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Processes influencing visual awareness during motion-induced blindness

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PROCESSES INFLUENCING VISUAL AWARENESS DURING MOTION-INDUCED BLINDNESS

BY

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DISSERTATION

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April 20, 2012

DEDICATION

"We do not so much need the help of our friends as the confidence of their help in need" – Epicurus (341-271 B.C.)

I have been fortunate in my life to have the support of some incredible and wonderful people. Without them, the last five years would have been intolerable, if not impossible.

My family has been my biggest dose of confidence, easily swallowed. My husband, Dan, although at times not able to comprehend the enormity of such an undertaking, still made sure my life was as easy as possible. Not bad for a guy who wasn't cognizant of the inner workings of the washing machine! My children, Kaleb, Jameson, and Trevor, have been just as gracious with their support. More importantly, they kept me laughing when I needed it most and soothed me with soulful music during many a late night. I hope that one day you allow me to reimburse you-except for the music part.

My closest, childhood friends, Kristine (Parker), Mike, Kevin (Harold), Philly and Tony, have provided continuous sustenance: both emotional and physical. I sense more "trips floating down the Seine experimenting with rubber water wings" as well as other "little divertissements" in our future!

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Anyone who knows me is aware of my lack of outward sentimentality. So for all posterity, I will attempt to write some saccharine prose that I may later deny or at least blame on a severe case of dissertation burnout out.

Get ready for a sweet ride as I thank the following people:

Andrew Leber—All kidding aside, anything that I write cannot begin to describe the knowledge, guidance, patience, understanding, and good humor he provided during the entire process. As an advisor, he gently pushed when it was needed but also gave me independence to find my own way. As a friend, he was my own personal cheerleader and will be greatly missed. As a life coach, I am grateful to have learned to never, ever place a bet with him. He will always win.

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ABSTRACT

PROCESSES INFLUENCING VISUAL AWARENESS DURING MOTION-INDUCED BLINDNESS

by

Erika T. Wells

University of New Hampshire, May, 2012

Visual illusions, such as motion-induced blindness, arise when the visual system, balancing speed and efficiency, summarizes the information it receives to form a percept. Motion-induced blindness (MIB) is characterized as the disappearance of a salient target when surrounded by a moving mask. Efforts to determine the mechanism have focused on the role of target characteristics on perceived disappearance by a coherently moving mask. In this dissertation, I take another approach, paying specific attention to the role of motion characteristics of the mask.

In Experiments 1, 2, 3, and 4, I investigate whether the property of common fate influences target disappearance by manipulating coherence of the mask elements. Results showed that as mask coherence increased, perceived target disappearance decreased. This pattern was unaffected by the lifetime of the moving dots, the dot density of the motion stimulus, the target eccentricity, or the number of motion trajectories contained in the mask.

The finding that motion coherence preferentially affected MIB prompted Experiments 5, 6, 7, and 8. Specifically, these experiments sought to investigate the spatial influence of mask motion on target disappearance. MIB was measured during conditions where opposing areas of motion coherence were confined locally surrounding the target or in more global areas across the display. The results revealed that motion coherence at more global locations, particularly at the area of fixation, had more influence on target disappearance compared to the coherence in proximity of the target and may reflect inability of the visual system to form a global motion pattern.

The possibility that global motion may give rise to MIB, motivated the final research avenue. Experiment 9 addressed the possibility that variability in motion processing of the mask affects target disappearance. Specifically, the strength of motion processing was measured using the motion aftereffect. Results showed a strong connection between the amount of motion processing dedicated to the mask and the amount of MIB.

As a whole, the findings show that motion processing, particularly during MIB, may be a driving force in our ability to perceive other objects in our environment.

CHAPTER 1

PROCESSING VISUAL INFORMATION FOR PERCEPTION

Perception is considered to be an internal reconstruction of an external reality, which gives the illusion of a complete, cohesive and veridical representation. Yet, the process of perception is similar to how an Impressionist artist creates a masterpiece. Impressionist painting is characterized by the use of short, choppy brush strokes to apply pure colors to a canvas. Colors and shading are not achieved by detailed blending of different colors on a palette and applying them to the artists' preconceived notion of a scene. Instead, the impressionist technique gives the illusion of an unfinished painting when viewed up close. However, step back a few feet and suddenly the painting is transformed into a cohesive image with depth, texture, shading, and brightness. Impressionists knew that emphasizing the overall effect was much more important than focusing on the details, and provided a richer, perceptual experience.

The same analogy can be used to describe how visual information is processed in the brain. The ultimate goal of the visual system is to create order and cohesion out of local, seemingly independent bits of information. In the process, less important information may be lost or discarded, but as in the Impressionist's painting, attending less to the details produces a far superior work of art. As we view the world, the sensory cells in our eyes receive a vast amount of light information. However, the visual system has an amazing ability to decrease the complexity of the visual information by grouping similar characteristics (Grossberg, Mingolla, & Ross, 1997). In fact, neuropsychological evidence from patients suffering from integrative agnosia (characterized as a deficiency in the ability to integrate local cues into global objects) has shown that the time required to process and perceptually group stimuli is delayed (Kurylo, Waxman, & Kezin, 2006) or even inhibited (Behrmann and Kimchi, 2003).

Parceling out the information to different layers or groups of neurons further reduces complexity. The different areas or layers process the visual information in a slightly different manner (Bullier, 2001). At various stages, the representation is fine-tuned with the information received from more selective processing (Marr, 1976). The retina, or more specifically the photoreceptors in the back of the eye, is the earliest site for registering light information. Each photoreceptor is responsible for collecting and transmitting a small proportion of the overall light energy received to cortical areas higher up in the visual system. While the light impinging on the eye at the level of the photoreceptors is a complex pattern of luminance levels and wavelength, an intricate network of connecting neurons reduces some of the complexity. These neurons (or ganglion cells) have a different ratio of correspondence depending on where in the retina they are located, allowing for the bulk of processing to be contained to a small area of visual precision in the fovea and allowing a more coarse integration of the signals to occur in the periphery (Vanessen, Anderson, & Felleman, 1992). Therefore, even though the fovea represents only two degrees of the visual field, most of the resolution or clarity in our perceptual image is derived from the information received in this area.

The next area where complexity in visual information is reduced occurs in the lateral geniculate nucleus (LGN). By the time the visual information leaves the retina and enters the LGN, it begins to be segregated according to attributes such as color, contrast, speed, and resolution (Livingstone & Hubel, 1988). Furthermore, the LGN is organized into multiple layers split according to the size of the cells contained within the layers. Parvocellular layers are comprised of small cell bodies whereas the magnocellular layers contain much larger cells. The division of these two layers does not appear to be limited to their anatomical size but appears to also have a functional difference. The magnocellular layers possess faster conduction time, sending signals to striate cortex approximately 10 ms before the parvocellular layers and most likely relay information about speed (Maunsell & Gibson, 1992). Color and form are transmitted via the parvocellular layer. The partitioning of function continues into higher cortical areas with a distinct parvocellular/magnocellular division being retained in early visual area (V1).

Lastly, specialized pathways have been identified for the processing of objects, spatial information and motion (Goodale & Milner, 1992; Mishkin, Ungerleider, & Macko, 1983; Tootell et al., 1995). In successively higher areas, a latticework of neural connections and associations allow for specific processing and integration (Varela, Lachaux, Rodriguez, & Martinerie, 2001). Areas of localization have reciprocal connections with lateral or subordinate areas allowing for fine-tuning and updating the visual information received (Bullier, 2001). In comparison to the Impressionist's painting, the visual system can process a seemingly disorganized collection of local points of details into a global representation with structure and form, constantly updating and revising the "canvas."

In the following chapters of this dissertation, I will examine instances where perception can fail (e.g. when information received may be lost from the final percept), mainly under laboratory conditions using visual illusions, specifically motion-induced blindness. In Chapter 2, I will briefly describe three different, but possibly related, visual illusions: filling-in, binocular rivalry, and motion-induced blindness. In Chapter 3, I will describe in more detail the characteristics of motion-induced blindness and will then present some of my early research in the field in Chapter 4. Finally, I will describe the current research undertaken for my dissertation on motion-induced blindness in Chapters 5 & 6.

CHAPTER 2

SOLUTIONS TO INCONSISTENT VISUAL INFORMATION

The illusion of completeness in visual information processing as described in Chapter 1 is so perfect that we typically are not conscious of any inconsistencies or loss of information; yet, these two occurrences exist. We can imagine that situations arise where incomplete or conflicting information may hinder an accurate analysis and the visual system must extrapolate or resolve the conflict. Thus, information may be rejected or added for the sake of a more accurate construction of the visual scene (Komatsu, 2006).

Filling-in

Inconsistency in visual information processing may arise prompting instances known as *filling-in* (Spillmann, Fuld, & Gerrits, 1976). The best example of filling-in occurs due to the physiology of our visual system. The retina, replete with photoreceptors tuned to capture incoming light and transform it into a neural signal for perception, has a small area devoid of photoreceptors (Polyak, 1957). This area constitutes a *blind spot* where there is a deficit of visual information received and therefore no neural signal is relayed into a perceptual representation (Ramachandran, 1992). As we view the external visual environment, we should perceive a hole or blank area correlating to the location of the blind spot. However, you can easily confirm this does not occur and what you do perceive is a complete picture without any missing information. Thus, your visual system has the ability to fill-in the empty spot in the image using information it has acquired from the surrounding area (Hindi Attar, Hamburger, Rosenholtz, Götzl, & Spillmann, 2007). In the case of the physiological blind spot, a complete perceptual representation is created from missing sensory information.

If the visual system receives conflicting information in areas other than the physiological blind spot, it may still proceed to resolve the discrepancy by reanalyzing the controversy using surrounding information (Ullman, 1976). Therefore, if our visual system encounters any incompatibilities, it fills-in with surrounding features (such as texture, color, or motion) and gives the perception of a complete image without discrepancies (Komatsu, 2006). The visual system, concerned with representing edges, borders, objects, and surfaces most likely makes assumptions about where these should be located and completes the image according to these assumptions (Ullman, 1976). Under laboratory conditions, researchers have been able to demonstrate robust filling-in under conditions of incompatible information (Kanizsa, 1976; Pinna, Werner, & Spillmann, 2003; Ramachandran, Geregory, & Aiken, 1993; Spillmann & Kurtenbach, 1992).

Binocular Rivalry

There may be instances, however, where the visual system cannot combine information into one comprehensive image. When the information received by the visual system is exceedingly ambiguous or conflicting, a singular image may not be formed and instead the visual system must attempt to resolve the conflict in a different manner. Most often, the visual system will attempt to minimize the uncertainty in the retained information by deciding between one of two possible constructs. Ambiguous information may be a common occurrence but the visual system is most likely able to instantaneously adopt the more probable solution, thereby erasing the existence of the other (Stadler & Kruse, 1995). Therefore, with normal viewing we perceive the most likely interpretation: ambiguity fades into oblivion, and we are none the wiser. However, we can experimentally invoke a situation known as *bistability* where the visual system is forced to abandon one percept for another, temporarily. This allows us the opportunity to study the processes underlying visual awareness.

One of the paradigms used to study the processes undertaken by the visual system to support conscious awareness is the presentation of rivaling images or bistable stimuli. Charles Wheatstone was one of the first to observe that incompatible images produced a condition where the images were not fused into a single image (Wheatstone, 1879). While studying how the visual system fused two images, he noticed that when an image of the letter "A" was presented to the left eye and an image of the letter "S" was presented to the right eye, the visual experience was not of the two letters combined (Wheatstone, 1879). Instead, their images would alternate back and forth, with the letter "A" being visible for a certain amount of time before it began to fade and then the letter "S" would emerge. Although Wheatstone (1879) did not give this phenomenon a name, we now refer to the illusion as *binocular rivalry*. Rivalry is the overarching category that now includes binocular rivalry and pattern rivalry. Overall, it is categorized as the temporary dominance of an image in awareness along with a corresponding suppression or disappearance of another.

Binocular rivalry appears to be affected by both local and global processes. Local inhibitory interactions between monocular neurons in the two eyes are presumed to be the driving force for local conflict in binocular rivalry. This is evident in the situation where the dominant and suppressed images engaged in binocular rivalry are switched, known more specifically as *stimulus rivalry*. For example, when one image becomes the dominant percept effectively suppressing the other image from awareness and the two images are then immediately switched between eyes, it is the dominant eye that determines the perception, not the image (Blake, Westendorf, & Overton, 1980). Therefore, if the left eye gained dominance with one image then the new image projected into that eye will suddenly be visible and the old image now presented to the right eye will be suppressed.

Other local characteristics of stimuli that have been known to induce binocular rivalry are differences in contrast, orientation, shape, color, and form (Blake, 2001). The greater the local conflict between the two images, the greater the perceptual alternation. Gratings that are at or near the threshold of visibility are enough to produce binocular rivalry as well as more complex images such as a house and face (Blake, 1977; Lee & Blake, 2002). Local interactions are also evident in the perceptual alternation of two images of the same face that are offset by 90 degrees (Boutet & Chaudhuri, 2001). In this case, the two face images were presented dichoptically (one to each eye) with one face oriented 45 degrees to the left and the other 45 degrees to the right. As the difference in orientation decreased, the rate of alternation followed. Contrast in color produced a similar effect. When a red and blue line are offset by 90 degrees and then presented dichoptically, they will engage in rivalry. However, the fluctuations significantly decrease as the color of one of the images is changed from blue to red (Andrews & Purves, 1997).

Global processes also play a significant role in binocular rivalry. When two different images are presented to different eyes they will rival continuously for dominance until removed from view. As previously discussed there is some thought that binocular rivalry arises due to the inhibitory effect of corresponding monocular neurons in the two eyes. Therefore, according to this interpretation if an image of a chimp and text are presented to the left and right eye, respectively, we should experience oscillating perceptions of first an image of a monkey and then an image with text. But what if the images are restructured or scrambled so that they contain portions of the old images in each new image and then these new images are presented independently to each eye (Figure 2.1, left). If the local interaction account holds, we should again perceive perceptual fluctuations of these two new images; in fact, we do experience binocular rivalry (Kovacs, Papathomas, Yang, & Feher, 1996). However, eventually participants may experience a global restructuring of the images into two complete and cohesive images of a chimp and text (Figure 2.1, right), which will then proceed to rival

(Kovacs, et al., 1996). Although we can argue that local interactions cannot be discounted, there also appears to be some global process of grouping, and thus object representation, involved

Figure 2.1. Stimuli used to test a local and global influence in binocular rivalry (From Kovåks, Papathomas. Yang, & Fehér, 1996. Copyright © 1996, The National Academy of Sciences of the USA).

Movement masking

There was a hint before the 1960's that during binocular rivalry, motion could produce enough visual conflict to cause suppression. While presenting different images to the left and right eye, Grindley and Townsend (1965) reported the odd occurrence that when one of the stimuli was physically shifted to ensure proper placement on the retina, subjects would report a momentary loss of perception of the other image in the other eye. These episodes (termed *movement masking*) did not appear to be unique to the stimuli used, as any movement presented to one eye would cause suppression in the other eye including a pencil being waved back and forth in front of the viewing aperture (Grindley & Townsend, 1965).

The authors followed up these casual observations with a set of experiments that detailed the characteristics of suppression by motion. When the left eye viewed a black square and the right eye viewed a motorized black wooden "arm", all subjects reported robust disappearance of the square: as if the mechanical arm "erased" the square as it passed over (Grindley & Townsend, 1965). On first inspection of these results, one might wonder if the disappearance of the square was triggered by the visual system's ability to extract different surfaces and depths from the information received. For example, if the arm appears to pass over the square, the visual system may fill-in the information of surface and depth creating a perception of the arm occluding or hiding the square. However, reconfiguring the setup so that the square and mechanical arm were presented to just the right eye did not produce suppression of the square suggesting something other than higher order surface processing or occlusion was involved (Grindley & Townsend, 1965).

The phenomenon of movement masking would almost remain buried in the binocular rivalry literature if not for John Mollon of the University of Cambridge who brought the phenomenon to the attention of Bonneh, Sagi and Cooperman. Bonneh and colleagues, in 2001, would report on a new phenomenon that appeared to be another form of movement masking. This new phenomenon would share similarities with binocular rivalry, in general, and movement masking, in particular.

CHAPTER 3

MOTION-INDUCED BLINDNESS

In their original work, Grindley and Townsend (1965) indicated that movement masking was just a highly specialized form of binocular rivalry and did not seem to be driven by mechanisms underlying monocular rivalry. However, Bonneh et al. (2001) presented evidence to the contrary. In their demonstration of a new visual illusion, a field of crosses was arranged in a square pattern rotating about a central axis (termed the "mask") and superimposed over three yellow disks (the "targets") aligned along an imaginary triangle (Figure 3.1). While viewing the single image dioptically (with both eyes), subjects reported multiple episodes where at least one of the targets disappeared. The phenomenon has become known as *motion-induced blindness (MIB)* and the resulting decrease in visual awareness has been described as originating due to mechanisms similar to binocular/monocular rivalry (Bonneh et al., 2001; Carter & Pettigrew, 2003; Kim & Blake, 2005) and/or filling-in (Hsu, Yeh, & Kramer, 2004, 2006).

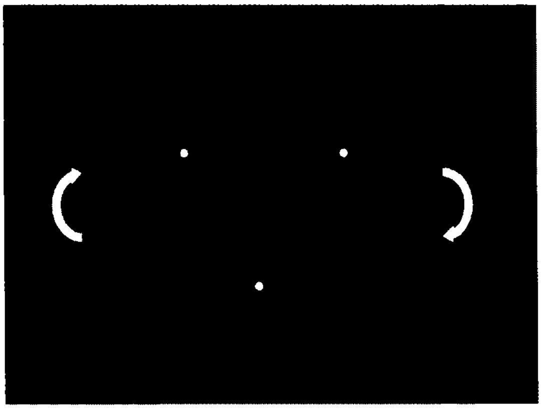

Figure 3.1. Facsimile of MIB stimulus. The blue crosses rotate around a central axis clockwise. Targets will perceptually disappear after a few seconds of steady fixation

Grindley and Townsend (1965), along with Bonneh et al. (2001), demonstrated that motion can produce enough conflict in the visual environment to interrupt the formation of a complete image. Therefore, it can be said that MIB has characteristics similar with rivalry in general. During rivalry, the greater the difference between the two images the greater the fluctuations. For instance, increasing the difference in color between two dissimilar images enhances binocular rivalry fluctuations. Investigating whether MIB would follow similar principles of rivalry, Bonneh et al. (2001) manipulated different attributes of both the moving image as well as the stationary targets. Their results strongly suggested that MIB stems from visual processes related to rivalry.

A luminance contrast effect is one of the first indications that MIB may not be inherently different from rivalry. Manipulating the luminance of the moving stimuli in relation to the targets produced an effect similar to what is observed in rivalry conditions. Given that a difference in luminance of 80% creates a robust disappearance or suppression effect of the target, when the mask is adjusted so that it produces a luminance difference of only 10%, disappearance is reduced (Bonneh, et al., 2001). Holding the mask luminance constant and varying the target luminance so that the difference in luminance between the mask and target ranged from 80% to 10% further reduced MIB. Similar effects have been found for differences in shape (Hsu, et al., 2004), speed (Bonneh, et al., 2001) and surface/depth (Graf, Adams, & Lages, 2002). For instance, using blue crosses as the moving elements and changing the target shape to a yellow cross instead of a circle or a square reduces the disappearance of the target (Hsu, et al., 2004; Figure 3.2).

