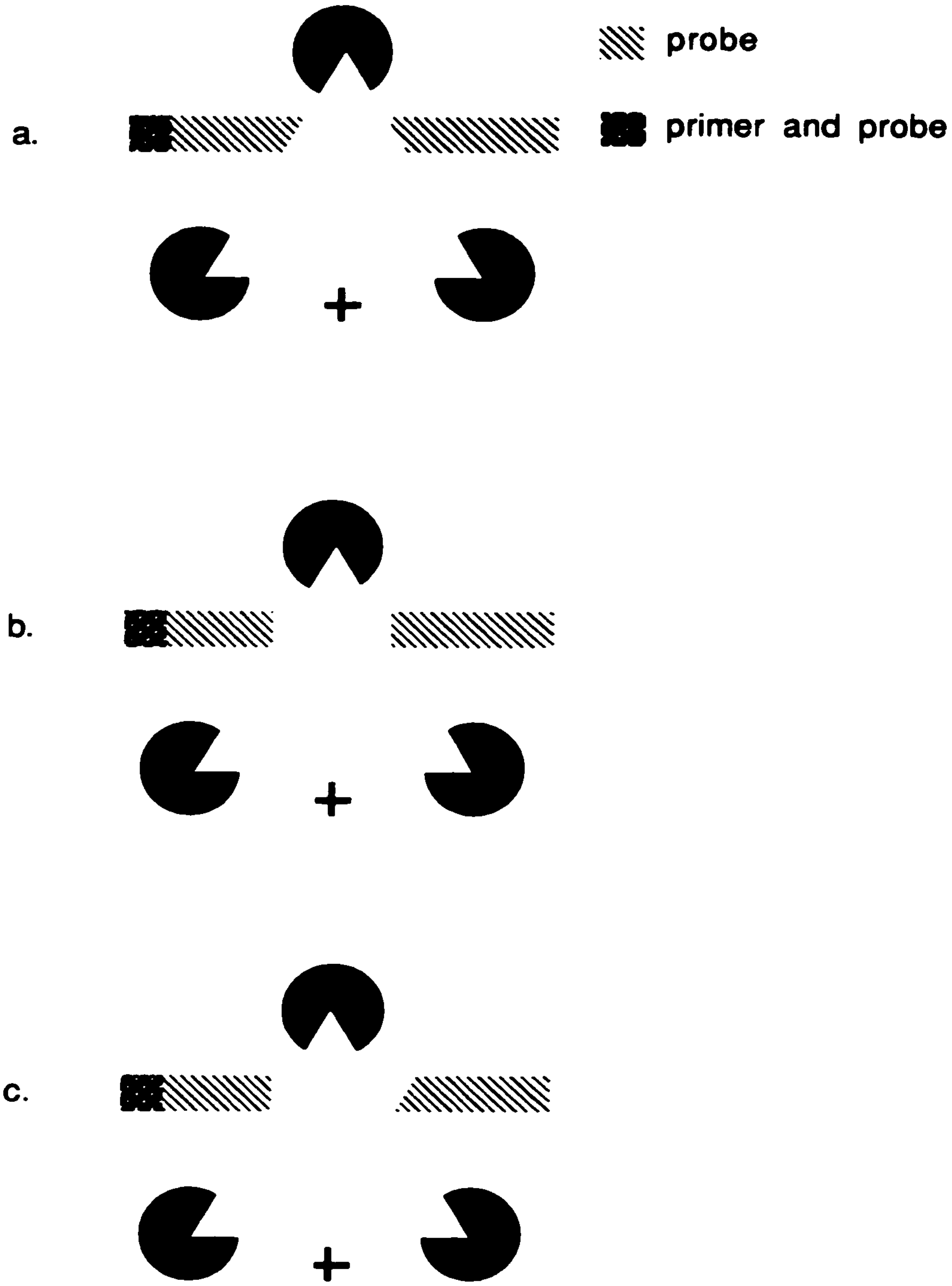

Figure 44. Example stimulus from Tse et al. (1995) used to claim that amodal and modal completion occur before motion processing. In (a) motion is experienced away from the primer within the probe object that is presented as being occluded by the illusory triangle. In (b and c) the claim is that no motion is usually reported as occurring in the portion of the probe that is on the opposite side of the illusory triangle because here amodal completion does not occur.