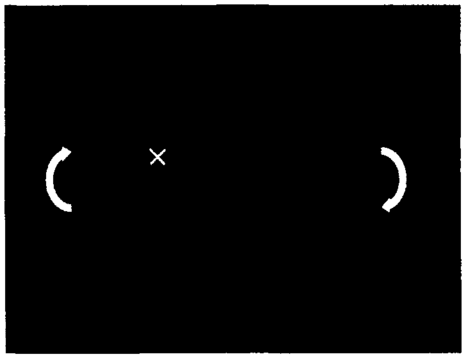

Figure 3.2. Adaptation of MIB stimulus showing a reduced shape contrast. From Hsu et al, 2004. Reproduced with permission from Elsevier.

Differential disappearance with surface contrast is seen when a mask is composed of ¾ circle shapes, such as is typically utilized in the Kanizsa illusion. This type of mask yields the perception of a surface when configured so that the openings are directed inward (Figure 3.3, left). When these shapes are arranged as such, the disappearance of the targets increases compared to when they are arranged with their sectors rotated outward (Figure 3.3, right; Graf, et al., 2002).

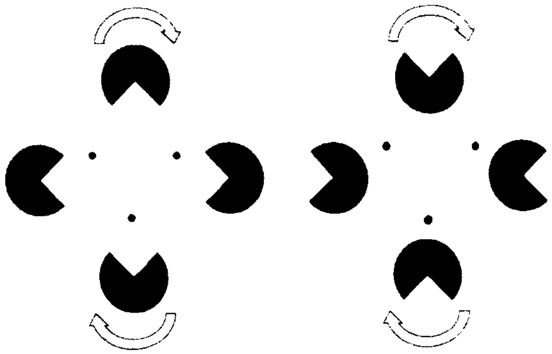

Figure 3.3. Reduced depth contrast in MIB. “Pac-man” elements arranged so that they form an illusory surface (left). On the right, the same elements are turned to diminish surface formation. From Graf et al., 2002. Reproduced with permission from Elsevier.

Another indication that MIB may fall under the guises of rivalry is seen under variable speeds of the moving stimulus. For instance, during movement masking it was revealed that the velocity of the moving stimulus affected the disappearance or suppression of the stationary stimulus in movement masking. The disappearance or suppression would increase up to an angular velocity of 20 deg., at which point disappearance would remain stable (Grindley & Townsend, 1965). A similar effect was observed for MIB, although the maximum angular speed investigated was only 6 deg. Therefore, these two phenomenon may share similar underlying mechanisms.

It is possible that MIB may be more analogous to the mechanisms instigating filling-in, both phenomenologically (Hsu & Yeh, 2004; Hsu, et al., 2006) and physiologically (New & Scholl, 2008). Some circumstances that precipitate filling-in are texture (either static or dynamic) and depth contrasts, as well as boundary effects. In filling-in, boundaries between two areas that are better defined tend to fill-in less often, particularly if the contours between the two areas are larger (De Weerd, Desimone, & Ungerleider, 1998). In MIB, when the peripheral target is constructed of a continuous circular outline, presumably demonstrating a more defined border, disappearance occurs less often than an irregularly outlined target (Hsu, Kramer, & Yeh, 2010). These results suggest that disappearance due to MIB may be mitigated by the processes underlying filling-in. Moreover, differences in surface interpretation can also activate filling-in. During filling in, the watercolor effect occurs when an irregular boundary is formed from two different contiguous colors: one considerably darker than the other (Pinna et al., 2003; Figure 3.4). The lighter colors will perceptually fill-in the space encapsulated by its border and be perceived as nearer to the observer compared to the area bordered by the dark color (Pinna & Grossberg, 2005).

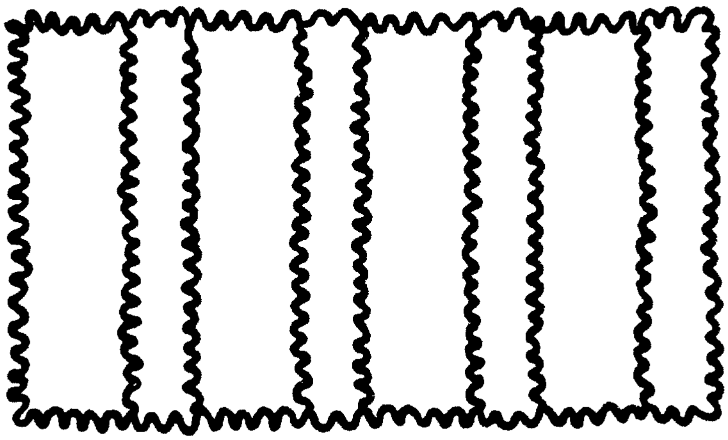

Figure 3.4. Watercolor illusion. Position of the low contrast and high contrast colors will alter the area that is filled-in and thus the surface perceived to be in front. From Pinna, Werner, & Spillmann, 2003. Reproduced with permission from Elsevier.

The surface or object that is perceived to be in front will be filled-in more often (Nakayama, Shimojo, & Ramachandran, 2009). The color spreading or the watercolor effect is just as influential in MIB disappearances. Applying surface completion effects to MIB using targets defined by the complementary colors used to induce the watercolor effect, Hsu et al. (2010) found that when the target was surrounded on the outside with the lighter color (creating the illusion that the darker bordered target was behind a much greater light colored surface (Figure 3.5, left) the target disappeared more often. The complement experiment, where the border colors were reversed and the target was perceived to be in front of the background (Figure 3.5, right), reduced disappearance. If MIB is not driven in part by a mechanism of filling-in but instead by other competing processes driving visual suppression of information then a watercolor effect should not have been observed.

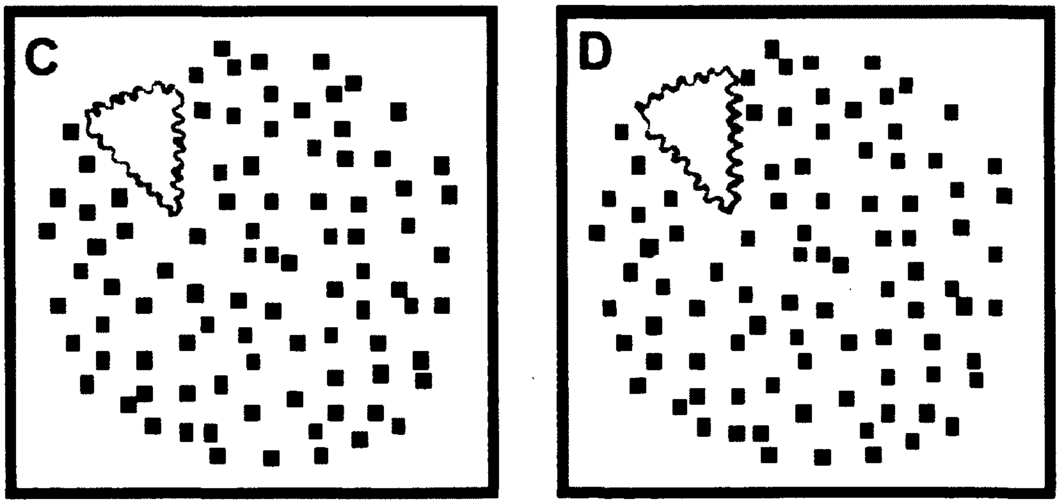

Figure 3.5. The target is a triangular shape with a double-edged border of which the outside edge is orange and the inside edge blue (Panel C) or the converse (Panel D). If drawn to scale in the proper colors, the stimulus leads to a watercolor illusion in which the orange color is perceived as either spreading away from the target covering the surface with the dots (Panel C) or across it (contained within the pie shape; Panel D). From Hsu et al., 2010. Reproduced with permission from Elsevier.

To further support a mechanistic interpretation of MIB by filling-in, it has been demonstrated that MIB shares some of the same attributes to filling-in at the physiological blind spot or other damaged areas of the retina where there is a lack of information processing. The blind spot or damaged area does not contribute to a cohesive representation because of the absence of neurons responsible for relaying signals for perceptual interpretation. The visual system counteracts this defect by filling-in or completing the space in the image with information gleaned from adjacent locations (Komatsu, Kinoshita, & Murakami, 2000; Ramachandran, 1992). New and Scholl (2006) demonstrated that although motion generated the disappearance of stationary objects in the display it was not the motion stimulus that necessarily fills-in. A circle or hole (containing just the background color) within a large square stationary texture (Figure 3.6) undergoes disappearance but is not completed or filled-in with the field of moving elements. Instead, it takes on the elements of the textured, stationary surround. A rivalry account would predict that the moving mask and anything else in the display would fluctuate, including the hole. Therefore, the hole should not be filled in with the texture, suggesting that these results offer an explanation more in line with filling-in and separate from the mechanisms underlying binocular rivalry.

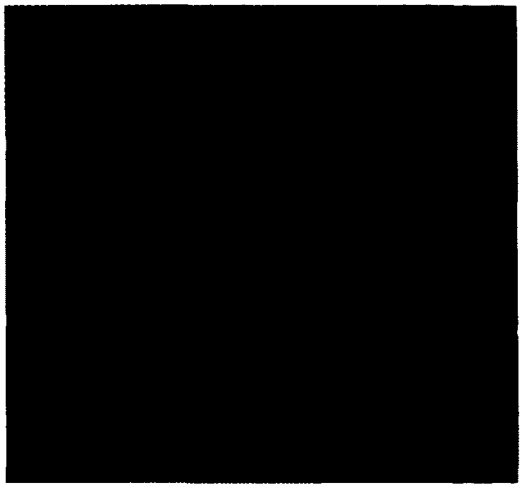

Figure 3.6. MIB stimulus using a target hole surrounded by a large textured surface covered by a rotating mask. Reproduced with permission from New & Scholl, 2008.

The comparison of MIB to perceptual filling-in strengthens when we look at the afterimage effects in the two phenomena. When an image is perceived, the visual system is receiving valuable information from lower visual areas such as the retina. Contrary to a light switch, the information is not instantly shut off when the image is removed. Instead it persists for a brief amount of time before it decays. Increasing the time the image remains on the retina can influence the degree to which one can perceive the residual information as an afterimage (Lin & He, 2009). Positive afterimages result in a hazy representation of the original image (Takahashi, Ejima, & Akita, 1988). Conversely, negative afterimages are an inverse of the original image: dark areas are now perceived as light and vice versa (Burbeck, 1986). Filling-in suppression generates a negative afterimage whose strength is not dependent on the degree of suppression indicating that filling in occurs after the retina (Shimojo, Kamitani, & Nishida, 2001). If afterimages with filling-in are not affected by the degree to which the image remains on the retina then it is possible that the mechanism involved in perceptual awareness occurs after the retina (Lin & He, 2009). Afterimages produced by adaptation in MIB shows a similar pattern of results (Hofstoetter, Koch, & Kiper, 2004). After recording the disappearance of one of two peripheral targets, participants also reported the presence and duration of an afterimage. The degree of disappearance and duration of an afterimage was then compared to when the target did not disappear. There was no significant difference between the duration of the afterimage when it was suppressed or present suggesting that visual awareness is post-retinal in MIB (Hofstoetter, et al., 2004). Therefore, the study of afterimages with suppression illusions (i.e., filling-in and MIB) has been an effective tool in understanding how and where conscious vision occurs (Lin & He, 2009). The similarity of the negative afterimage effects in MIB and filling-in suggests that they occur due to similar mechanism further along in the processing streams.

The illusion of MIB affords us the opportunity to understand the mechanisms that give rise to visual awareness. In the next few chapters, I describe research that will help illuminate the processes that influence perception and allow us to better understand why some information may be discarded from the perceptual image.

CHAPTER 4

THE ROLE OF MASK COHERENCE IN MOTION-INDUCED BLINDNESS

One characteristic common to disappearance phenomena, in general, and MIB, in particular, is the degree to which disappearance is affected by the shared featural organization between the mask and the targets. For instance, common Gestalt properties such as continuity, proximity, and connectedness of the target in relation to the mask can greatly impact perceived disappearance. In their seminal work on MIB, Bonneh et al. (2001) reported an influence of continuity between the targets on their dominance in perception. When targets are two Gabor patches aligned in an orthogonal orientation within a moving mask, perception involves the alternation of an individual grating with both gratings rarely disappearing together. However, when the targets are arranged contiguously, both targets tend to appear and disappear more often as a group. The continuity of a border can also impact the perceived appearance and disappearance of a target. A circular target outlined with a dashed line will have a tendency to disappear as a complete object giving the illusion that the circular target alternates between present and absent. When the same dashed lines in the border of the target are rotated 90 degrees, thereby disrupting the continuity, the individual components will more likely disappear independent of each other. Perception in this case tends to involve portions of the circular target disappearing compared to the entire object. Perceived continuity between the mask and target can also have a profound effect on target disappearance (Hsu, Yeh, & Kramer, 2004). For instance, a target positioned in the center of a moving mask so that it is continuous with the array of moving mask elements produces far less disappearance than when the target is displaced from the center, eliminating the property of continuity (Figure 4.1).

Proximity cues can modulate the perception of completed objects, and thus the degree to which target components disappear separately (Shibata, Kawachi, & Gyoba, 2007). Targets separated by a smaller gap produce more instances of simultaneous and synchronous disappearance and reappearance of the individual targets as if they formed a completed object. As the gap between the individual elements increases, perceived grouping diminishes and the individual target elements are more apt to disappear independently and asynchronously. A similar occurrence is observed with simple targets arranged linearly in the periphery. The smaller the spatial separation between the individual targets the more often they disappeared together (Bonneh et al., 2001). Distal targets, conversely, tended to disappear one at a time.

The gestalt property of similarity, particularly between the target and mask, likewise affects the amount of MIB experienced. Hsu et al. (2004) showed that contrasting features in the mask and target increased disappearance. When the mask contained rotating blue-cross elements, a yellow stationary target identical in shape experienced less disappearance compared to when the target was a completely different shape, such as a square.

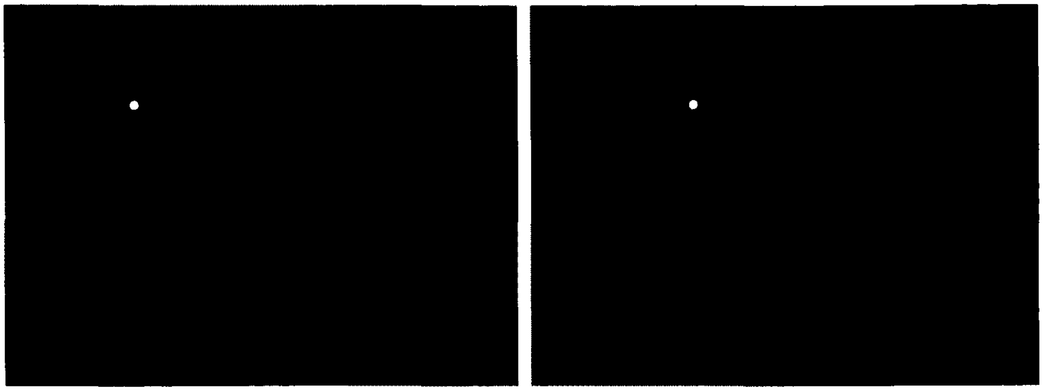

Figure 4.1. Example of the MIB stimulus used to investigate grouping cue of continuation in perception. Left: Good continuation; Right: Poor continuation. See text for additional information (From Hsu et al., 2003. Reproduced with permission from Elsevier).

While gestalt properties of the targets can impact the degree of disappearance in MIB, we wondered whether a gestalt property solely inherent to the mask could contribute to the perceptual disappearance in MIB. Specifically, we asked whether the property of common fate in the motion of the mask elements would impact perceived disappearance of peripheral targets in a manner similar to that observed with continuity, proximity, and similarity of the targets. While MIB has typically utilized coherently grouped mask elements moving with common fate, there are indications that a mask lacking the property of common fate may still produce incidents of MIB. Bonneh et al. (2001) described evidence of disappearance with “Brownian” or random-walk motion, although the amount of disappearance for this type of motion was not directly compared to more coherently structured motion. Leopold, Wilke, Maier, and Logothetis (2002) also found that randomly moving dots could induce disappearance, although they did not compare this stimulus to a coherent motion stimulus. Therefore, it is unclear to what degree motion coherence modulates MIB. The lack of systematic manipulation of gestalt motion grouping in MIB makes it particularly ripe for further investigation.

In this study, I used random dot stimuli to progressively increase the proportion of dots displaying coherent motion in order to evaluate behaviorally the effect of common fate on target disappearance.

Experiment 1: Mask Coherence

Method

Subjects

Fifteen and 24 participants with normal or corrected-to-normal visual acuity took part in Experiments 1a and 1b, respectively. All were students from the University of New Hampshire, Durham and received partial course credit. Informed consent was obtained from each participant.

Stimuli

Stimuli were generated with an Apple G4 desktop computer using Matlab (Mathworks, Natick, MA) with PsychToolbox extensions (Brainard, 1997; Pelli, 1997) and presented on a 19 in. CRT display (ViewSonic G90fb) at a viewing distance of 50 cm. Stimuli consisted of a mask containing 480 blue moving square dots each subtending 0.20 deg^2 on a black background. A white fixation cross was located in the center of the screen and a yellow circular target (0.55 degree diameter) was displayed in the upper left quadrant at 3.36 deg to the left of fixation and 3.29 deg above it, yielding an eccentricity of 4.70 deg (see Figure 4.2). Dot displays were confined within an area subtending 31.63 deg width x 23.20 deg height, centered in the middle of the screen with a density of 0.65 dots/deg^2.

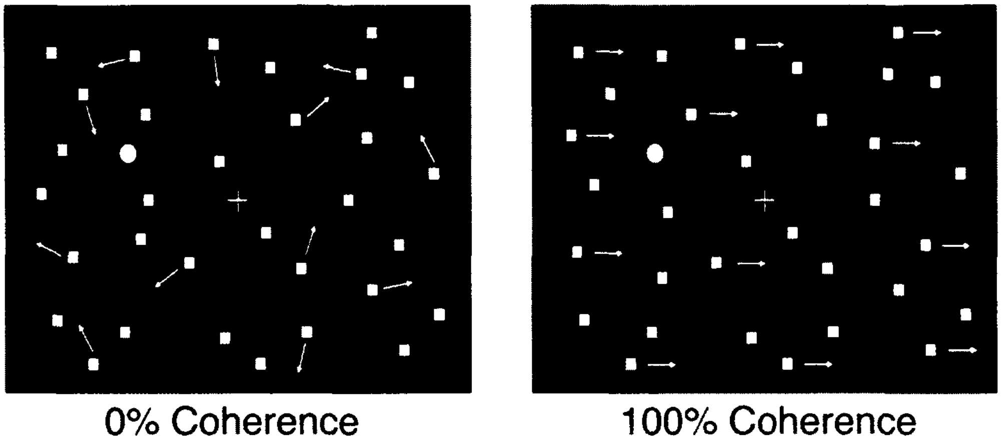

Figure 4.2. Representation of stimuli used for testing the effect of motion coherence on disappearance due to MIB. All square dots, comprising the mask, were blue and moved at the same speed (see text for details). Representative arrows indicate motion directions of individual dots and were not present in the actual stimulus. The stationary target (circle) was yellow.

In Experiment 1a, each dot was present for the duration of the trial (eternal lifetime). Specifically, each dot was drawn in a random location on the first frame of the mask presentation and then followed a predictable, linear direction path for each subsequent frame. In Experiment 1b, each dot's lifetime was limited to 235 ms, at which point it was replaced by another dot in a new, randomly selected location. Groups of new dots were distributed evenly at intervals of 47 ms. While dots were displayed, they traversed the screen until reaching the end of the aperture at which time they reentered the display from the opposite side, maintaining the same trajectory as before (e.g., dots reaching the left border of the aperture reentered at the same vertical position on the right side in the subsequent frame; dots reaching the top border reentered at the same horizontal position on the bottom). Motion contrast in the mask was created by changing the proportion of dots moving in a coherent direction. Coherence was defined as the percentage of pattern elements moving in the same direction. Coherence varied between 0, 33, 66, and 100 percent of the number of dots in the moving pattern. On a given trial, all coherent dots moved in one of four canonical global directions (up, down, left, right). Each incoherent dot was assigned a random number from one to 360 that determined the angle of trajectory. All dots moved at a fixed speed of 8.51 deg/s.

Design & Procedure

Each participant completed a practice session of six trials, each lasting 30 s. Then, participants viewed a total of 96 trials, also 30 s each, with coherence randomized across trials. A self-timed break after each set of 16 trials was provided. Participants were instructed to maintain gaze on the fixation cross and keep the peripheral target in their awareness. Participants were further instructed to press the right shift key when they saw the target disappear and release it upon target reappearance.

Results and Discussion

Experiment 1a

Here, and in all subsequent analyses of variances, we used Mauchly's test of sphericity to assess whether our data violated this assumption. If significant, we used the Greenhouse-Geisser corrected degrees of freedom and the adjusted *p*-value in our reported statistics. Holm-Bonferroni corrections were used to test the significance of all post-hoc pair-wise comparisons.

An episode of target disappearance was defined as the time between the response button being depressed and then released. The total time of MIB episodes in a trial was used to determine the mean percentage of disappearance across all trials as a function of coherence (Figure 4.3A). [1]

The results were compared in a one-way, repeated-measures ANOVA, which confirmed a statistically significant main effect of coherence, F (3, 42) = 28.15, $p < 0.001$, $\eta^2_{\text{partial}} = 0.67$. Specifically, the percent time of disappearance of the target increased as the motion coherence decreased. Pair-wise comparisons revealed no difference in disappearance between 0% and 33% coherence. There was a significant difference in disappearance between the 0% and 66% coherence level ($p = 0.005$). However, the main effect seemed to be driven by a significant difference in disappearance at the 100% coherence compared to 0%,

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[1] Some researchers have normalized individual subject data prior to statistical analysis to reduce intersubject variability in disappearance due to MIB (e.g., Libedinsky, Savage & Livingstone, 2009; Wallis & Arnold, 2009). To ensure that the specific analysis did not influence the pattern of results, we reanalyzed using normalized data from all of the experiments reported. Both the numerical patterns and statistical results were unchanged.

33%, and 66% (all *p*-values < 0.001). Therefore, introducing a certain amount of random motion into the moving pattern significantly increased target disappearance.

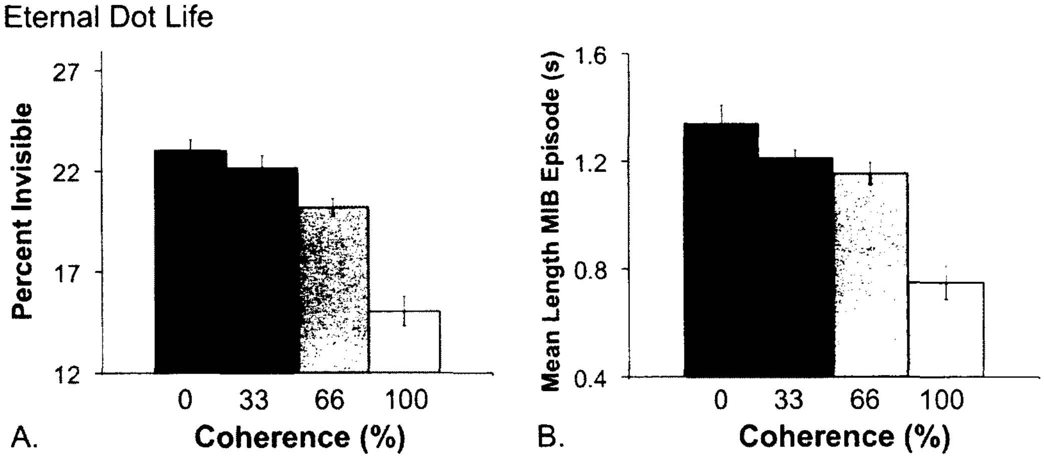

Figure 4.3. Results for Experiment 1a. (A) Percent of target invisibility for the different coherence conditions for dots remaining on the screen for the duration of the trial. (B) Mean length of MIB episodes for the different coherence conditions for dots remaining on the screen for the duration of the trial. Error bars indicate within subject ±1 SEM.

We also investigated whether the increased percentage of time the target disappeared in the incoherent condition was due to an effect of longer episodes of disappearance compared to the coherent condition (Figure 4.3B). The mean MIB episode across each trial was analyzed by a one-way, repeated-measures ANOVA revealing that the episode duration was significantly longer in the incoherent condition, $F\ (1.71, 23.88) = 17.33$, $p < 0.001$, $\eta^2_{\text{partial}} = 0.55$. Again, the significant main effect seemed to be due to a difference between the incoherent masks (0%, 33%, and 66%) and the 100% coherent mask (all *p*-values < 0.001). There was no difference in disappearance between the masks containing intermediate degrees of incoherent motion.

Overall, we found that common fate had a detrimental effect on perceived disappearance in MIB. We will first describe additional results before discussing the implications of this finding.

Experiment 1b

We next tested the possibility that our pattern of results may have been impacted by temporal properties of the mask. In Experiment 1a, the coherent dots remained on the screen for the entire trial duration. Here, we presented the same conditions as in Experiment 1a, except now each dot remained on the screen for a limited lifetime before it was replaced by new dots (see Method, above).

Results showed a similar pattern of percent disappearance to that of Experiment 1a (Figure 4.4A). That is, the percentage of time the target disappeared increased as the coherence level decreased. A one-way, repeated measures ANOVA found a significant main effect of coherence, F (1.55, 35.61) = 4.10, $p = 0.034$, $\eta^2_{\text{partial}} = 0.15$. Pair-wise comparisons revealed that the main effect was driven by a significant difference in disappearance at the 100% coherence compared to 0%, 33%, and 66% (all $p \leq 0.03$). There was no difference in disappearance between the 0%, 33%, and 66% coherence condition. These results clearly show, once again, that more coherence produced less disappearance in total.

Furthermore, similar to the results in Experiment 1a, the mean length of an MIB episode was greater for incoherent motion than for coherent motion (see Figure 4.4B). A one-way, repeated measures ANOVA showed that the difference was significant, F(3, 69) =18.17, $p < 0.001$, $\eta^2_{partial} = 0.62$. A significant difference in MIB duration was found for the 0% coherent mask compared to when the mask contained 33%, 66%, or 100% coherently moving dots (all $p \leq 0.001$). Also, there was a significant difference in the mean length of an MIB episode when the mask contained incoherent motion compared to when it contained 100% coherent motion (all *p*-values < 0.001).

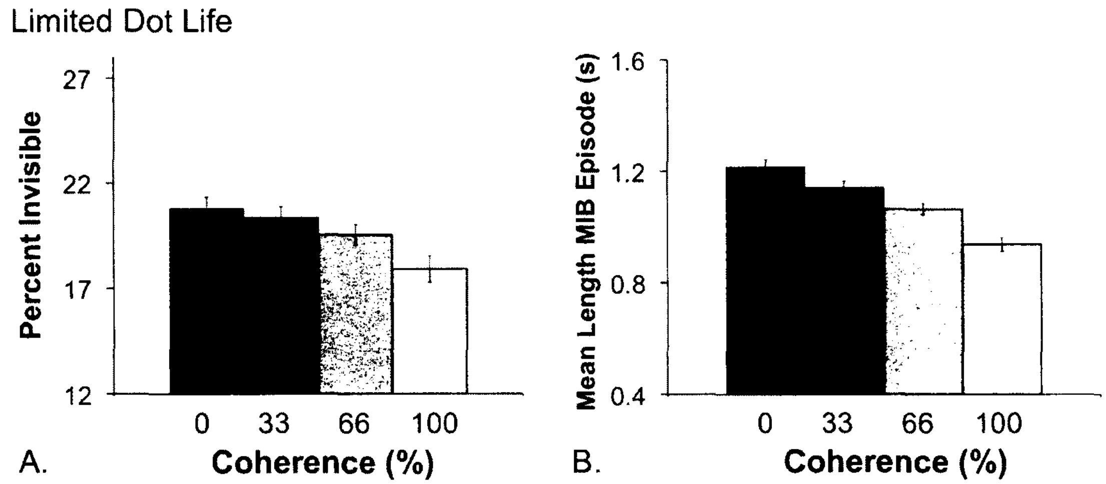

Figure 4.4. Results for Experiment 1b. (A) Percent of target invisibility for the different coherence conditions for dots remaining on the screen for a limited time. (B) Mean length of MIB episodes for the different coherence conditions for dots remaining on the screen for a limited time. Error bars indicate within subject ±1 SEM.

In summary, with both eternal and limited dotlife (Experiments 1a and 1b, respectively), a mask devoid of the property of common fate produced significantly more disappearance.

Experiment 2: Eccentricity of Target

We also tested whether the target eccentricity affected the pattern of results. It has been shown previously that targets at greater eccentricities show greater initial time to fade (Hsu et al., 2004). We questioned whether this phenomenon interacted with the present coherence manipulation. We varied the eccentricity of the target as well as the motion coherence of the MIB mask. If the relationship between mask coherence and MIB is specific to the eccentricity used in the previous experiment (4.70 deg), then we may fail to replicate this pattern at smaller or greater eccentricity values. Alternatively, the relationship between mask coherence and MIB may generalize across various eccentricities.

Method

The methods and procedure were the same as in Experiment 1b. Here, we varied the target eccentricity, selecting randomly from one of three eccentricities (2.00, 4.50 or 6.00 degrees) on each trial.

Subjects

Eighteen new participants with normal or corrected-to normal visual acuity participated.

Results and Discussion

The overall impact of coherence was not affected by eccentricity; the percentage of time a target disappeared as well as the mean length of an MIB episode was significantly greater when surrounded by an incoherent mask (Figure 4.5). Using a 4 (coherence) by 3 (eccentricity) two-way, repeated-measures ANOVA, we first compared the percentage of time the target remained invisible (Figure 4.5A). We found a significant main effect for coherence, F(3, 51) = 4.73, $p < 0.01$, $\eta^2_{partial} = 0.22$, replicating our results from Experiment 1. Pair-wise comparisons revealed that the disappearance of the target was significantly different between 0% and 100% ($p = 0.005$), as well as between 33% and 100% coherence ($p = 0.008$). A significant main effect was also found for eccentricity, F(2, 34) = 51.68, $p < 0.001$, $\eta^2_{partial} = 0.75$. Pair-wise comparisons revealed a significant difference in disappearance between all eccentricities (all $p < 0.001$). These eccentricity effects replicate previous findings showing enhanced MIB with increasing eccentricities (Hsu et al., 2004). Importantly, a significant eccentricity by coherence interaction was not found, F(6, 102) = 0.75, $p = 0.61$, $\eta^2_{partial} = 0.04$.

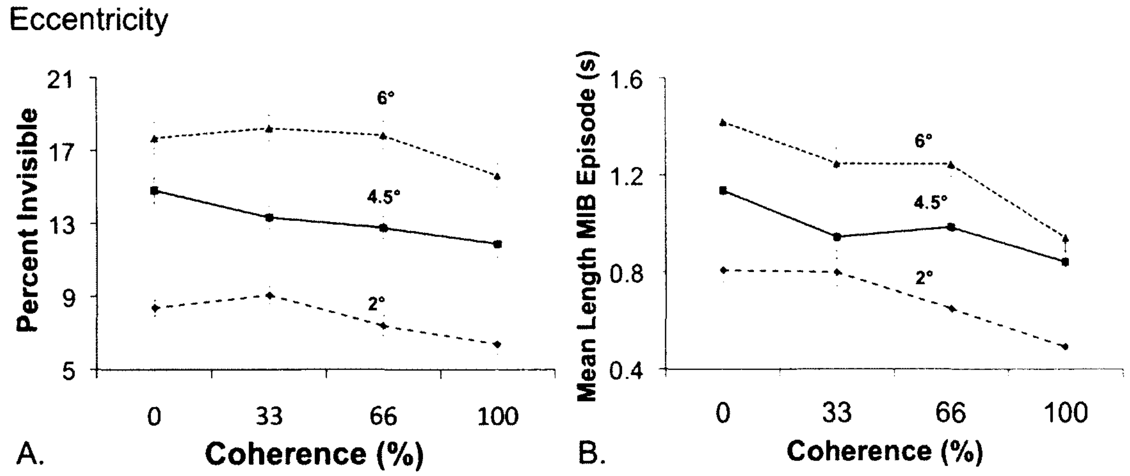

Figure 4.5. Results for Experiment 2 (eccentricity). Graphs show (A) Percent of target invisibility for the different coherence conditions for 3 different eccentricities (2, 4.5, and 6 deg). (B) Mean length of MIB episodes for the different coherence conditions for 3 different eccentricities (2, 4.5, and 6 deg). Error bars indicate within subject ±1 SEM.

We also tested the mean length of an MIB episode as a function of eccentricity and coherence using a 4 (coherence) by 3 (eccentricity) two-way, repeated-measures ANOVA (Figure 4.5B). Again, we found a significant main effect for coherence, F(1.97, 33.42) = 9.67, $p < 0.002$, $\eta^2_{\text{partial}} = 0.57$, replicating the results obtained for MIB duration in Experiment 1. Pair-wise comparisons revealed a significant difference for a mask containing 0% coherent motion vs. masks containing 33%, 66%, and 100% coherently moving dots (all $p < 0.02$). A significant main effect of eccentricity, F(2, 34) = 22.40, $p < 0.001$, $\eta^2_{\text{partial}} = 0.57$ was also obtained, lending further support for an influence of target eccentricity on MIB (Hsu et al., 2004). Pair-wise comparisons showed a significant difference between all eccentricities (all $p < 0.003$). Finally, a significant eccentricity by coherence interaction was not obtained, F(6, 102) = 0.85, $p = 0.53$, $\eta^2_{\text{partial}} =$ 0.05.

To summarize, the current findings show that the impact of mask coherence on MIB-described in Experiment 1 is not specific to a particular range of eccentricities.

Experiment 3: Dot Density of Mask

We next found it necessary to investigate whether the effect of common fate on disappearance due to MIB would generalize across multiple dot densities. The role of dot density has previously been established to be central to both MIB and more broadly, in the visual processing of moving stimuli. With respect to MIB, Bonneh and colleagues (2001) found that dot density had a pronounced effect on target disappearance, with greater disappearance at higher dot densities. For present purposes, it is prudent to understand whether the effect of motion coherence is influenced by dot density. Perhaps more importantly, there is evidence beyond the MIB literature that the perception of coherent motion may be strongly influenced by dot density. On the one hand, studies using functional MRI (fMRI) and magnoencephelography (MEG) have shown that a high-density, random dot stimulus elicits greater activation in the motion sensitive middle temporal (MT/V5) area of the brain when the dots move with coherent motion compared to when they move incoherently (Braddick et al., 2001; Rees, Friston, & Koch, 2000). On the other hand, McKeefry et al (1997) obtained the reverse pattern with a much lower dot density; explicitly, fMRI revealed a greater activation for incoherent motion compared to coherent motion in MT. It has been argued that the lower density used by McKeefry et al. explains the divergent results (Braddick et al., 2001). Given that the neural processing – and perceptual consequences – of coherent motion may be influenced by dot density, it follows that the effect of coherence on MIB may be contingent upon dot density.

The dot density of Experiment 1 may be judged to be somewhat sparse, at 0.65 dots/deg^2. Therefore, to test whether the overall pattern we obtained with incoherent motion in Experiment 1 was specific to low dot density, we substantially increased the dot density, by a factor of 9.2, to 6.02 dots/deg^2. This exceeded the maximum dot density used by Bonneh et al. (2001), which we calculated to be 5.3 dots/deg^2.

Method

With the exception of the increased dot density (6.02 dots/deg^2), the methods and procedure were the same as in Experiment 1b.

Subjects

Twenty-nine new participants with normal or corrected-to normal visual acuity participated.

Results and Discussion

Results were similar to Experiments 1a and 1b, with respect to how MIB changed as a function of mask coherence (Figure 4.6).

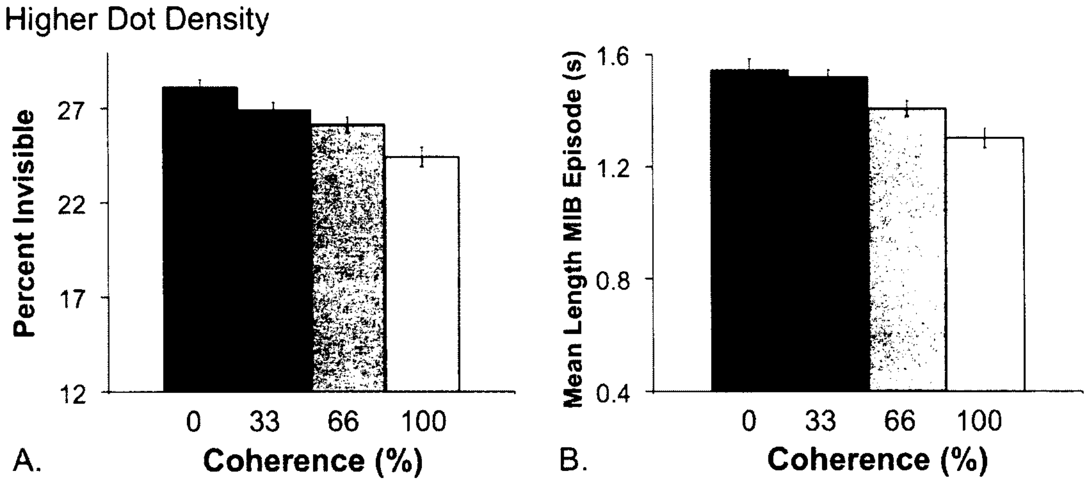

Figure 4.6. Results for Experiment 3 (higher dot density). Bar plots show (A) Percent of target invisibility for the different coherence conditions for dots remaining on the screen for a limited time. (B) Mean length of MIB episodes for the different coherence conditions for dots remaining on the screen for a limited time. Error bars indicate within subject ±1 SEM.

As in the previous experiments, a one-way, repeated-measures ANOVA on percent disappearance, across the four levels of coherence, produced a significant main effect, $F(3, 84) = 9.44$, $p < 0.001$, $\eta^2_{\text{partial}} = 0.25$ (Figure 4.6A). Specifically, the target disappeared for a greater percentage of the time when the mask was incoherent compared to when it was comprised of coherent motion; pair-wise comparisons revealed a significant difference in disappearance between 0%, 33%, and 66% compared to the 100% coherent condition (all $p <$ 0.03). A significant difference in disappearance was also found between 0% and 33% as well as between 0% and 66% ($p < 0.01$). Similar to our findings in Experiment 1a and 1b, incoherent motion still exhibited the greatest impact on disappearance.

The main effect of the length of MIB episodes was also significant, $F(3, 84) = 9.26$, $p < 0.001$, $\eta^2_{partial} = 0.25$ (Figure 4.6B). Pair-wise comparisons also found a significant difference between the masks comprised of incoherent motion and a mask containing coherently moving dots (all *p*-values < 0.02).

We also directly examined the effect of dot density by comparing the results from Experiment 1b (low density) and 2 (high density). We tested whether the percentage of time a target disappeared was affected by a change in dot density using a 4 (coherence) by 2 (density) mixed-design ANOVA. We observed a significant main effect of coherence on the percentage of time the target remained invisible, $F(2.13, 108.86) = 12.35$, $p < 0.001$, $\eta^2_{partial} = 0.20$. A significant main effect was also found for dot density, $F(1, 51) = 5.44$, $p = 0.02$, $\eta^2_{partial} = 0.10$, replicating previous work showing increased MIB with increased density (Bonneh et al., 2001). A significant dot density by coherence interaction for the percentage of time a target remained invisible was not found, $F(2.13, 108.86) = 0.23$, $p = 0.81$, $\eta^2_{partial} = 0.004$.