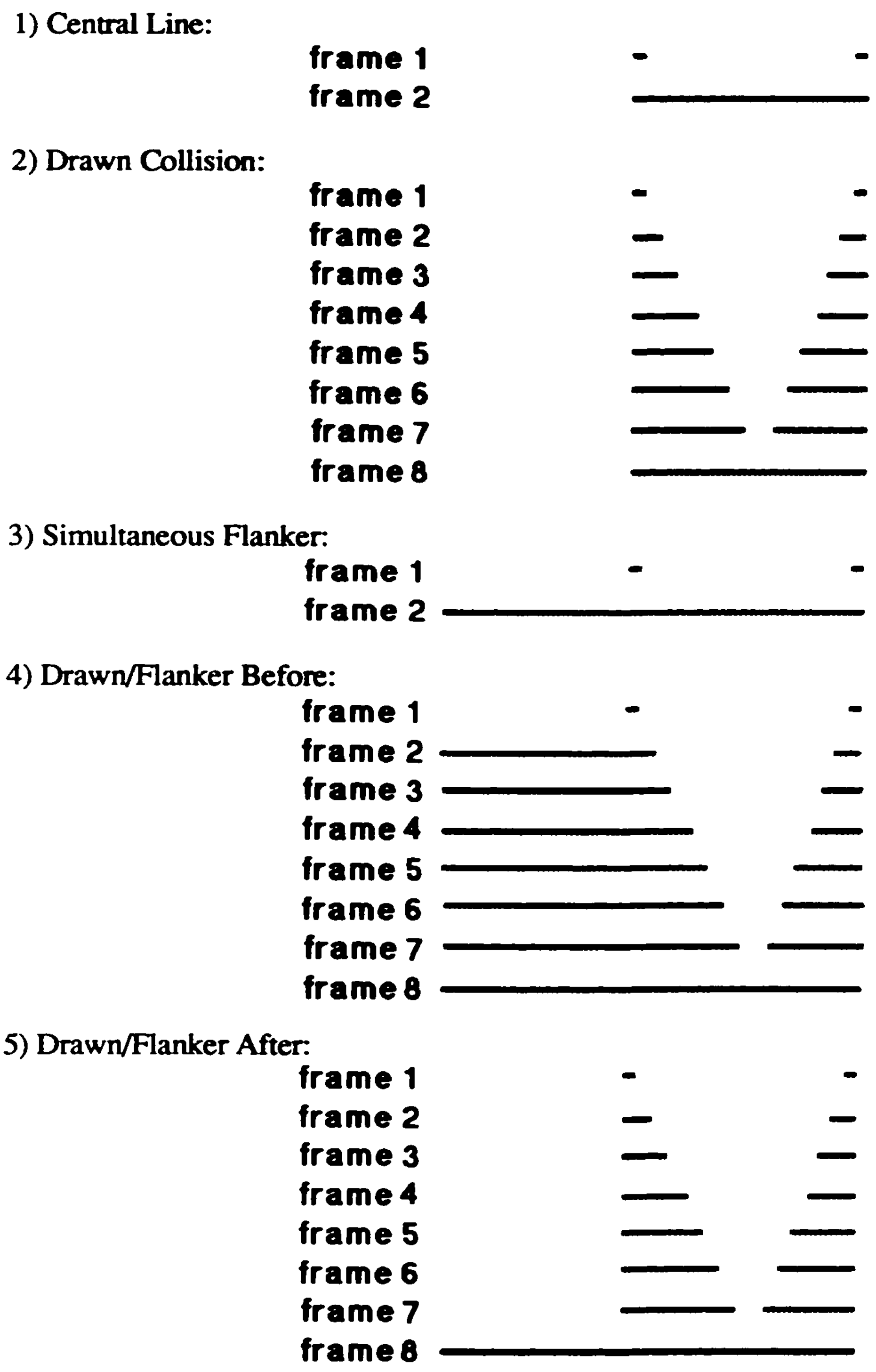

Figure 45. The conditions of Experiment 8. See the text for details.

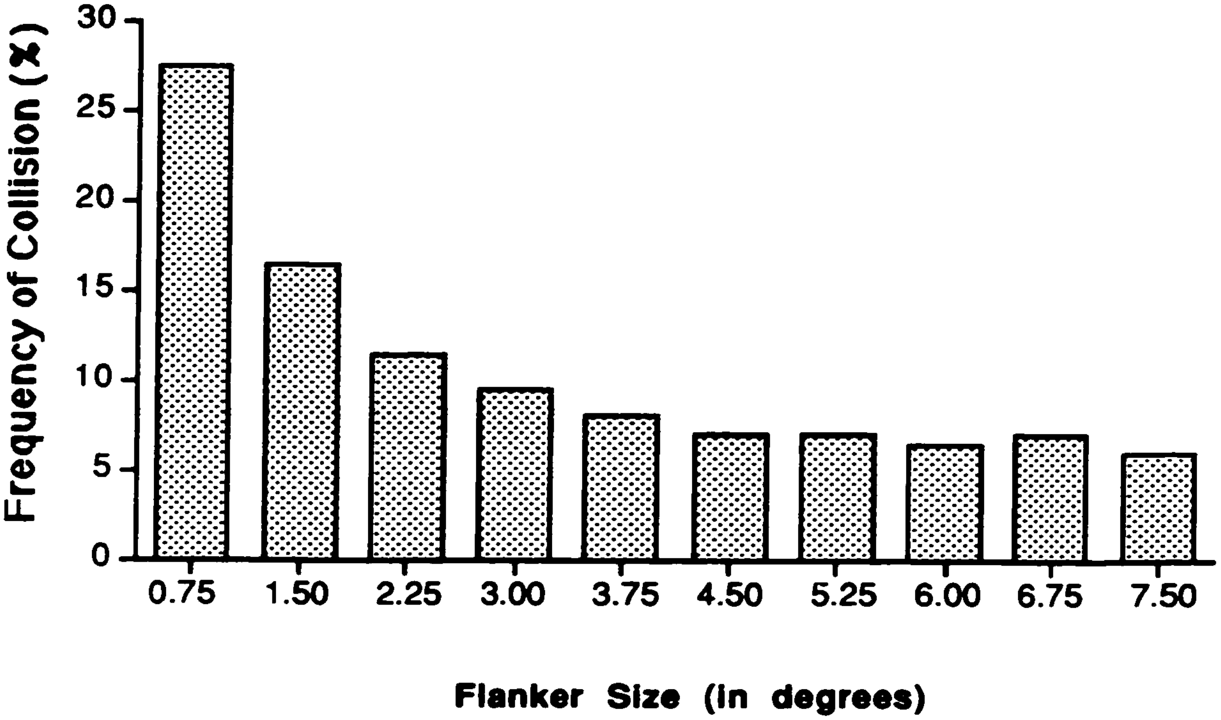

Figure 46. The bars reflect the frequency of collision report within the display's central bar as a function of the size of the flanker in Experiment 9.