Similarly, we tested the average length of an MIB episode as a function of coherence and dot density using a 4 (coherence) by 2 (density) mixed-design ANOVA. Again, we found a significant main effect for coherence, $F(3, 153) =$

23.16, $p < 0.001$, $\eta^2_{partial} = 0.31$, and dot density, $F(1, 51) = 4.58$, $p = 0.037$, $\eta^2_{partial} = 0.08$, on the average length of a MIB episode. We did not observe a significant coherence by density interaction for the average length of an MIB episode, $F(3, 153) = 0.21$, $p = 0.89$, $\eta^2_{partial} = 0.004$, further confirming that the relationship between coherence and MIB was similar across the different dot densities.

In sum, the data from Experiment 3 show that the results obtained in Experiments 1a and 1b cannot be explained by the relatively low dot density used in the mask.

Experiment 4: Motion Trajectories

In Experiments 1, 2, and 3, we found that disappearance was reduced when the mask elements were grouped according to the gestalt property of common fate. We manipulated common fate by physically changing the percentage of dots that moved in a coherent direction, and the trajectories of each of the non-coherent dots were determined randomly. Here, we questioned how the number of total motion trajectories influenced MIB. We constructed a stimulus for which the number of motion directions could move on 1, 3, or 5 motion trajectories but separated these trajectories by diverse values of angular deviations. This type of stimulus was informed by the knowledge that the perceptual system averages across small divergences in motion direction to produce an overall percept of unidirectional motion indistinguishable from absolute coherent motion (Williams & Sekuler, 1984). When the angle between different motion directions is very small, the visual system groups the different trajectories into a percept of coherent motion (or common fate) regardless of the number of directions contained in the stimulus (Watamaniuk, Sekuler, & Williams, 1989). However, if the motion diverges by more than 10-20 degrees, the visual system is unable to maintain the percept of coherent motion and will instead perceive dots moving in independent directions (Mather & Moulden, 1980; Watamaniuk et al., 1989). We thus set out to make two observations in this study. First, at what value of angular deviation does MIB begin to increase? Second, at the larger angular deviations, is MIB influenced by the total number of independent trajectories in the mask (i.e., 3 vs. 5 directions)?

Method

The methods and procedure were similar to Experiment 1b. However, in Experiment 4 the moving stimulus could contain one, three, or five different motion directions. On *1-direction* trials, dots traveled en masse in one of four cardinal directions (left, right, up, or down; Fig. 4.7, left). On *3-direction* trials, one-third of the dots moved in the predetermined cardinal direction, one-third of the dots maintained a fixed clockwise trajectory defined by an angular deviation (θ) from the cardinal direction, and the remaining one-third of the dots maintained a fixed counterclockwise trajectory defined by the same angular deviation (-θ; Fig. 4.7, middle). In the *5-direction* trials one fifth of the dots moved in the cardinal direction, another fifth of the dots moved at a fixed (θ) clockwise angular deviation from the cardinal direction, and another fifth moved at a fixed (-

θ) counterclockwise angular deviation, bearing similarity to the 3-direction condition. In addition, another fifth of the dots moved on a trajectory measuring θ/2 in a clockwise angular deviation from the cardinal direction, while the final fifth moved with a counterclockwise angular deviation of -θ/2 (Fig. 4.7, right). The number of motions, the cardinal direction, and the angular deviation (θ) were randomly selected on each trial and an equal number of all trial types were presented. To gain a robust sample of angular ranges, the values of θ were parametrically varied, using values of 10, 20, 40, and 60, and selected randomly on each trial.

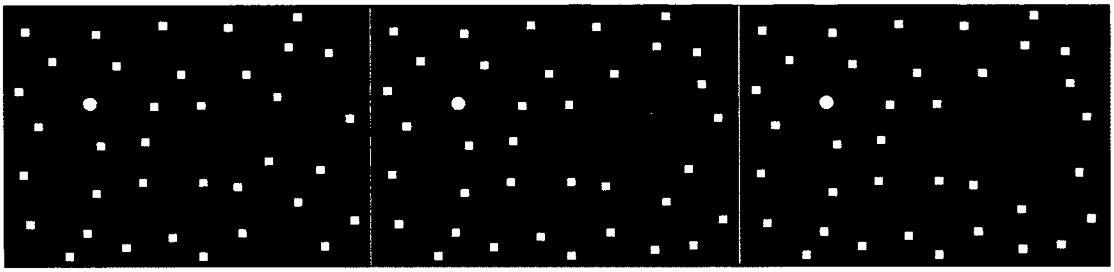

Figure 4.7. Representation of stimuli used for testing motion directions on disappearance due to MIB. Motions in the mask were 1-direction (left), 3-directions (middle) and 5-directions (right). Trajectories for motion were separated by an angular deviation, θ or θ/2 (see text for details). A white cross was located in the middle of the screen to aid in fixation (removed from depiction for clarity). The size, shape and colors of dots and target were the same as in Experiment 1 and 2.

Subjects

Eight new participants with normal or corrected-to-normal visual acuity each completed 288 trials over the course of two sessions.

Results and Discussion

To examine the angular deviation at which MIB increases, we performed a series of planned comparisons for the percentage of time the target disappeared

(Figure 4.8A). Specifically, we averaged the 3- and 5-direction conditions at each angular deviation, comparing these means to the 1-direction baseline condition. Based on the visual system's ability to integrate multiple motion trajectories into a coherent percept at small angular deviations, we would predict that there would be no difference between a stimulus containing multiple trajectories separated by small angular deviations and 1-direction coherent motion (Watamaniuk et al., 1989). In line with this prediction, we found that the multiple direction masks did not differ significantly from the 1-direction mask at 10 degrees of angular deviation, $t(7) = -0.79$, $p = 0.45$. However, as angular deviation increases to 60 degrees, exceeding the limit of coherent motion integration (Mather & Moulden, 1980), we should see more MIB for the multi-directional masks compared to a mask having only one coherent direction. In agreement with this line of reasoning, we found greater disappearance for the masks having more than one direction compared to the 1-direction mask, $t(7) = -3.11$, $p = 0.02$. There was no significant difference between the 1-direction mask and the masks containing multiple directions with an angular deviation of 20 degrees, $t(7) = -2.94$, $p = 0.05$, and 40 degrees, $t(7) = -1.93$, $p = 0.10$.

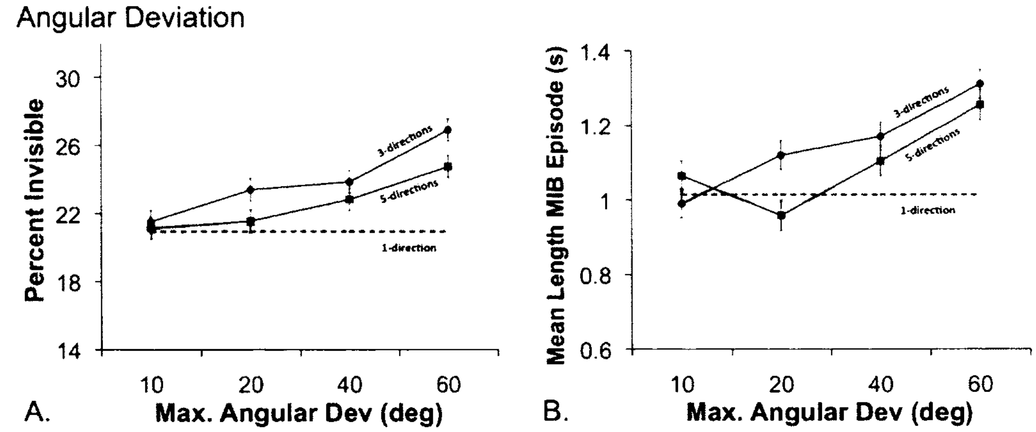

Figure 4.8. Results for Experiment 4. (A) Percent of target invisibility for the varying number of directions in the moving mask for dots remaining on the screen for a limited time as a function of angular separation between the different motion directions. (B) Mean length of MIB episodes for the varying number of directions in the moving mask for dots remaining on the screen for a limited time as a function of angular separation between the different motion directions. Error bars indicate within subject ±1 SEM. The baseline 1-direction condition is represented as a dotted line with the height of the shaded area corresponding to ±1SEM.

We also tested the mean length of an MIB episode for the 1-direction mask compared to masks containing multiple motion directions using the same procedure described above (Figure 4.8B). Planned comparisons revealed no significant difference between the 1-direction mask and the mask comprised of multiple directions when the angular deviation separating the motion trajectories was 10 degrees, $t(7) = -0.20$, $p = 0.85$, as predicted by earlier work (Watamaniuk et al., 1989). When the angular deviation increased to 60 degrees, beyond the limits of motion integration (Mather & Moulden, 1980), the mean length of an MIB episode was significantly greater for the multi-directional masks, $t(7) = -6.72$, $p < 0.001$. Again, no significant difference was seen for the intermediate angular deviations of 20 degrees, $t(7) = -0.34$, $p = 0.74$, and 40 degrees, $t(7) = -1.78$, $p = 0.12$.

Next, we specifically examined whether more motion directions in a mask would translate to more MIB. Using a 2 (3-direction vs. 5-direction) by 4 (θ) two-way, repeated-measures ANOVA, we measured the percentage of time a target disappeared within a 30 s trial (Figure 4.8A). The main effect of motion direction showed that more directions did not increase MIB; in fact, 3 directions produced significantly more disappearance than 5 directions (23.91% vs. 22.55%, respectively), $F(1, 7) = 15.13$, $p = 0.006$, $\eta^2_{partial} = 0.68$. A significant main effect of θ was also found, $F(1.39, 9.72) = 8.03$, $p = 0.01$, $\eta^2_{partial} = 0.53$, reflecting the increased disappearance at increased angular deviation. Further, no significant interaction was found, $F(3, 21) = 0.90$, $p = 0.46$, $\eta^2_{partial} = 0.11$.

We also conducted a 2 (3-direction vs. 5-direction) by 4 (θ) two-way ANOVA on the mean length of an MIB episode (Figure 4.8B). No significant difference was observed between the 3-direction and 5-direction conditions, $F(1, 7) = 3.77$, $p = 0.09$, $\eta^2_{partial} = 0.35$. A significant main effect was observed for θ, $F(3, 21) = 11.68$, $p < 0.001$, $\eta^2_{partial} = 0.63$, with no interaction found between number of motion directions and θ, $F(3, 21) = 2.26$, $p = 0.11$, $\eta^2_{partial} = 0.24$.

To summarize this experiment, we found that at 10 degrees of angular deviation, there was no significant difference in MIB between a mask possessing 1-direction coherent motion and masks containing multiple motion directions. At 60 degrees of angular deviation when the process of coherent motion integration is exceeded (Mather & Moulden, 1980; Watamaniuk et al., 1989), we observed more MIB for masks with multiple motion directions. Furthermore, we found that at the larger angular deviation of 60 degrees, increasing the number of motion directions included in the mask – i.e., from 3 to 5 – did not predict greater MIB.

General Discussion

We found that perceptual organization of moving dots by common fate significantly influenced the perceived disappearance of a peripheral target in MIB. Specifically, the more the dots moved with coherent motion, the less often the target disappeared. This pattern was unaffected by the lifetime of the moving dots, the dot density of the motion stimulus, or the eccentricity of the target. Further, while greater angular deviation between dot trajectories gradually increased MIB, the total number of independent motion trajectories did not explain disappearance. Below, we discuss how the present results fit with other bistable phenomena as well as several proposed mechanisms described in the MIB literature.

Filling-in and Rivalry

How do our findings compare to other instances in which perceptual awareness fluctuates? One similar finding comes from studies of perceptual filling-in, in which episodes of such filling-in are also affected by common fate (Welchman & Harris, 2000). Specifically, the initial time to fade for a target area comprised of incoherently moving dots surrounded by noise was significantly faster compared to when the target dots moved coherently. Another effect of coherence on filling-in was found when the coherence of the background was altered (Spillmann & Kurtenbach, 1992). Here, a background of coherent motion significantly increased the time for a uniform peripheral target to initially fade. Perceptual filling-in may be analogous to processes of the visual system responsible for suppressing retinal anomalies (Ramachandran & Gregory, 1991); a mechanism recently suggested to be a component of MIB (New & Scholl, 2008). Binocular rivalry, characterized by the oscillating perceptions of different patterns when presented to different eyes, is similarly affected by coherence. In one study of this phenomenon that seems particularly analogous to the present MIB study, Silver and Logothetis (2004) found that an incoherent random dot pattern presented to one eye produced greater periods of dominance of that eye (i.e., suppression of the stimulus in the other eye) compared to a coherent pattern. Comparable to the findings by Spillmann et al. (1992) and Silver et al. (2004), we found a significant impact of common fate, suggesting that these perceptual phenomena may share similar underlying mechanisms (Carter & Pettigrew, 2003; Hsu et al., 2004).

Suppression in early visual areas

Why might there be similar effects of coherence in the distinct perceptual illusions of MIB, perceptual filling-in, and binocular rivalry? The answer may lie in lower-level visual representations of the competing visual stimuli, particularly when motion is involved. Although Bonneh et al. (2001) discounted the involvement of early visual areas in MIB, recent work by Donner and colleagues (2008), Libedinsky, Savage, and Livingstone (2009), and Schölvinck and Rees (2010) points to a potentially important role for V1 in perceptual awareness of the target. Libedinsky et al. (2009) reported that patterns of firing activity to target objects in monkey V1 cells were modulated in the presence of a moving mask despite the use of a protection zone that ensured the mask elements would not appear within the classical V1 receptive fields of the recorded neurons. Donner et al. (2008) observed a numerical, albeit non-significant, decrease in fMRI activation in human V1 associated with the stationary target along with significant increases in activation in dorsal areas representing the moving mask (particularly V3A) during episodes of MIB. Similar modulation of neural activity in early visual areas has been found for other phenomena associated with periods of invisibility. For instance, during binocular rivalry, an object suppressed from visual awareness shows a significant reduction in V1 activity compared to when it is visible (Lee & Blake, 2002). However, Schölvinck and Rees (2010) reported stronger fMRI activity in areas V1 and V2 compared to V5 with the perceptual disappearance of the target in MIB. The conflicting response of V1 activity related to the target during MIB may be a factor of the subtle differences in global motion between a random dot 3D structure from motion mask (Donner et al., 2008) and a 2D rotational mask (Schölvinck and Rees, 2010). It is possible that any change in the global characteristics of the mask in MIB, including motion coherence, can impact the activity of V1 thereby affecting the amount of disappearance.

Suppression in higher visual areas

In contrast to invisibility that is precipitated by activity in V1, MIB could originate in higher visual processing areas such as the middle temporal area (MT) and V3A. According to one motion processing model, the perception of motion occurs when extrastriate areas such as MT and V3A combine the signals arising from many direction or orientation selective neurons located in V1 across space and time (Rust, Mante, Simoncelli, & Movshon, 2006). As alluded to above, Donner and colleagues (2008) observed a decrease in fMRI activation in human ventral visual areas associated with the stationary target along with an increase in activation in dorsal areas representing the moving mask (particularly V3A) during episodes of MIB. These results suggest that disappearance of a target during MIB may occur through suppression from higher motion processing areas. Flickering and motion stimuli have been shown to produce similar activity in V3A (Liu, Slotnick, & Yantis, 2004) and a suppressive mechanism may help to explain why flicker also induces MIB (Kawabe & Miura, 2007; Wallis & Arnold, 2008). Human brain imaging studies have shown that different types of global motion activate cortical area V3A differentially (Koyama et al., 2005) raising the possibility that this area may also suppress activity in V1 preferentially. Extrastriate areas have also been implicated in the perceptual alternations with other bistable stimuli (Kleinschmidt, Büchel, Zeki, & Frackowiak, 1998). Given the fact that MIB shares characteristics with other perceptual phenomena, such as binocular rivalry (Carter & Pettigrew, 2003), it follows that an analogous mechanism of suppression by higher visual areas may also be involved in MIB.

However, our results do not appear consistent with a high-level suppression account. That is, the high-level account would predict greater MIB with greater coherence, since areas such as MT and V3A favor coherent over incoherent stimuli (Braddick et al., 2001; Rees et al., 2000). Because we did not measure neural activity in this study, we cannot be sure how lower and higher visual areas would respond to the different levels of coherence during MIB. Thus, future work aimed at measuring neural activity during an MIB task with a coherence manipulation might help to reconcile the various findings supporting roles for early vs. later visual areas in producing this disappearance phenomenon.

Motion streak suppression

We considered the possibility that processes fundamental to the integration of local motion signals were a factor in modulating disappearance with a coherent mask. As an object proceeds along a trajectory, each location in time is recorded by the activation of successive neurons in the visual system leaving a virtual trace of the spatial progression of motion (or a "motion streak"). These motion streaks are spatially integrated by the visual system to aid in our ability to determine the direction of global motion but these residual clues are suppressed from awareness (Geisler, 1999). Recent work by Wallis & Arnold (2009) presumes a mechanism of motion streak suppression in MIB, bolstered by their finding that MIB is greater at the trailing edge of motion as opposed to the leading edge. One might thus question how motion streak suppression influenced the present results. Specifically, it is possible that an incoherent mask creates greater motion streak suppression, producing the higher degrees of MIB we observed with this mask. It has been shown that a group of dots possessing incoherent local motion signals can produce motion streak suppression, provided the global motion signal is coherent—as is the case with Glass patterns (Ross, Badcock, & Hayes, 2000). However, little is known about the occurrence of motion streak suppression with a globally incoherent stimulus, which we used in this study. Therefore, further research is needed to expand our understanding of the relationship between motion coherence and motion streak suppression during MIB.

Surface Completion

Surface completion in MIB has previously been discussed by others (Graf, Adams, & Lages, 2002; Lages, Adams, & Graf, 2009). For instance, grouping Kanizsa "pac-man" elements to induce a completed surface produced greater disappearance than when the Kanizsa elements were rotated 180 degrees, thereby eliminating the perception of a surface (Graf et al., 2002). Gestalt processes are key to image segmentation, and common fate is advantageous for the determination of different depth surfaces — as evidenced by the "pop out" of a motion surface once a small percentage of static dots begin to move in a coherent direction (Ehrenstein, Spillmann, & Sarris, 2003). Thus, with a mask grouped according to common fate, the visual system may easily process the elements into one good surface, while a mask with little common fate contains more complexity and may result in poorer surface segmentation. The ability of the visual system to more easily delineate a coherent motion surface compared to an incoherent motion surface may arise due to response differences in V1 (Lamme, 1995) and/or V2 (Bakin, Nakayama, & Gilbert, 2000) receptive fields. In a V1 receptive field, motion in the preferred direction evokes an enhanced response when there are other similarly moving objects located in the surround (Lamme, 1995). In comparison, a V1 cell's response to the preferred motion direction is inhibited when surrounding objects having a non-preferred motion direction (Lamme, 1995). Likewise, V2 receptive fields show activation enhancement with complementary orientation in the surround as well as inhibition of activation when the surrounding area contains objects with a collinear orientation (Bakin et al., 2000). Therefore, any decrease in disappearance when the mask elements are grouped according to common fate may merely reflect a decrease in surface processing load beginning in V1 and extending to V2.