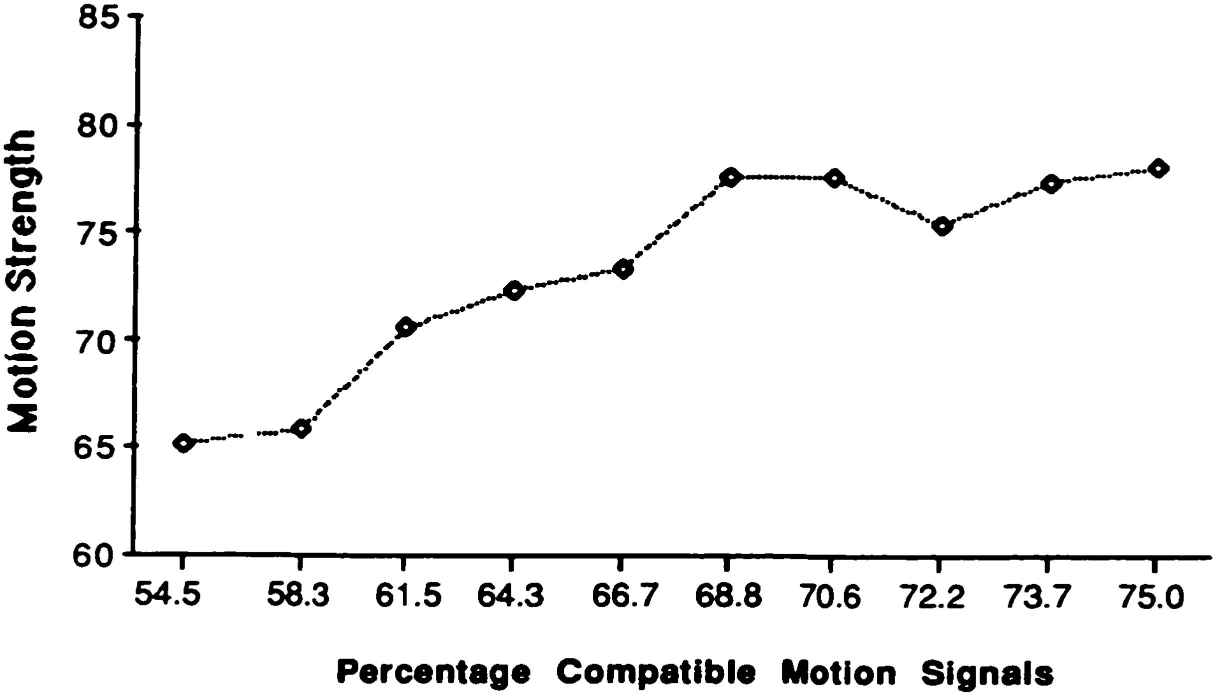

Figure 47. The values on the abscissa represent the percentage of signals that on the gradient account would produce motion signals in the display in a direction away from the primers. The line plot indicates that the experienced motion strength was an increasing function of the flanker size.