Adaptation

It has been suggested that adaptation contributes to target disappearance during MIB (Gorea & Caetta, 2009). The mechanisms of target adaptation and/or prolonged inhibition by the moving mask may reduce the target's perceived brightness, such that it temporarily falls below its detection threshold, particularly in the presence of a mask that is moving (and thus not adapting to the same degree as the target). This adaptation/inhibition process is thus hypothesized to produce transient perceptual disappearance (Caetta, Gorea, & Bonneh, 2007;

Gorea & Caetta, 2009). Such an account is supported by the observation that MIB increases during the early stages of a trial, prior to reaching asymptote (Gorea & Caetta, 2009). Our data may offer a novel contribution to this idea, as the time-course of MIB could vary as a function of coherence.

Possible Evidence of Adaptation Across a Trial

To this end, we combined the results from Experiment 1a and 1b, dividing the data into bins as described in Gorea and Caetta (2009). Note that each bin in the present analysis encompassed 5s epochs spanning the 30 s trial, as compared to 10 s epochs across a 60 s trial in Gorea and Caetta (2009).

Results are consistent with the interpretation that differential adaptation across coherence levels could underlie disappearance (Figure 4.9). We performed a 4 (coherence) by 6 (bin) two-way, repeated-measures ANOVA and found a significant main effect for coherence, $F(2.33, 88.60) = 31.54$, $p < 0.001$, $\eta^2_{\text{partial}} = 0.45$, as our earlier analyses on these data revealed. More relevant to the current analysis, a significant main effect for bin was observed, $F(3.24, 122.98) = 25.32$, $p < 0.001$, $\eta^2_{\text{partial}} = 0.40$. These findings are consistent with the basic adaptation effect of Gorea and Caetta (2009). Moreover, the interaction was also statistically significant, $F(9.13, 346.92) = 3.77$, $p < 0.001$, $\eta^2_{\text{partial}} = 0.10$. Specifically, in the 0% coherence condition, the mean length of an MIB episode increased by 35.75% between bins 1 and 4 and increased by only 4.20% between bins 5 and 6. The difference was less pronounced with the 100% coherent mask. Here, the initial increase for the beginning 20 s of the trial was 8.25% with a final increase of 4.04% between bins 5 and 6. Planned contrasts between the 0% and the 100% masks revealed a significant difference in the change in MIB for the initial 20 s of the trial, *t*(38) 5.20, $p < 0.001$. The change in mean duration of MIB episodes between bins 5 and 6 was not significantly different between the two types of masks, *t*(38) = 0.82, $p = 0.42$.

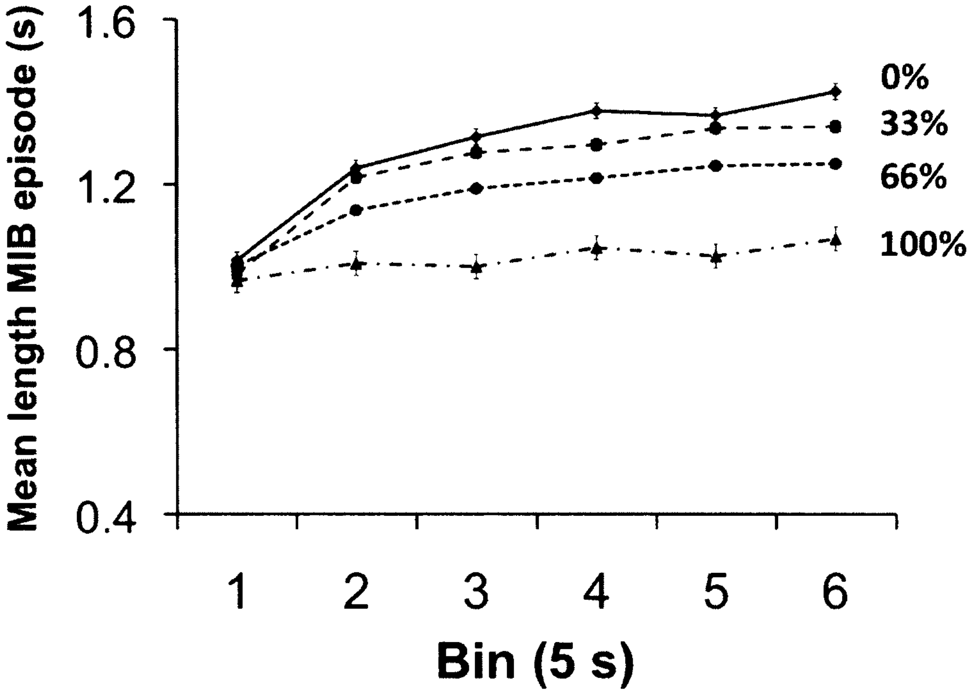

Figure 4.9. Average length of an MIB episode in each 5s bin within a 30 s trial. Data are averaged across Experiment 1a and 1b. Error bars are ±1 SEM.

The results described above reveal a novel pattern: adaptation effects increase dramatically as mask coherence is reduced. This pattern provides a plausible mechanism for why MIB varies with motion coherence. The explanation is two-fold, based on adaptation to the target coupled with inhibition by the mask, as put forth by Gorea and Caetta (2009). First, the adaptation to the stationary target could create a situation where the target dips temporarily below threshold reducing its visibility. Secondly, the simultaneous adaptation to a coherent mask reduces its inhibitory role on the target. However, an incoherent mask is subject to less adaptation, allowing it to continuously exert stronger inhibition on the target throughout the duration of the trial. In the next chapter, I begin to address the role of adaptation/inhibition on target disappearance in depth, specifically during conditions of varying motion coherence.

CHAPTER 5

EVALUATING LOCAL VERSUS GLOBAL INFLUENCES OF MIB

MIB is believed to occur due to interactions between the mask and target given that the probability a target will disappear is greatly reduced in the absence of a mask (Gorea & Caetta, 2009). The previous chapter explored the motion parameters of the mask that influenced target disappearance. However, one important question, which drives the current study, is whether the phenomenon acts locally or globally.

A number of studies have found evidence to suggest that the influence of the mask acts locally around the target (Libedinsky, Savage, & Livingstone, 2009; Wallis & Arnold, 2009). For example, when few mask elements are spatially limited to the area immediately surrounding the target, disappearance is not significantly different compared to when the number of elements are increased to form a more globally distributed pattern (Libedinsky et al., 2009). The lack of an effective change in disappearance with an increasingly larger mask suggests that any global influences may be minor compared to spatially restricted, local suppressive mechanisms. Moreover, placing the target and mask in opposing hemifields, thereby eliminating local competitive interactions between the mask and target, had an adverse effect on perceptual disappearance further implicating local interactions in MIB (Libedinsky et al., 2009).

The influence of local spatial interactions in MIB may also help to explain why increasing the density of items in the mask results in an increase in target disappearance (Bonneh, et al., 2001; Wells, Leber, & Sparrow, 2011). It is presumed that the greater the number of mask elements surrounding the target, the greater the likelihood of the mask elements being in close proximity to the target, effectively contributing to greater local mask-target interactions. These findings may also be associated with the interaction between the motion traces left behind when an object moves and the target (Wallis & Arnold, 2009). When motion occurs, the brain must register the objects position in space and time, creating a virtual cortical index to aid in perception (Geisler, 1999). The "motion streaks" that result from processing motion are suppressed from awareness and it is this suppression that may influence MIB disappearance. Evidence to support such a claim arise from the findings that movement away from a target, presumably in the wake of a motion streak, increases disappearance of the stationary target compared to when the mask is just approaching the target. Thus, the more moving items in the display, the stronger impact from motion streak suppression.

While MIB has been considered to arise due to local interactions, an alternative explanation could also be used to interpret MIB. In particular, the findings described above may occur due to a global interaction between the mask and target. For instance, Bonneh et al. (2001), Libedinsky et al. (2009), Wallis and Arnold (2009) and Wells, et al. (2011) included a *protection zone* or blank area surrounding the target. It has been shown that disappearance of the target is not eliminated by the absence of mask elements at the location of the target, hinting at the possibility that the global presence of motion in MIB is important. In fact, the protection zone surrounding the target can be as large as 1 deg in diameter before disappearance begins to be affected (Bonneh et al., 2001). As the separation between the mask and target increases to 2 deg in diameter, the probability of target disappearance is reduced but not eradicated. In a study comparing perceived disappearance during MIB with perceptual disappearances induced with flickering flankers, Kawabe and Miura (2007) found that a target bordered by spatially limited areas of coherent motion could induce target disappearance and this gap could be as large as 1.36 deg before disappearance was adversely affected.

A global interaction account may also help explain the findings of reduced but still evident MIB when the mask is placed in only one hemifield (Libednisky et al., 2009). Studies investigating the global effects of motion find that extended viewing of a moving stimulus in one location can produce a motion aftereffect in a remote location not subjected to motion adaptation (von Grünau & Dubé, 1992). Based on these long-range effects of motion, finding a decreased amount of MIB by confining the mask to only one hemifield may not be conclusive evidence that MIB is driven by local interactions but instead is influenced by more global, long-range properties of motion. Furthermore, if global interactions are a potential mechanism underlying MIB then it is also not surprising that Libedinsky et al. (2009) found no significant difference in disappearance between a small and large field mask. Considering the fact that global motion coherence influences

MIB (Wells et al., 2011), the lack of any difference in MIB may have been the result of similar global coherent motion and not solely the influence of local spatial effects.

The fact that the current evidence supporting a local interaction account of MIB could also be explained by a global interaction mechanism, we sought to disentangle the relative impact of local and global interactions in the following study. Here, we behaviorally investigated the involvement of local versus global interactions in MIB by exploiting the differential motion coherence effects in MIB recently reported by Wells et al. (2011). Specifically, as the motion coherence of the mask is increased (i.e. from dots moving with 0% coherence to dots moving with 100% coherence), target disappearance is reduced. This differential effect of mask coherence on target disappearance allows us a unique opportunity to pinpoint the relative influences of spatial interactions between the target and the mask. By selectively manipulating the degree of motion coherence within spatially confined regions of the mask, we can begin to decipher the impact of local versus global interactions in MIB. In particular, if local interactions are the driving force in MIB, we would expect the motion around the target to drive MIB. However, if more global interactions underlie target disappearance in MIB then we would expect the motion coherence in the areas exclusive to the target to influence target disappearance.

Experiment 5: Spatial location of incoherent motion

Method

Subjects

Fifteen participants with normal or corrected-to-normal visual acuity took part in Experiment 5. All were students from the University of New Hampshire, Durham and received partial course credit. Informed consent was obtained from each participant.

Stimuli

Stimuli were viewed from a distance of 50 cm. on a 19 in. CRT display (ViewSonic G90fb) powered by an Apple G4 desktop computer. The design and implementation of the stimuli were achieved using Matlab (Mathworks, Natick, MA) with PsychToolbox extensions (Brainard, 1997; Pelli, 1997. The stimuli consisted of a mask composed of three distinct, evenly spaced, columns of 49 moving dots each subtending 0.20 degrees with a dot density of 0.91 dots/deg^2 and maintaining a speed of 8.51 deg/s. Each column subtended 3.98 degrees x 13.60 degrees, was surrounded by a gray aperture and positioned on a black background (Figure 5.11). The columns were separated by a distance of 1.59 deg and a fixation cross was placed at the center of the middle column.

Each dot in a column had a limited lifetime of 237 ms at which point it was replaced by another dot in a randomly determined position. Incoherent motion was achieved by assigning each dot a random angle of trajectory from one to 360 degrees with a new angle and position being randomly determined for each new dot "birth". When a dot reached the edge of the column aperture, it was replaced by another dot in an equivalent location on the opposite side. Coherent dots followed a predictable linear downward trajectory. We specifically eliminated the use of horizontal coherent motion to avoid the perception of motion colliding with the columns but it should be noted that our earlier studies revealed no difference in target disappearance between coherent motion in any of the four cardinal directions, i.e. up, down, left, or right).

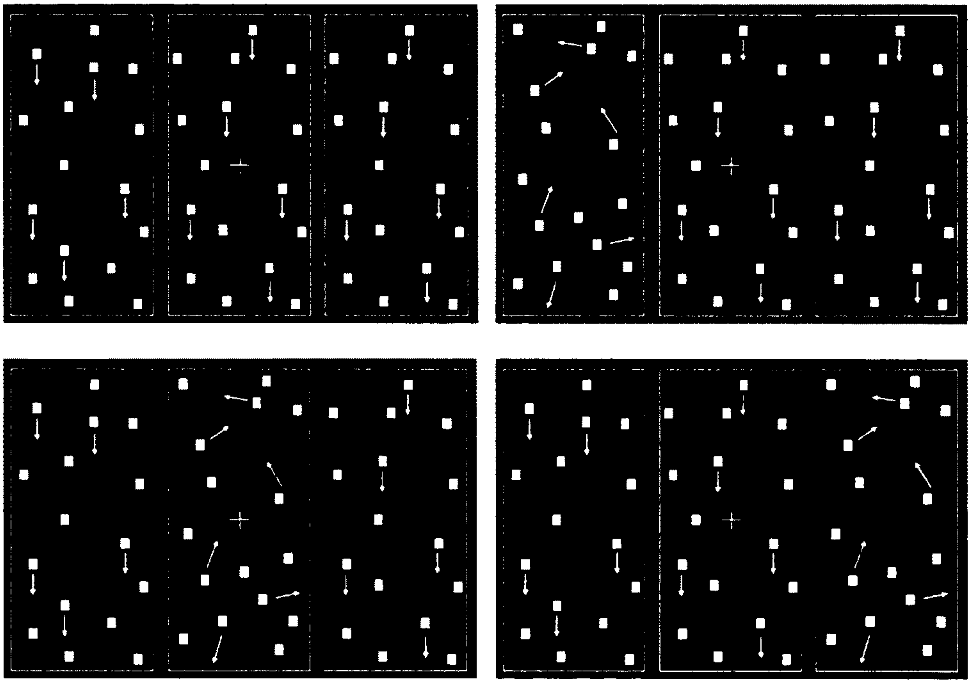

Figure 5.1. Experiment 5— variable location of incoherent motion. Representation of mask stimuli used to test to role of local versus global influence on a peripheral target in MIB. In all experiments, the moving square dots were blue and the peripheral, circular target was yellow. A visible, gray frame outlined each column. Arrows, here depicting the overall motion in each column, were not present in the actual stimulus.

While maintaining gaze on the fixation cross in the center column, observers were instructed to report the perceived disappearance of a peripheral

0.55 deg diameter circular target. Participants were instructed to press the right shift key when they saw the target disappear and release it upon target reappearance. The location of the target was randomly selected on each trial to appear either in the left or right column positioned at an eccentricity of 6.47 deg. The eccentricity of the target was far enough to insure approximate placement in the center of the column. On 75% of the trials, local coherence values were manipulated so that one of the 3 columns (left, middle or right) contained 0% coherent motion while the other two columns contained 100% coherent motion (Figure 5.1, top right, bottom). The location of incoherent motion was randomly assigned and equally distributed across the trials. For the remaining trials, all columns contained coherent motion (Figure 5.1 top left).

Design & Procedure

Each participant completed a minimum practice session of six trials, each lasting 30s. Following the practice trials, participants completed a total of 96 trials, also lasting 30s. A self-timed break after each block of 16 trials was provided.

Results and Discussion

When the data violated the assumption of sphericity as indicated using Mauchly's test of sphericity, we used the Greenhouse-Geisser corrected degrees of freedom and the adjusted *p*-value in our reported statistics. We used Holm-Bonferroni corrections when deciding the significance of all pairwise comparisons.

The location of the incoherent motion appeared to influence the percent of time the target was perceived to disappear during a 30s trial (Figure 5.2a). A one-way repeated measures ANOVA showed a main effect for the location of the incoherent motion, F (3, 42) = 5.72, $p < 0.003$, $\eta^2_{partial} = 0.29$. Pairwise comparisons revealed a significant difference between the perceived disappearances at fixation compared to when the incoherent motion was located at the target (12.66% vs. 10.14%, respectively; $p < 0.002$). A significant difference in disappearance was also found for incoherent motion at fixation compared to when the display contained all coherent motion (Mean=10.38% $p \leq 0.02$). There was no significant difference for percent disappearance when the incoherent motion was located in the target column or the opposite column. No significant difference in disappearance was revealed when all the columns contained coherent motion and when incoherent motion was found at the target location or opposite to the target location. This suggests that the more global location of the motion at fixation appears to significantly impact disappearance due to MIB.

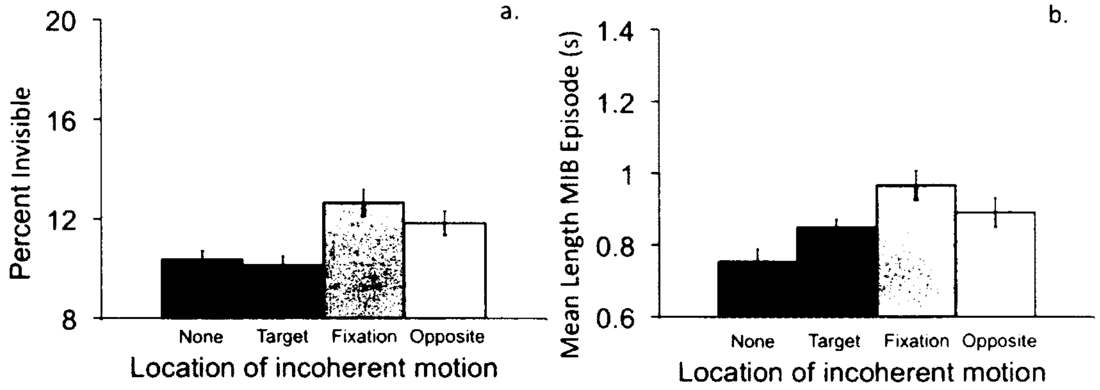

Figure 5.2. Results of Experiment 5—variable location of incoherent motion. a). Percent perceived invisibility of the peripheral target for conditions where there was no incoherent motion, Incoherent motion located in the target column, at fixation, or in the column opposite to the target. b). Mean length of an MIB episode for conditions where there was no incoherent motion, Incoherent motion located in the target column, at fixation, or in the column opposite to the target. Error bars indicate within-subject variability ±1 SEM.

We also tested the average length of an MIB episode during a 30s trial. A one-way repeated measures ANOVA showed a main effect for the location of the incoherent motion, F(3, 42) = 4.79, $p < 0.01$, $\eta^2_{\text{partial}} = 0.26$ (Figure 5.2b). Again, the least amount of disappearance was reported for the condition where all columns contained coherent motion (Mean=0.75 s) as predicted by the results reported by Wells et al. (2011). A significant difference was found between the mean length of an MIB episode when the columns contained all coherent motion and when incoherent motion was located at the fixation (Mean=0.96 s; $p<0.008$). No other comparisons were significant.

In summary, we found a significant effect for the location of motion coherence. In particular, we found that the difference in disappearance was driven by motion separate from the target, specifically at the location of fixation.

The data from the present experiment suggests that global processes impact disappearance more than a local interaction account.

Experiment 6: Spatial location of coherent motion

In order to further test the impact of global versus local effects on disappearance we created a stimulus that was complementary to that in Experiment 5. Now, instead of manipulating the location of a column of incoherent motion, we varied the spatial position of one area of coherent motion. Again, if local motion exerts control over the degree of disappearance during MIB, we would expect to see disappearance reduced when coherent motion was found coinciding with the target location. However, if MIB is driven by a more global mechanism, we should see perceptual disappearance of the target decline when the coherent motion in the display is situated farther from the target. Furthermore, if there is a limit to the global effects of the coherent motion a similar pattern found in Experiment 5 should emerge. Specifically, we should see the least amount of disappearance when the coherent motion is located at fixation with no difference in disappearance when it is spatially restricted to the target area or opposite to the target.