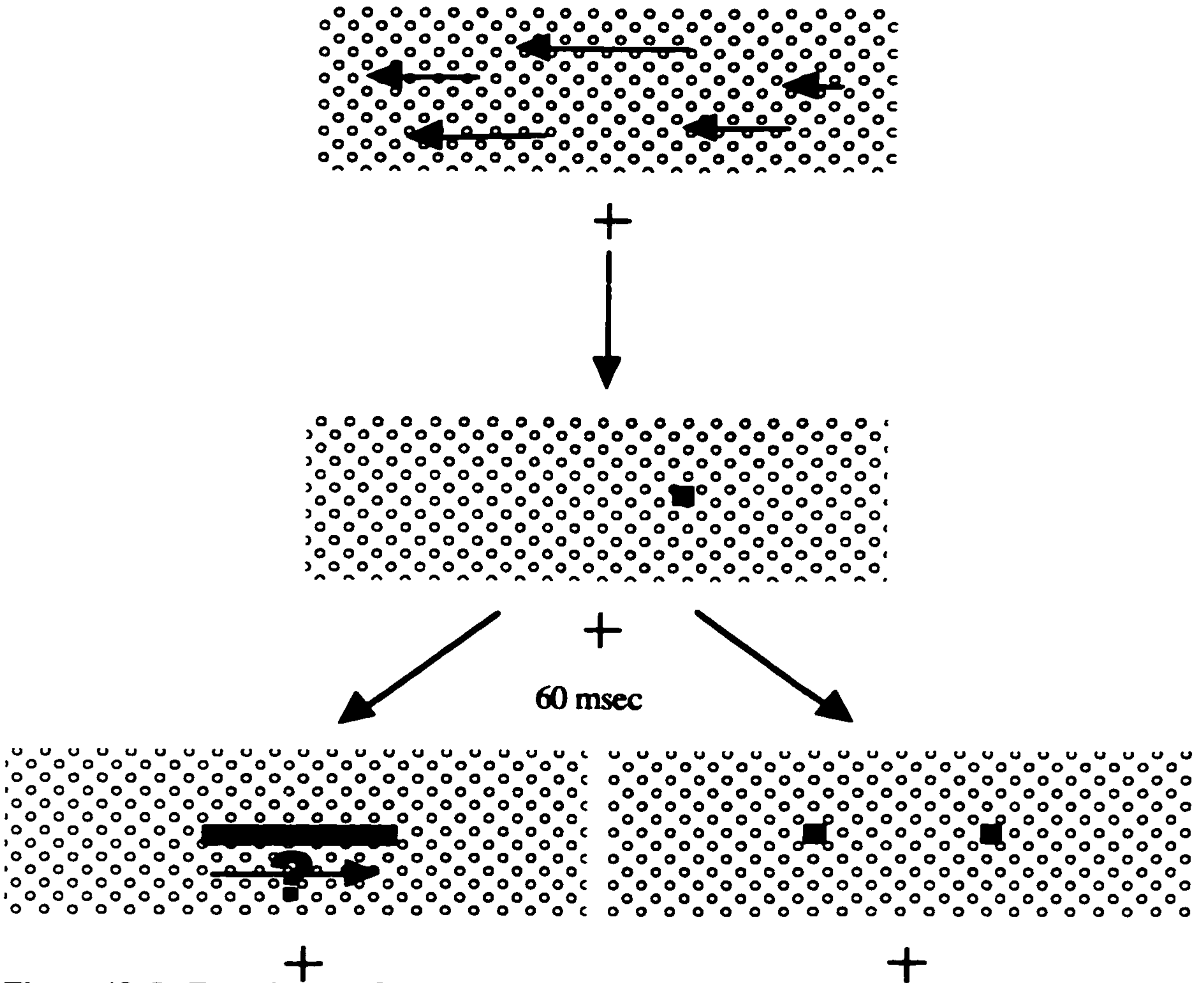

Figure 48. In Experiment 10 observers were exposed to a moving dot field. After an adaptation period, the dot field ceased moving and a primer was presented followed by either a bar probe or a dot probe.

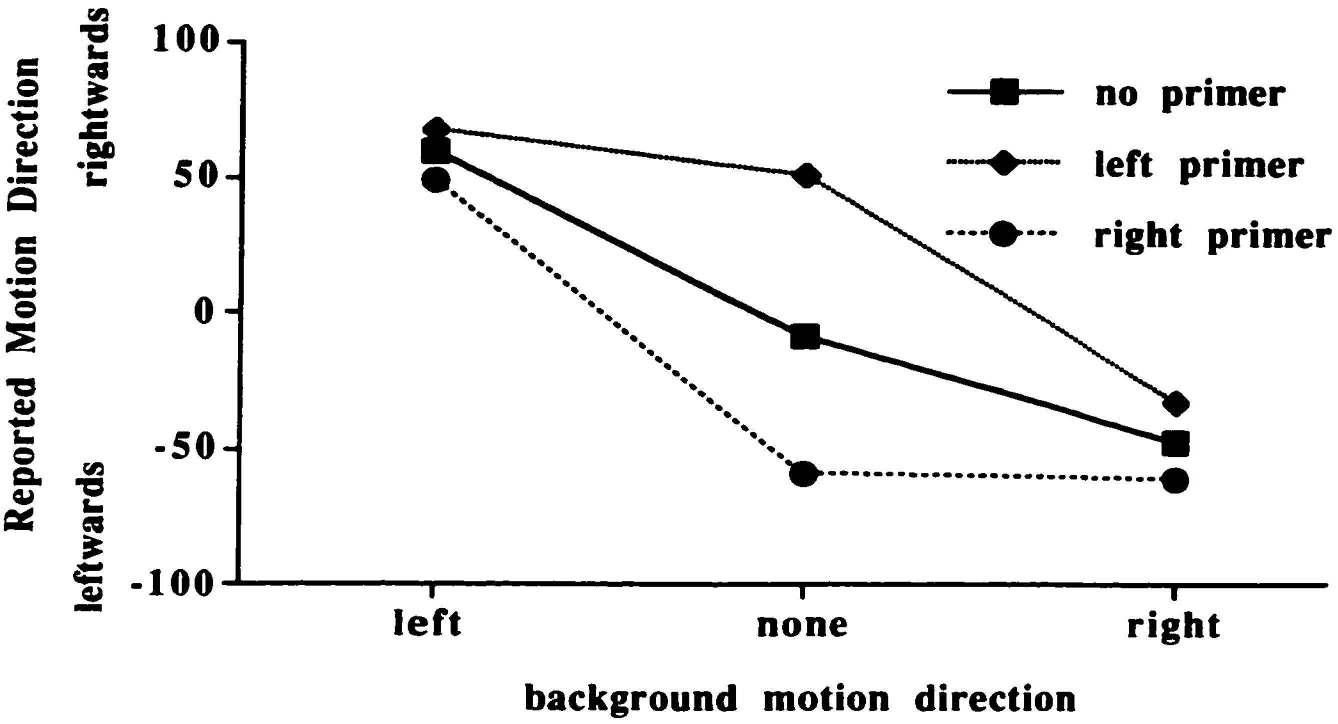

Figure 49. Cell means for the bar probe as a function of the background motion in Experiment 10. When the background was moving, overall display motion experienced was always in the opposite direction, even when this conflicted with normal ILM.

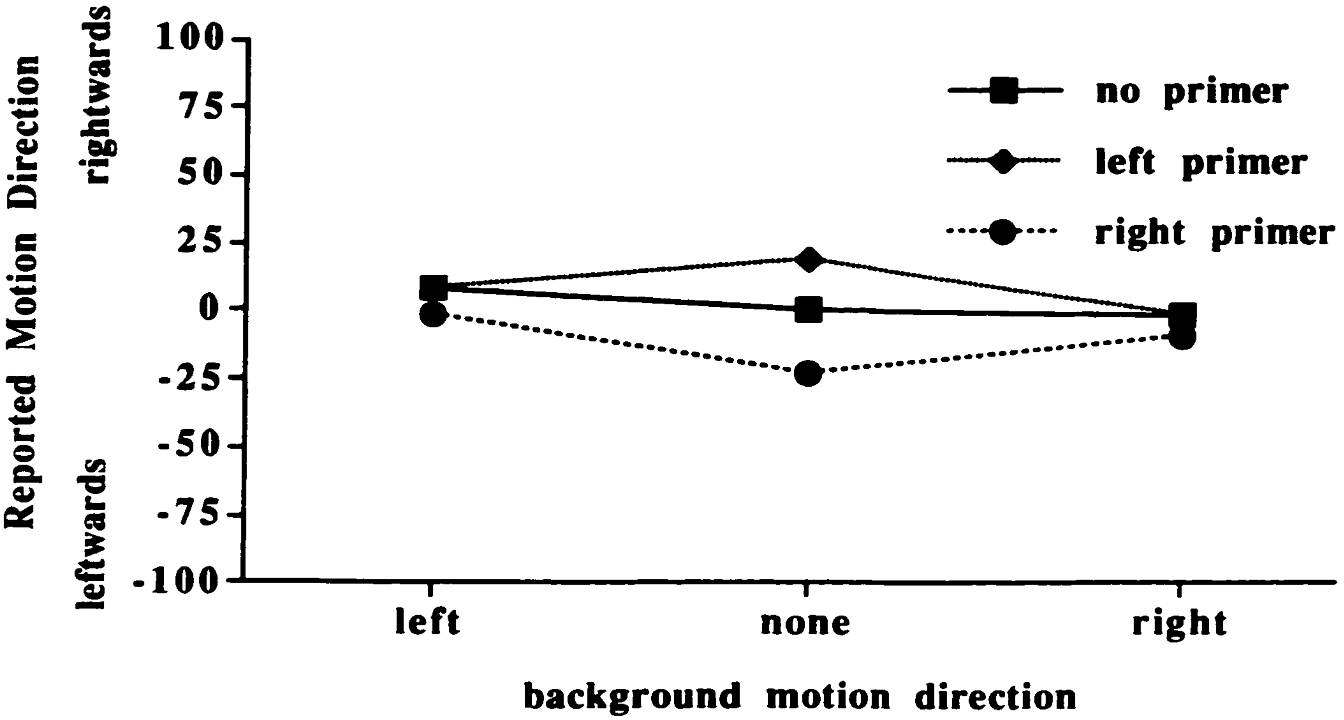

Figure 50. Cell means for the dot probe as a function of the background motion in Experiment 10. Overall motion ratings were weak when a moving background was presented, and weaker than the bar probe even when there was no moving background.