Method

The methods used in the current experiment were the same as in Experiment 5 except where noted.

Subjects

Seventeen participants with normal or corrected-to-normal visual acuity took part in Experiment 6.

Stimuli

On 25% of the trials, all columns contained incoherent motion (Figure 5.3, top left). On the remaining 75 % of the trials, the motion coherence in one of the 3 columns (left, middle or right) contained 100% coherent motion while the other two columns contained 0% coherent motion (Figure 5.3 top right, bottom). Again, the location of coherent motion was randomly assigned and equally distributed across the trials.

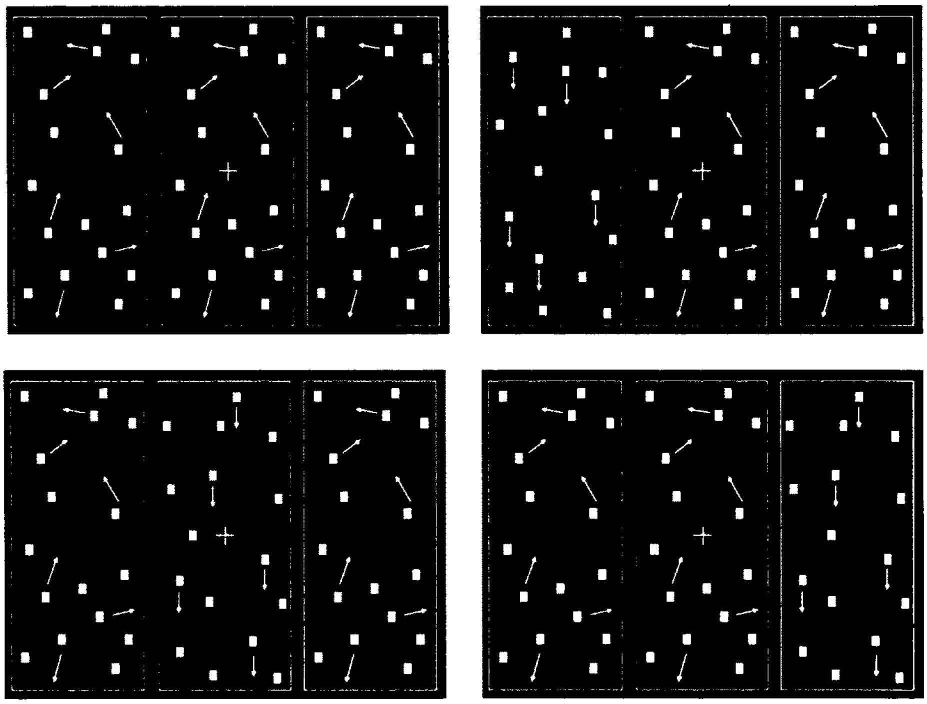

Figure 5.3. Experiment 6—variable location of coherent motion. Representation of mask stimuli used to test to role of local versus global influence on a peripheral target in MIB. In all experiments, the moving square dots were blue and the peripheral, circular target was yellow. A visible, gray frame outlined each column. Arrows, here depicting the overall motion in each column, were not present in the actual stimulus.

Results and Discussion

Once again, the effect of manipulating motion coherence in one of three columns influenced the percentage of perceived disappearance of the peripheral target within a 30s trial (Figure 5.4a). A repeated measures ANOVA showed a significant effect for location of the coherent motion, $F(3, 75) = 4.86$, $p < 0.006$, $\eta^2_{\text{partial}} = 0.23$. The main effect reflected the decrease in disappearance by the motion at fixation. Perceived disappearance decreased significantly when the motion of the dots at fixation was coherent (14.91%) compared to when coherent motion was located with the target (18.23%; $p < 0.007$) or when all three columns contained incoherent motion (17.56%, $p < 0.013$). The percentage of perceived disappearance for all three columns containing incoherent motion was not significantly different from the perceived disappearance with coherent motion in the target or opposite column (all $p \geq 0.50$).

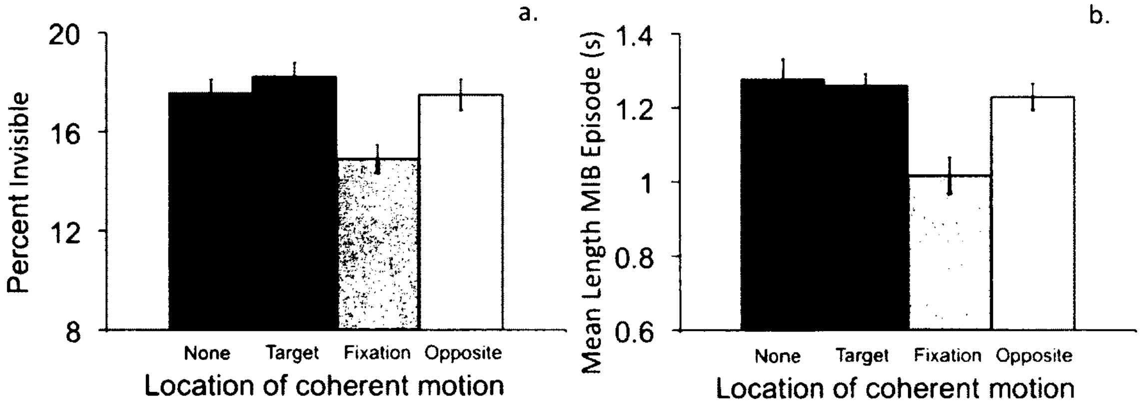

Figure 5.4. Results of Experiment 6—variable location of coherent motion. a). Percent perceived invisibility of the peripheral target for conditions where there was no coherent motion, coherent motion located in the target column, at fixation, or in the column opposite to the target. b). Mean length of an MIB episode for conditions where there was no coherent motion, coherent motion located in the target column at fixation or in the column opposite to the target. Error bars indicate within-subject variability ±1 SEM.

The motion contained in the different columns also influenced the average length of an MIB episode (Figure 5.4b). Specifically, a one-way repeated measures ANOVA revealed a significant main effect for column coherence, $F(3,42) = 5.66$, $p < 0.003$, $\eta^2_{\text{partial}} = 0.26$. Pairwise comparisons revealed a significant difference between the length of an episode when the coherent motion was at fixation compared to when motion in all the columns contained incoherent motion (1.02 s vs. 1.26 s, respectively; $p < 0.003$). Furthermore, the average length of an MIB episode increased significantly when all the columns contained incoherent motion compared to when the fixation column motion was replaced with coherent motion (1.28 s vs. 1.02 s; $p < 0.013$). No other pairwise comparisons were significant.

To summarize, once again we found a significant effect of the location of motion coherence on MIB. A distinct effect for the coherence at fixation suggests that MIB is the result of more global interactions arising between the mask and the target. According to a local interaction account of perceived disappearance during MIB, we would have expected more disappearance when incoherent motion was located in the same column as the target in Experiment 5. Similarly, we should have seen the reverse effect or less disappearance when coherent motion was located in the same column as the target in Experiment 6. However, the results from Experiments 5 and 6 indicate that a more global influence is operating during MIB as indicated by the lack of a significant impact on target disappearance by the motion surrounding the target. Moreover, there appears to be a limit to the long-range effects of motion coherence. Any change in the amount of disappearance due to the presence of incoherent or coherent motion was not affected by a spatial separation greater than that found at the location of fixation.

However, it is possible that motion processing across the visual field is scaled, with preference given to the fovea and thus, the motion located at fixation (Wright, 1986; van der Grind, Verstraten, & Zwamborn, 1994). Therefore, we were interested in whether the global influences of MIB would remain once the motion at fixation became less influential. Therefore, the motion at fixation was removed, reducing its overall contribution to the visual scene, leaving motion only at the target or opposite to the target. If global motion processing is a factor in determining MIB then disappearance of the target should be significantly impacted by the motion coherence of the mask located opposite to the target. However, if there is a local component of motion on MIB, disappearance should be determined by the motion coherence located around the target.

Experiment 7: Elimination of motion at fixation

Method

The methods used in the current experiment were the same as in Experiments 5 except where noted below.

Subjects

Fifteen subjects with normal or corrected-to-normal visual acuity took part in Experiment 7.

Stimuli

The mask was similar to the mask used in Experiments 5 and 6. However, the moving dots in the middle column with the fixation cross were removed. Motion was therefore contained to the column with the target as well as to the column opposite to the target. The aperture outlining the central column remained visible.

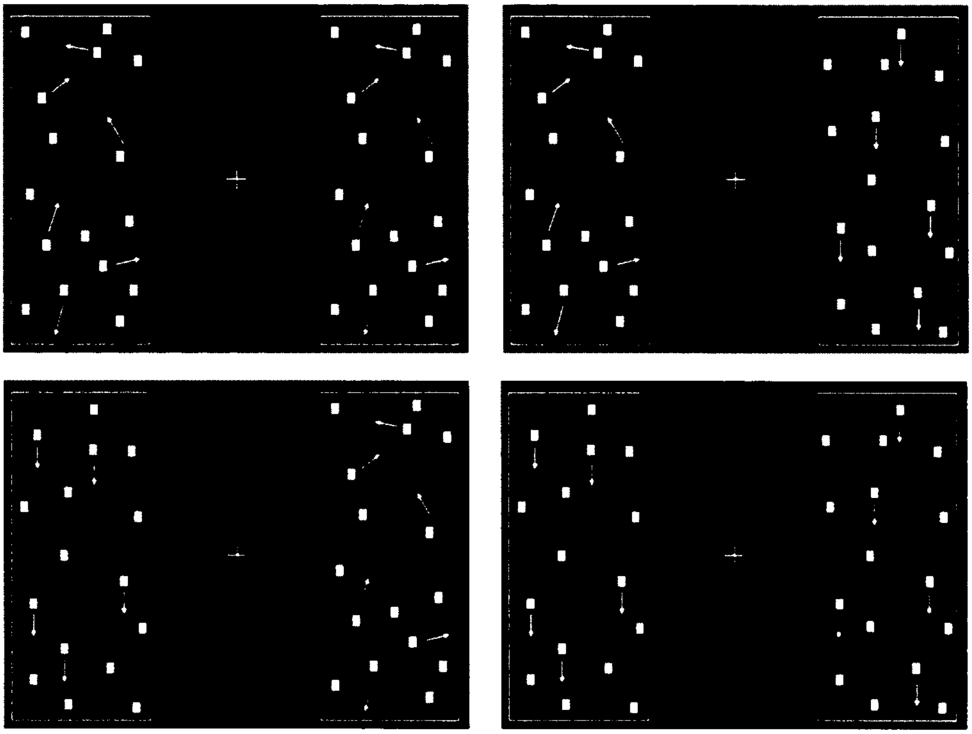

Figure 5.5. Experiment 7. Fixational motion removed to eliminate possible effect of central motion spreading. In all experiments, the moving square dots were blue and the peripheral, circular target was yellow. A visible, gray frame outlined each column. Arrows, here depicting the overall motion in each column, were not present in the actual stimulus.

Coherence of the dots in the two outer columns was randomly selected from either coherent or incoherent motion on each trial and was independent of the motion in the opposing column. Therefore, four different motion combinations were possible: 1) Incoherent motion in the target column with incoherent motion in the column opposite to the target, T_{incoh}-O_{incoh}, (Figure 5.5, top left), 2) incoherent motion in the target column with coherent motion in the column opposite to the target, T_{incoh}-O_{coh}, (Figure 5.5, top right), 3) coherent motion in the column containing the target with incoherent motion contained in the column opposite to the target, T_{coh}-O_{incoh} (Figure 5.5, bottom left), and 4) coherent motion in the column containing the target with coherent motion contained in the opposite column, T_{coh}-O_{coh} (Figure 5.5, bottom right). Again, coherent motion was limited to the downward trajectory.

Results and Discussion

Removing motion at fixation did not appear to change the interpretation of a global influence of the mask on the percentage of perceived disappearance of the peripheral target within a 30s trial (Figure 5.6a). A two-way (2 target motions x 2 opposite motions), repeated measures ANOVA showed no significant effect for the motion contained in the column with the target, $F(1, 14) = 0.51$, $p = 0.49$, $\eta^2_{partial} = 0.04$. Therefore, the percentage of time the target was perceived to be invisible was not dependent on the coherence of the motion contained locally around the target. However, there was a significant main effect for the motion contained in the column opposite to the target, $F(1, 14) = 7.77$, $p < 0.02$, $\eta^2_{partial} = 0.36$. No significant interaction was observed, $F(1, 14) = 2.55$, $p = 0.13$, $\eta^2_{partial} =$

0.15. Therefore, removing motion at fixation did not appear to affect the impact of global interactions compared to local interactions in target disappearance.

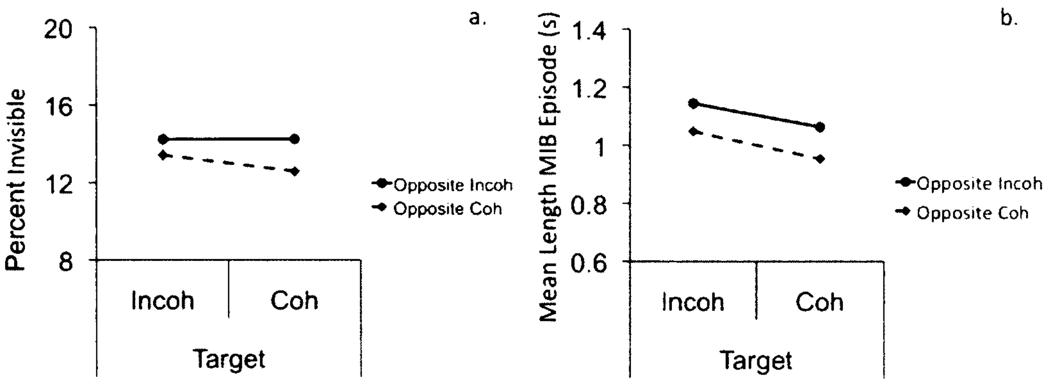

Figure 5.6. Results of Experiment 7—motion removed at fixation. a). Percent perceived invisibility of the peripheral target for varying combinations of motion types at the target (X-axis) and opposite to the target (separate plot lines). b). Mean length of an MIB episode for varying combinations of motion types at the target (X-axis) and opposite to the target (separate plot lines). Error bars indicate within-subject variability ±1 SEM.

A similar analysis was conducted for the mean length of an MIB episode for the 4 motion combinations (Figure 5.6b). Here, a two-way (2 target motions x 2 opposite motions), repeated measures ANOVA showed no significant effect for the motion contained in the column with the target, F(1, 14) = 3.32, $p = 0.09$, $\eta^2_{partial} = 0.19$. Again, a significant main effect was found for the motion type located in the column opposite to the target, F(1, 14) = 12.56, $p < 0.005$, $\eta^2_{partial} = 0.47$. No significant interaction was observed, F(1, 14) = 0.02, $p = 0.89$, $\eta^2_{partial} = 0.002$. These results suggest that the mask lends a more global influence on the mean length of an MIB episode compared to any local interaction around the target.

To summarize, we found that the presence of motion coherence in the column opposite to the target was still influential in determining the probability that the stationary target would disappear. In particular, in Experiment 7 motion in the more global location opposite to the target modulated the effect. Incoherent motion in the column opposite to the target increased disappearance while coherent motion opposite to the target decreased the likelihood of perceptual disappearances. The present results are consistent with research showing a long-range influence of motion processing across spatially remote areas (von Grünau & Dubé, 1992), giving credence to a global motion processing mechanism in MIB.

When motion at fixation was eliminated, the global influence on target disappearance was not eradicated. In visual perception, global motion processing can be significantly affected by the presence of incoherent motion. It is suspected that the random motion signals in incoherent motion may be more difficult to interpret as global motion due to its inherent ambiguity (Durgin, 2002). When both columns contained elements moving in the same coherent direction, the visual system may have been able to process the global motion cues more efficiently due to a decrease in ambiguity. With an increase in motion processing efficiency, any spatial conflict that may arise between the processing of the target and the mask is resolved more quickly (Graf et al., 2002; Lages, Adams, & Graf, 2009). In fact, neurophysiological data have revealed a faster propagation of coherent motion signals from V1 to higher cortical areas compared to incoherent motion cues (Ulbert, Karmos, Heit, & Halgren, 2007) and may reflect a gain control mechanism designed to increase efficiency of global motion processing (Harrison, Stephan, Rees, & Friston, 2006). Therefore, the increase in disappearance with incoherent motion anywhere in the display may reflect an increase in motion processing due to conflicting motion signals.

In the final experiment, we sought to behaviorally test whether global motion processing, specifically ambiguous or conflicting global motion, would impact MIB. To this end, we conducted an experiment similar to Experiment 7 with an additional condition—the presence of opposing, coherent motion in the two columns. The presence of two different global motion directions in separate spatial locations in the MIB display should introduce more ambiguity in global motion processing, predicting more disappearance compared to the conditions where the motion coherence in the two columns do not conflict.

Experiment 8: Motion conflict.

Method

Subjects

Twenty subjects with normal or corrected-to-normal visual acuity took part in Experiment 8.

Stimuli

The mask was similar to the mask used in Experiment 7 (Figure 5.5). Motion in the display was once again restricted to the two outside columns: the column containing the target and the column opposite to the target. The motion in each column was randomly selected on each trial from incoherent motion, coherent motion in the downward direction, and coherent motion in the upward direction. The selection of motion in each column was independent from the motion contained in the opposing column. Therefore, five separate motion conditions were possible on each trial. Now, conditions featured the four conditions from Experiment 3 (T_{incoh}-O_{incoh}, T_{incoh}-O_{coh}, T_{coh}-O_{incoh}, T_{coh}-$O_{coh-same}$), with the addition of a fifth condition—coherent motion in the two columns moving in opposite directions (T_{coh}-$O_{coh-diff}$). The fifth condition (Figure 5.7) was our critical condition to test the possibility that a conflict in global, motion processing may account for our previous findings of increased disappearance when incoherent motion was located anywhere in the display. The other four conditions were a replication of Experiment 7.

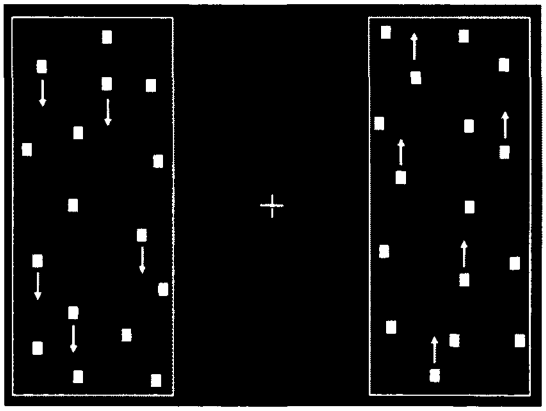

Figure 5.7. Experiment 8—Motion conflict. Column conditions in Experiment 3 were the same as in Experiment 2 with the addition of a fifth motion combination—opposing motion directions in the two columns. Again, arrows depicting the overall motion in each column were not present in the actual stimulus.

Results and Discussion

For the present rationale suggesting that global motion conflict influences MIB, we were interested in the condition where the motion at the target and opposite to the target was at odds. If target suppression allows the visual system to resolve the conflict between the stationary target and the global motion structure of the mask, as suggested by Graf et al. (2002) and Lages et al. (2009), then the greater the conflict, the more often the target will be perceived to disappear. Therefore, opposing coherent motion signals in the two columns should introduce more conflict, and thus more perceived target disappearance, compared to the condition where the coherent directions are equal. Likewise, the condition where the coherent motion signals are in opposite directions should not be significantly different to the condition where both columns contain the inherently ambiguous or conflicting incoherent motion.