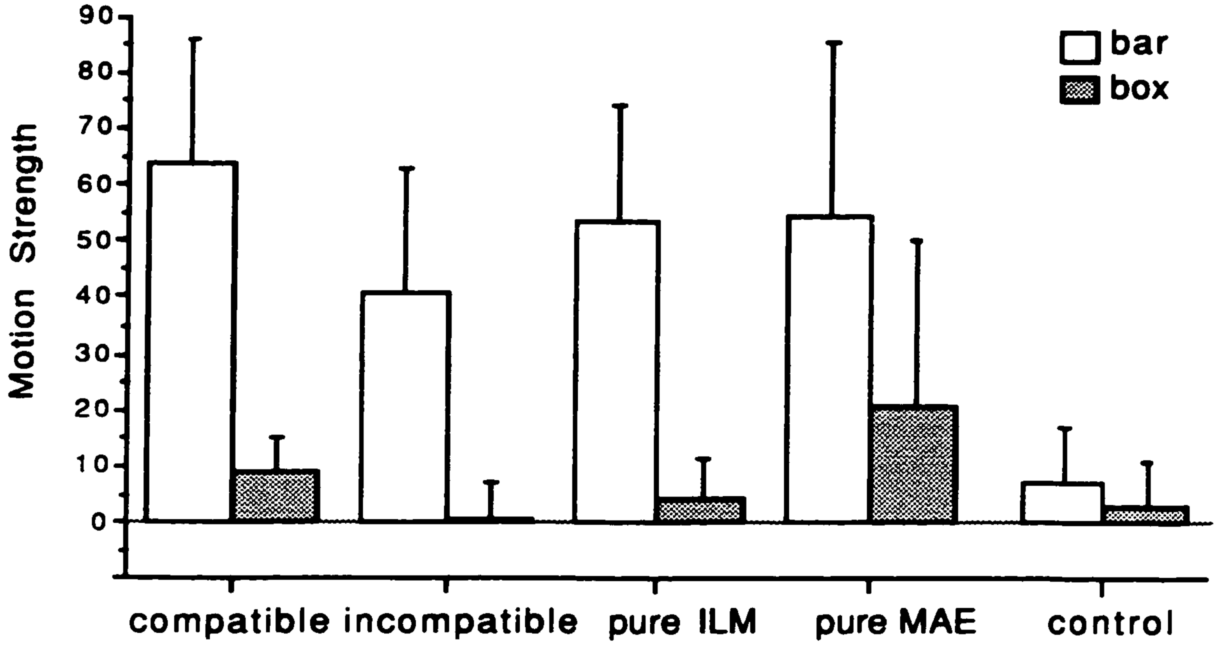

Figure 51. Absolute motion strength ratings for the conditions examined in Experiment 10. When ILM was incompatible with the MAE (incompatible condition), motion was weaker than when it was compatible with the MAE (compatible condition). When there was no moving background, ILM was strong (pure ILM condition), and when there was no primer presented before the probe, a MAE resulted (pure MAE condition). Error bars represent one standard deviation.

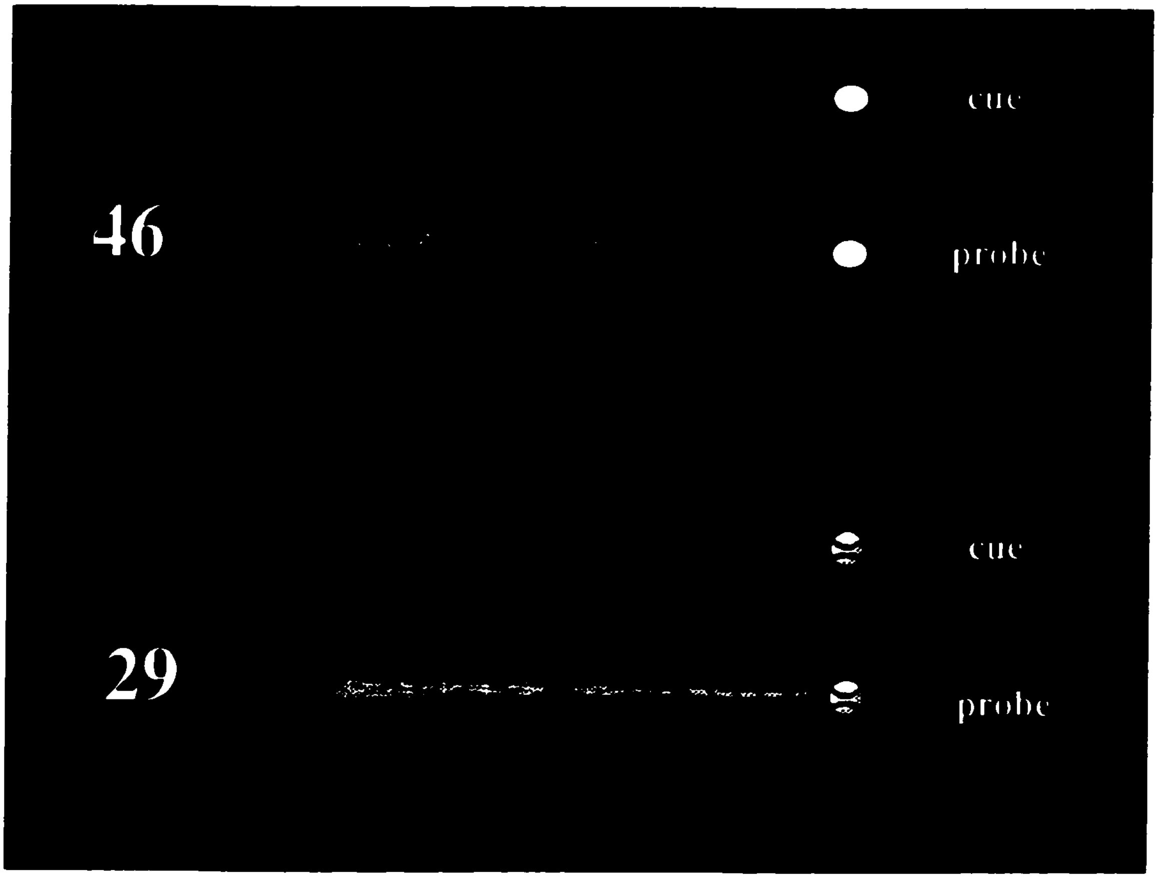

Figure 52. Motion ratings within the probe were stronger when the display objects were less easy to identify (top) than when they were identifiable objects (bottom).

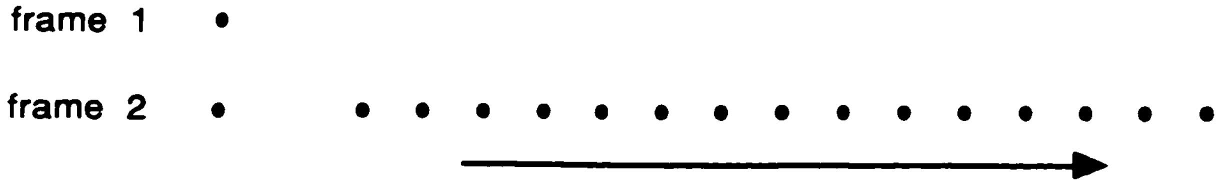

Figure 53. ILM occurs even when the probe is not a unified object.

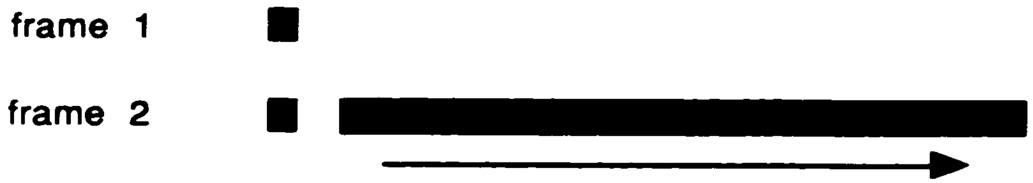

Figure 54. The simple form of the illusion in which there is a gap between the primer and probe.

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