To test these predictions we ran a paired samples t-test on the percentage of time the target remained invisible for same and different coherent motion combinations, T_{coh}-$O_{coh\text{-}same}$ and T_{coh}-$O_{coh\text{-}diff}$ (Figure 5.8a). We found a significant difference between these two conditions, $t(19) = -2.25$, $p < 0.04$. No significant difference was found for the percentage of time the target was perceived to disappear when the motion in both columns was incoherent (T_{incoh}-O_{incoh}) and when the motion in both columns was coherent but in the opposite direction (T_{coh}-$O_{coh\text{-}diff}$).

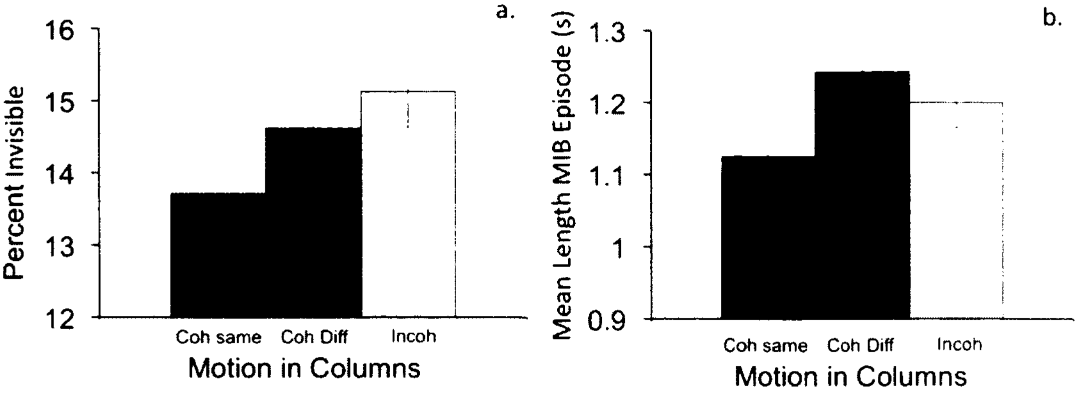

Figure 5.8. Results of Experiment 8—motion conflict. a). Percentage of time the peripheral target was perceived to disappear for mask containing two columns having coherent motion in the same direction (black bar), coherent motion in opposite directions (dark gray bar), or incoherent motion (light gray bar). b). Mean length of an MIB episode for mask containing two columns having coherent motion in the same direction (black bar), coherent motion in opposite directions (dark gray bar), or incoherent motion (light gray bar). Error bars indicate within-subject variability ±1 SEM.

We also ran a paired samples t-test for the mean length of an MIB episode for different coherent motion in both columns compared to the same motion directions, T_{coh}-$O_{coh\text{-}diff}$ vs. T_{coh}-$O_{coh\text{-}same}$, as well as incoherent in both columns, T_{coh}-$O_{coh\text{-}diff}$ vs. T_{incoh}-O_{incoh} (Figure 5.8b). No significant difference was found for either pairing, $t(19) = -1.62$, $p = 0.12$ and $t(19) = 0.67$, $p = 0.51$, respectively.

The influence of global vs. local interactions was also investigated by comparing incoherent motion with coherent motion when they moved in the same direction. Specifically, we compared the percentage of time the peripheral target was perceived to disappear as a function of incoherent or coherent motion at the target in combination with incoherent or coherent motion in the same direction in the opposite column. A two-way, repeated measures ANOVA was conducted and included only the original four conditions tested in Experiment 7 (Figure 5.9a). Results equivalent to Experiment 3 were obtained. Once again, the motion opposite to the target had the greatest impact on disappearance, F(1,19) = 4.90, $p < 0.04$, $\eta^2_{partial} = 0.21$. The motion at the target did not appear to change the percentage of time the target was perceived to be invisible, F(1,19) = 0.00, $p = 0.99$, $\eta^2_{partial} = 0.00$. No interaction was observed, F(1,19) = 0.23, $p = 0.64$, $\eta^2_{partial} = 0.01$.

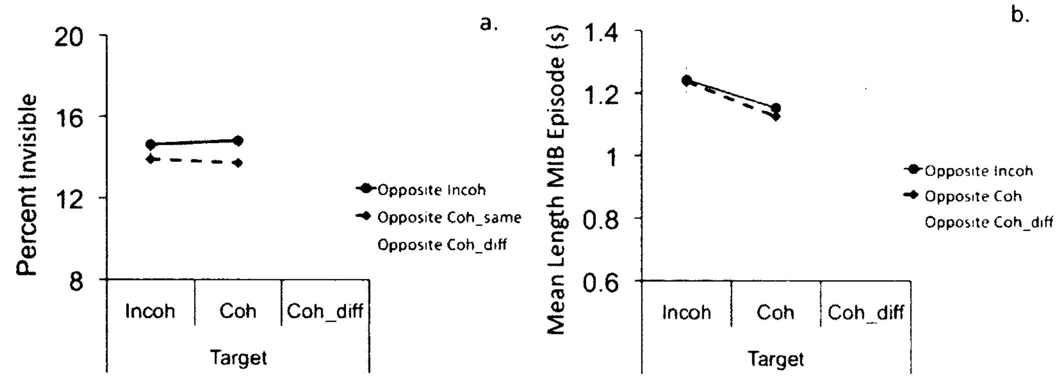

Figure 5.9, Results of Experiment 8—All mask conditions. a). Percent perceived invisibility of the peripheral target for varying combinations of motion types at the target (X-axis) and opposite to the target (separate plot lines). Single square marker shows the percent invisible when motion in the two columns was in opposite directions. b). Mean length of an MIB episode for varying combinations of motion types at the target (X-axis) and opposite to the target (separate plot lines). Single square marker shows the percent invisible when motion in the two columns was in opposite directions. Error bars indicate within-subject variability ±1 SEM.

We also conducted a 2 (target motion) x 2 (opposite motion) two-way, repeated-measures ANOVA for the mean length of an MIB episode (Figure 5.9b). Here, we were unable to replicate our previous findings from Experiment 2. We found no difference in the mean length of an MIB episode for different motion types opposite to the target, F(1,19) = .10, p = 0.75, $\eta^2_{partial}$ = 0.01. The mean length of an MIB episode for motion at the target was also not significantly different for the different motion types, F(1,19) = 4.08, p = 0.07, $\eta^2_{partial}$ = 0.18. Likewise, we did not observe an interaction, F(1,19) = 0.08, p = 0.79, $\eta^2_{partial}$ = 0.004. While both measures are typically used to measure the magnitude of MIB, we feel that our failure to replicate our previous findings for the measure of the mean length of an MIB episode could be explained by Levelt's (1967) second proposition concerning dominance times in perceptual rivalry. In particular, an increase in the strength of one stimulus compared to another in rivalry situations usually produces an overall increase in the amount of time the stronger stimulus is observed. However, the increase is not due to longer individual periods of dominance but shorter periods of suppression. A similar situation has been known to occur in MIB (Carter & Pettigrew, 2003).

Overall, it appears that when conflicting motion signals are present in the mask, the more often the target will perceptually disappear.

General Discussion

The above experiments sought to investigate the role of local versus global influences on disappearance due to MIB. We used a stimulus manipulation previously shown to modulate MIB (i.e. greater disappearance with less coherence, Wells et al., 2001). By replacing a small area of a coherently structured mask with incoherent motion either locally or globally to the target, we could measure the effect on disappearance. In general, we found greater evidence to support an influence of global motion processing in target visibility compared to local influences. Specifically, we found the target was more likely to be perceived as invisible when the incoherent motion was located more globally to the target (Experiment 5). However, the effect was spatially limited—incoherent motion at fixation had a greater impact on disappearance compared to when it was located in an area surrounding the target or opposite to the target. Including an area of global motion structure in an otherwise incoherent, unstructured mask had the reverse effect—decreasing the probability that the target would disappear but again, the effect was limited to the global position at fixation (Experiment 6).

The global influence of the mask was most likely not a result of fixational motion spreading overriding subtler, local interactions. When motion was eliminated at fixation, the motion type present in the more global location opposite to the target modulated target (Experiment 7). Specifically, we found a significant difference in perceived target disappearance for incoherent motion compared to coherent motion located in a distant location opposite to the target. Motion type immediately surrounding the target did not influence perceptual disappearance.

Finally, we investigated whether the presence of any conflicting information in global motion processing of the mask elements would impact perceptual disappearance of the target (Experiment 8). An increase in global motion conflict arising within the mask would predict greater disappearances due to MIB. We found that when the global motion signals of the mask were different or conflicting, as is the case with incoherent motion or opposing motion vectors in the two columns, the target disappeared more often.

How do our current findings coincide with what we know about visual perception? It is possible that the motion in the MIB mask produces areas of suppression due to neural inhibition similar to what is thought to occur with contrast matching. When the contrast of two stationary targets is compared, the contrast of one of the targets is reduced by the presence of a single moving item in its vicinity and this zone of suppression can extend many degrees in front or behind the location of the moving object (Chappell, 2007). The authors point out that the suppression may arise due to inhibition but do not dismiss the possibility that habituation may also be involved. While we admit that the mechanisms underlying contrast decrement may be different than visibility during MIB, in light of the recent findings by Gorea and Caetta (2009) that the contrast of the MIB target is reduced during episodes of MIB further suggests the possibility that long-range inhibition or habituation is involved. Specifically, we suggest that the inhibition/habituation may arise from the global interpretation of the mask.

In the study of neural interconnectivity in motion, evidence exists to support the possibility that the disappearance due to MIB may arise due to global motion processing. Studying the response of multi unit neural activity under different types of global motion, Harrison et al. (2007) found that the visual areas responsible for processing local motion cues could be influenced by the global context of the motion. In particular neural responses in V1, where local motion cues are presumed to be integrated, would decrease if the global motion was coherent compared to when the motion was incoherent. Harrison et al. (2007) posit that the hierarchical nature of the visual system allows for constant fine-tuning of responses in an effort to increase processing efficiency. In fact, both global and local motion areas in the brain have been suggested to influence MIB (Donner, et al., 2008; Scholvinck & Rees, 2010). If the mask is unable to be interpreted as possessing global motion structure in higher cortical areas then we would predict that the activity in V1 would remain high, creating long term conflict with the activity due to the target and thus greater MIB. Given that conflict seems to be a necessary component of MIB (Bonneh et al, 2001; Lages et al., 2009), it is possible that competing neural activity between the stationary target and the moving mask, precipitated by global motion processing, differentially affects disappearance.

Conclusions

In summary, we found evidence for a global influence on disappearance due to MIB compared to a local, competitive interaction effect as had been suggested previously (Bonneh et al., 2001; Libedinsky et al., 2009). We found MIB was modulated depending on the motion in a location separate from the target or when the motion in the mask contained conflicting motion signals. It is possible that the ability of the visual system to process coherent motion signals as opposed to ambiguous or conflicting motion decreases the conflict between the mask and target, decreasing the perceptual disappearance of the target.

CHAPTER 6

THE ROLE OF MOTION PROCESSING IN MOTION-INDUCED BLINDNESS

As previously discussed in Chapter 4, an initial increase in disappearance of the target in MIB is most likely generated by adaptation of the target Gorea & Caetta, 2009). Comparing initial target disappearance for conditions where the mask was moving, stationary, or absent, Gorea and Caetta (2009) revealed support for a mechanism of target adaptation: target disappearance for all three conditions increased in the early stages of the trial. However, the magnitude of the initial target disappearance was greater when the mask was in motion compared to when the mask was stationary or absent. The authors further report a greater increase in target detection thresholds across the trial for a target surrounded by a moving mask compared to when the target was surrounded by a stationary mask or no mask at all. These findings suggest that although adaptation of stationary objects occurs frequently in visual perception, in MIB it is exacerbated.

Examination of the variable mask coherence data reported in the first experiment in Chapter 4 of this dissertation, reveal that within the first 5s of the trials there is no difference in initial disappearance between the different coherence levels in the masks (Figure 4.9). If target adaptation is indeed one of the mechanisms underlying MIB then at the earliest stages of MIB, target adaptation appears to be similar across the different coherence levels. Moreover, if target adaptation is facilitated by the competition between the representations of the moving mask and stationary target (Gorea & Caetta, 2009) then the different mask conditions appear to contribute equally at this stage of the trial. However, with longer viewing, target disappearance diverges as a function of coherence level; a mask with greater coherence had less likelihood of target disappearance as opposed to a mask devoid of coherent motion. The differential amounts of MIB in later stages of the trial hint at the possibility that the different mask types contribute unequally to target adaptation. Therefore, target disappearance during MIB may be the result of two processes that may not be mutually exclusive: 1) an initial increase in target disappearance due to target adaptation and/or 2) the ability of the mask to promote further target adaptation over the course of the trial.

The ability of a mask to promote target adaptation may be a result of the strength of its representation within the visual system. If we assume that the saliency of a mask feature correlates to its representation in the visual system (Goodyear & Menon, 1998; Tootell, et al., 1995) then it is possible that altering the representation would interfere with MIB. Support for this assumption is revealed under variable contrasts and speed of the mask— low luminance contrast or a slower speed of the mask reduces target disappearance compared to a mask possessing higher luminance or speed (Bonneh, et al., 2001). Analogous to the effects of strength of luminance contrast or speed representations, it is possible that representations of motion within the visual system could likewise affect target adaptation. A strong representation of the mask may be able to compete more with the target leading to long-term target adaptation; a weaker representation of the mask may affect the ability to sustain the adaptive state of the target thereby reducing MIB. It appears from the data that an inequity in mask coherence on target adaptation may reflect fluctuations in the strength of the representation of the mask with greater viewing time.

How is it possible that the strength of the mask fluctuates within a trial? Prolonged viewing of motion, particularly unidirectional, coherent motion, results in adaptation—or a decline in the responsiveness, and thus the sensitivity, of the neurons coding for that particular motion (Anstis, Verstraten, & Mather, 1998). The result is a decrease in the representation of that particular motion direction within the visual system as evidenced by a decreased ability to detect the adapted motion direction (Levinson & Sekuler, 1976). It is conceivable that with the typical exposure time of 30 s in an MIB trial, motion adaptation to the mask occurs, diminishing its ability to compete with the target. Coupled with initial target adaptation, prolonged mask adaptation may inhibit any additional target adaptation. In fact, Gorea and Caetta (2009) report little change in the duration of target disappearance after the initial increase. In comparison, the strength of the representation of an incoherent mask would remain strong given its resistance to motion adaptation. In this case, the competitive forces between the mask and target would allow for continued target adaptation and, thus, increased disappearance.

In order to assess motion adaptation, the technique of motion aftereffect (MAE) is utilized. MAE occurs under instances of prolonged viewing of coherent motion in one direction, and results in an illusion of motion in a static image in the opposite direction. The dynamic motion aftereffect (DMAE) is a variation on the classic MAE, instead making use of dynamic motion to measure illusory motion (Hiris & Blake, 1992). Here, adaptation to coherent motion produces the illusion of opposite motion in a proportion of randomly, moving dots. The number or proportion of dots moving in the adapting direction needed to cancel the effect determines the strength of the DMAE (Hiris & Blake, 1992). Therefore, DMAE is a useful tool to assess the magnitude of motion adaptation, providing an indirect measure of the extent to which the motion is processed (Hiris and Blake, 1992; Blake & Hiris, 1993; Chaudhuri, 1990). Greater motion processing of the mask correlates to a greater representation within the visual system thereby producing a stronger DMAE.

In the current study, I will investigate whether magnitude of MIB is associated with the strength of adaptation to coherent motion. Given the relationship between the amount of motion processing in the mask and the strength of a DMAE, a few predictions can be made concerning MIB. If a greater representation of the mask leads to more MIB then in trials where there is a greater amount of MIB, a stronger DMAE should be observed. Conversely, in trials where MIB is less, the DMAE should be weaker.

Experiment 9: Measuring Motion Aftereffect in MIB

Method

Subjects

Four participants with normal or corrected-to-normal visual acuity were recruited from the Psychology Department at University of New Hampshire, Durham and were compensated $7.00/session. Each participant completed eight sessions—two practice sessions and six experimental sessions. Informed consent was obtained from each participant at the beginning of each session.

Stimuli

Stimuli were generated with a Mac Mini using Matlab (Mathworks, Natick, MA) with PsychToolbox extensions (Brainard, 1997; Pelli, 1997) and presented on a 19 in. CRT display (ViewSonic G90fb) at a viewing distance of 50 cm. Stimuli consisted of blue, randomly moving square dots each subtending 0.20 deg^2 on a black background and moved with an angular velocity of 8.51 $dots/deg^2$.

Practice Session

Dot displays were confined within a circular area having a radius of 7.50 deg, centered in the middle of the screen with a density of 2.68 $dots/deg^2$. A gray frame having a thickness of 0.16 deg outlined the circular aperture. On each trial, the coherence of the moving dots was varied, being randomly selected from the set of coherence values ranging from 0% to 100% moving either to the left or to the right. A coherence of 100% signified that all of the dots moved in the same direction (left or right) at the same time while a coherence of 0% signified that all of the dots moved with random trajectories, independent of each other. A coherence value in between these two extremes would have a mixture of coherent and random motion within the same stimulus. For example, a coherence value of 39% constituted a stimulus having 39% of the dots moving with coherent motion and 61% of the dots moving in random directions.

Experimental Session

MIB task: This segment was comparable to the standard MIB trial originally described in Chapter 4. The MIB stimuli were the same as the coherence manipulation described in Experiment 1a. In brief, a white fixation cross was located in the center of the screen and a yellow circular target (0.55 degree diameter) was displayed in the upper left quadrant at 3.36 deg to the left of fixation and 3.29 deg above it, yielding an eccentricity of 4.70 deg (see Figure 4.2). Dot displays were confined within an area subtending 31.63 deg width x 23.20 deg height, centered in the middle of the screen. Nishida and Ashida (1997) reported a stronger dynamic motion aftereffect when a stationary border, particularly in the periphery, surrounded the adapting motion. Therefore, in order to obtain the strongest MAE, a gray, square frame bordered the area containing the dots. Furthermore, the number of dots was increased to yield a dot density of 2.68 dots/deg^2 and they remained on the screen for the duration of the 30s segment. On ½ of the trials, the mask motion consisted of dots moving with 0%

coherent (or random) motion. For the remaining ½ of the trials, the mask moved with 100% coherent motion, equally divided between left- and rightward motion.

DMAE task: The stimuli were comparable to the random dot stimuli presented in the practice session, however, on each trial the coherence of the dots was limited to 0%, 25% and 50% coherence. The direction of the coherently moving dots was randomly selected on each trial from rightward or leftward movement.

Design and Procedure:

Practice Session

Each participant completed two practice sessions—each session consisted of five blocks of 60 trials for a total of 600 trials. Because of time constraints, some completed these sessions on the same day. However, a practice session and an experimental session were never run concomitantly. The practice session consisted of judging the coherence of a random dot stimulus using a rating scale. The scale ranged from -100% (left direction) to 100% (right direction; Figure 6.1). For instance, if a random dot stimulus contained 25% of the dots moving to the left, participants would make the appropriate response by clicking the scale on the left at the point indicating 25% coherence. Immediately after participants responded, visual feedback was given in the form of two colored arrows. A green arrow was presented at the position on the scale corresponding to the participant's choice while a magenta arrow was presented at the position indicating the correct coherence. Participants were told to be as accurate as possible reducing the distance between the green and magenta arrow.

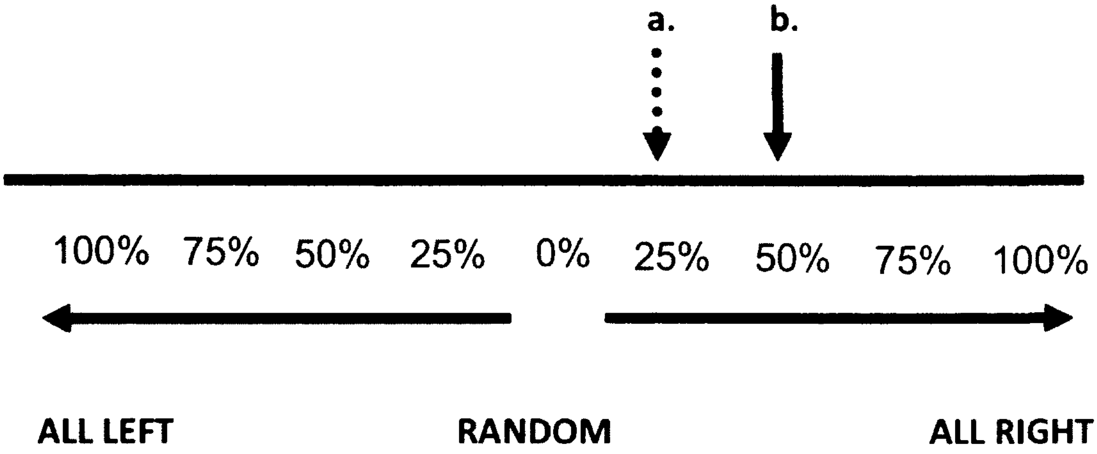

Figure 6.1. Scale used to judge the coherence of a random dot stimulus in the practice session. Solid arrow (a) represents the green arrow used to indicate the participant's choice. The dashed arrow (b) indicates the magenta arrow used to indicate the correct coherence (b). A similar scale was used for the DMAE task in the experimental sessions but feedback was eliminated.

Experimental Session

Each participant completed 96 trials in each session for a total 576 trails. A trial was comprised of the MIB task followed by the DMAE task, with an interstimulus interval of 100 ms. A self-timed break after each set of 24 trials was provided.

<u>MIB task:</u> The procedure for the MIB task was identical to Experiment 1a described in detail in Chapter 4. In short, participants viewed a moving mask stimulus for 30 s and recorded the disappearance of a peripheral target.

Participants signaled the disappearance of the target by pressing and holding the right shift key. Participants were told to release the right shift key as soon as the target reappeared. The time between a key press and key release constitutes the length of an MIB episode.

DMAE task: Immediately after the end of the MIB segment, the stimulus for the DMAE task was presented. Presentation time was 2s, comparable to DMAE test stimulus presentation times used in the past (Hiris & Blake, 1992). After the test pattern was removed, participants immediately made a judgment on the perceived coherence by clicking on a scale indicating the overall motion of the test stimulus. A DMAE was determined when the perceived coherence deviated from the actual coherence. A stronger DMAE will result in a larger deviation from the true coherence of the DMAE test stimulus. MIB tasks where the mask contained 0% coherent motion were used as a measure of bias estimation in the DMAE judgment task. With 0% coherent moving stimuli, motion adaptation is minimal and therefore, any deviation from the actual coherence can be interpreted as a response bias. All DMAE judgments for each subject within a session were normalized against the DMAE responses after viewing a 0% coherent mask in the MIB task.

Results and Discussion

Practice Sessions

The average deviations reported below are absolute values of participant's deviation from the actual coherence. Numbers in parentheses are the standard deviations (SD) between a participant's coherence decision and the correct coherence. Participant's appeared to be able to discriminate the correct coherence of randomly moving dots during the practice phase. In order to test for any effects of practice session, we binned the coherence values into 10 bins with a range of 20% coherence for a total of 5 bins for the left motion direction and 5 bins for the right motion direction (0% to 20%, 21% to 40%, 41 to 60%, etc). The non-directional 0% coherence was included in the first bin of each motion direction and therefore, this bin was slightly larger in range (21%). The 0% coherence accounted for a maximum of only 1.7% of the total trials and most likely did not affect the deviation in that bin. On average, participant's deviated from the correct coherence by an average of 3.03% (1.95%) in the judgment of the coherence of the moving dots with a range of 1.96%-4.18% (1.76% to 2.05%). We compared each of these coherence bins across sessions in a paired samples t-test and found a significant effect of session, $t(40) = 2.22$, $p < 0.04$. Over the course of the 2 sessions, participant's deviation form the correct coherence decreased from a mean deviation of 4.43% (3.00%) in session 1 to a mean deviation of 3.16% (2.52%) suggesting participant's improved with practice and over time, were able to accurately estimate the actual coherence contained in the motion stimulus.

Experimental Sessions

The deviation in a participant's judgment of the DMAE test stimuli from the actual coherence was considered to be the measure of the DMAE. To control for intersubject variability, we converted each participant's deviation from the actual coherence of the DMAE test stimuli on each trial to a z score. The mean and SD for the new distribution was chosen based on the expected mean for deviations from the actual coherence of the DMAE test following viewing of an incoherent MIB mask. Based on the observed mean of -0.003% and SD of 0.53% for deviations of the DMAE test stimulus under these conditions, we assumed no motion adaptation occurred and thus, centered the z distribution on a mean of 0 and a SD of 0.5. A positive z-score indicated that the DMAE was biased towards motion in the left direction and a negative z-score indicated the DMAE was biased towards the left direction.

1. Evidence for a DMAE

We found that the type of MIB mask did result in a shift in the perceived coherence of the test stimuli as expected under motion adaptation (Figure 6.2). Specifically, the coherent mask resulted in a significant difference between the actual coherence of the dynamic motion test stimulus and a participant's judgment of the perceived coherence whereas there was no effect with an incoherent MIB mask. We conducted a one-way, repeated-measures ANOVA and found a significant effect of MIB mask type on DMAE, $F(2,34) = 126.42$, $\eta^2_{\text{partial}} = 0.88$. Therefore, we were confident that the MIB mask containing random dots moving with coherent motion produced a DMAE.

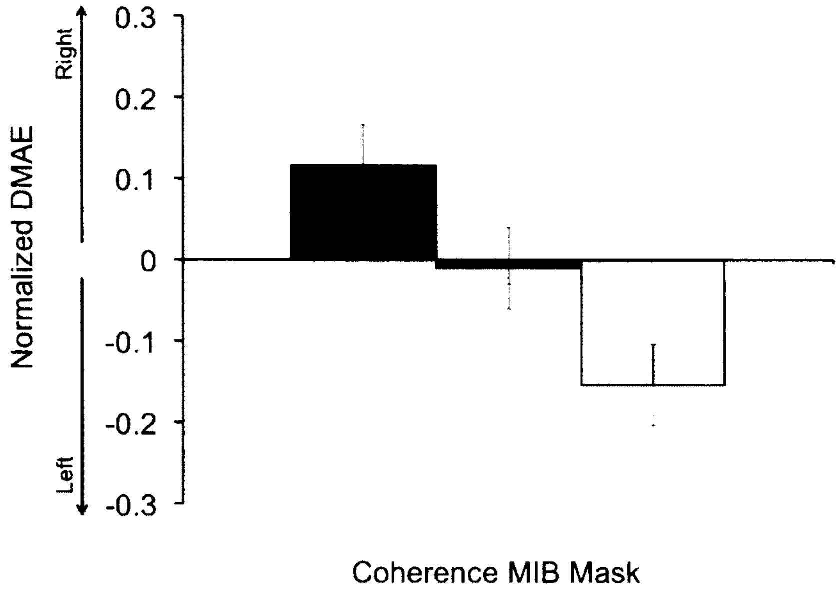

Figure 6.2. Normalized magnitude of DMAE for a MIB mask moving with coherent motion to the left (black bar), moving with incoherent motion (dark gray), or moving with coherent motion to the right (light gray). A positive score indicates perceived direction to the right and a negative score indicates perceived direction to the left. Error bars indicate within-subject variability ±1 SEM.

2. DMAE as a function of MIB duration

Next, we investigated whether the amount of MIB varied as a function of motion processing devoted to the mask. To this end, we categorized the mean length of an MIB episode into separate bins depending on whether the trial produced mean target disappearances that were low (LO), medium (MED), or high (HI). The range of mean MIB durations in each bin were determined by finding the 33rd and the 66th percentile of the set of mean MIB durations within each session. Thus, the first bin contained all the mean MIB durations that were less than the 33rd percentile for each session, the second bin contained the mean

MIB durations between the 33rd and the 66th percentile, and the third bin contained all the mean MIB durations greater than the 66th percentile.

For each bin, we calculated the magnitude of the standardized DMAE when the MIB task preceding the DMAE task contained a mask having 100% coherent motion. However, there is a possibility that participants exhibited a response bias in the DMAE task, producing an overestimation or underestimation in the variable. Given that no DMAE was observed for the incoherent mask, the assumption was that any deviation in the DMAE test stimulus in this condition constitutes a response bias. Therefore, the DMAE z-scores produced by adapting to left and right 100% coherent MIB masks were corrected for any response bias by subtracting the z-score for the judgment of the test stimuli when the MIB mask contained incoherent motion. Finally, to avoid negating any effect of overall DMAE when combining a deviation in the left (or negative) direction and a deviation in the right (or positive) direction, we transformed the deviations to absolute values. A one-way, repeated-measures ANOVA was performed on the corrected, absolute DMAEs within each bin for all 6 sessions. No significant difference for the strength of the DMAE for varying magnitudes of mean MIB duration was found, $F(2,34) = 1.61$, $p = 0.21$, $\eta^2_{\text{partial}} = 0.09$ (Figure 6.3).

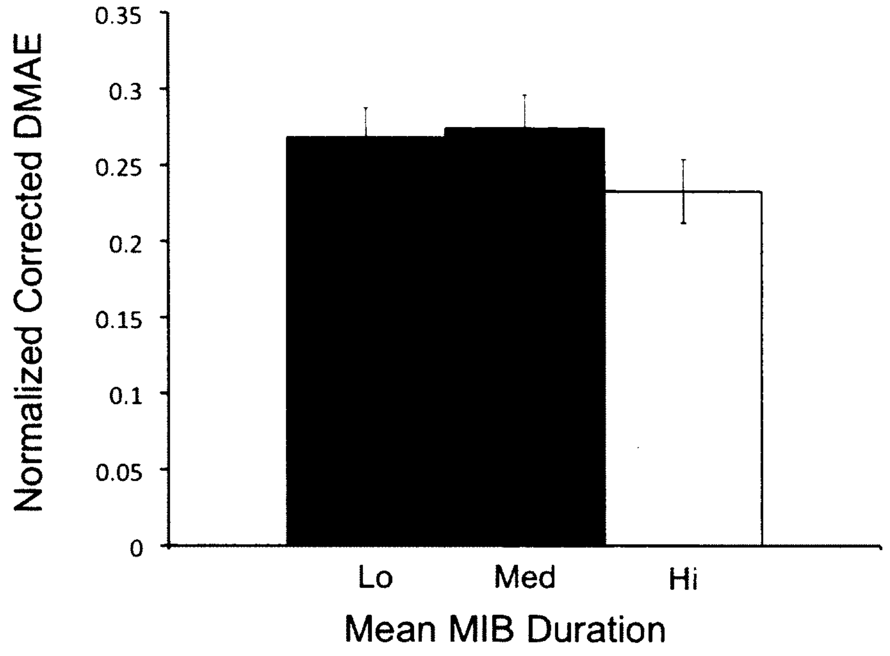

Figure 6.3. The abscissa plots the mean length of an MIB episode after binning according to whether the episode was characterized as being low, medium or high. The ordinate plots the absolute normalized, corrected DMAE (see text for more details). Error bars indicate within-subject variability ±1 SEM.

3. Possible direction selectivity of DMAE

The lack of any significant difference in the strength of the corrected DMAE across low, medium, and high levels of mean MIB duration caused us to consider whether our DMAE measure might be further biased. It has been reported that the MAE produced by adapting to translational motion may only be observed in a test stimulus containing dots moving in the same direction as the adapting direction (Raymond & Braddick, 1996) and may be more of a concern with larger dot densities (Van Wezel & Britten, 2002). Considering that our dot density was comparable to the 2.80 dots/deg^2 used by Van Wezel and Britten (2002), we felt it necessary to investigate the possibility that our DMAE was skewed by collapsing across stimuli not exhibiting a DMAE. Therefore, it is possible that we diminished the MIB effect by including those combinations where motion adaptation was not observed.

To evaluate whether motion adaptation in the experiment was directionally sensitive, we plotted the normalized DMAE for all directions of the test stimuli after participants viewed a coherent MIB mask moving to the left, to the right and after viewing incoherent motion. If the DMAE was not dependent on the type of motion contained in the DMAE test stimuli, expected results would be three parallel but shifted curves. Deviations reported after viewing a coherent MIB mask moving to the left should be shift up towards the positive z-scores, Moreover, any deviation experienced after an MIB trial containing coherent motion to the right, should be skewed towards the left or towards more negative z-scores. However, examination of the resulting plot reveals that the shift is dependent on the type of DMAE test stimulus presented (Figure 6.4). Specifically, when the adapting MIB mask and the DMAE test stimulus were in the same directions, the reported coherence deviated significantly from the incoherent condition or when motion adaptation was absent. Paired-samples t-test showed a significant difference between a left coherent MIB mask and the DMAE test stimuli containing 25% and 50% of the dots moving in the left direction, $t(22) = -5.95$, $p < 0.001$ and $t(22) = -4.18$, $p < 0.001$, respectively. Likewise, there was a significant difference in the deviations between an MIB mask moving with rightward coherent motion and the deviation reported for an incoherent MIB mask when the test stimuli were comprised of 25% and 50% of the dots moving coherently to the right, t(22) = 8.41, p < 0.001 and t(22) = 5.01, p < 0.001, respectively.

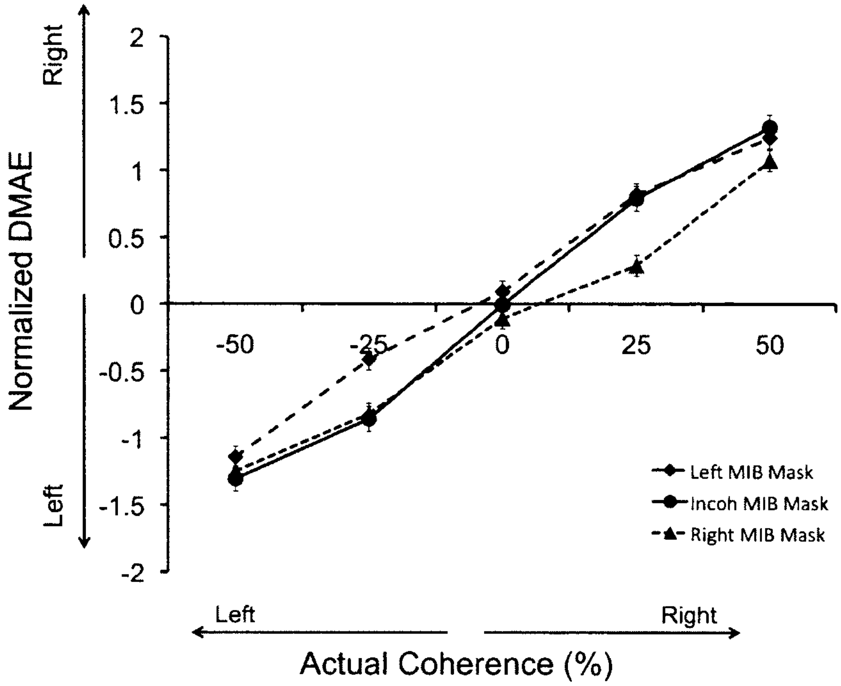

Figure 6.4. Graph of the DMAE for MIB masks containing coherent motion to the left (diamond), incoherent motion (circle), or coherent motion to the right (triangle). The abscissa plots the actual percentage of dots in the DMAE test stimulus moving with coherent motion. A negative number indicates the motion was towards the left and a positive number indicates motion to the right. On the ordinate is the normalized DMAE. A positive value indicates the perceived motion is towards the right and a negative number indicates the perceived motion was towards the left. Any deviation away from incoherent motion indicates a DMAE was experienced. Error bars indicate within-subject variability ±1 SEM.

A paired samples t-tests found no significant difference in the deviation reported when viewing a leftward moving MIB mask and a DMAE test stimulus that contained 50% and 25% of the dots moving to the right, t(22) = 2.56, *p* = 0.10 and t(22) = −1.15, *p* =0.26, respectively. In addition, a paired-samples t-test failed to find a significant difference in the deviation between a DMAE test stimulus containing 50% of the dots moving to the left after viewing a MIB mask moving to the right, $t(22) = -1.36$, $p = 0.19$, or a DMAE test stimulus containing 25% of the dots moving to the left after viewing a MIB mask moving to the right, $t(22) = -1.09$, $p = 0.29$. These results are in agreement with other findings suggesting that the DMAE is dependent on the direction of the test stimulus in relation to the adapting direction. Therefore, our concerns that our data analysis may have been moderated by including test directions where DMAE did not occur were justified.

4. Direction specific DMAE and MIB

The knowledge that the DMAE was not equal across all test stimuli presented during the DMAE task prompted the decision to restrict the data to include only trials where a DMAE occurred. In order to investigate the impact of motion processing on MIB, the one-way, repeated-measure ANOVA for the three categories of MIB (Low, Med, Hi) was repeated, selecting only the normalized and corrected DMAE data that corresponded to conditions where DMAE test stimulus matched the direction of the coherent MIB mask. What emerged when restricting the data set by these parameters was a pattern suggesting that the amount of motion processing dedicated to the MIB mask influenced the amount of MIB (Figure 6.5). Specifically, results indicated a marginally significant difference between the amount of MIB produced by the mask and the strength of the DMAE, $F(2,30) = 3.02$, $p = 0.06$, $\eta^2_{\text{partial}} = 0.17$. This marginally significant result might have been the result of a reduction in the number of trials and therefore additional data collection is underway to increase power.

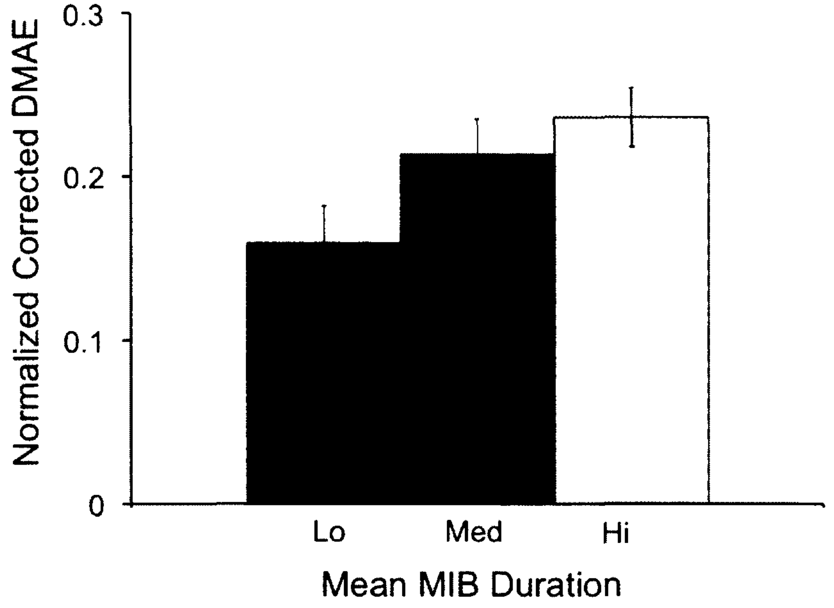

Figure 6.5. Magnitude of the mean length of an MIB episode after partitioning into bins indicating a low, medium, or high amount of MIB. The ordinate plots the absolute normalized and corrected DMAE (see text for more details). Error bars indicate within-subject variability ±1 SEM.

General Discussion

After participants viewed an MIB mask that contained coherent motion, a measurable DMAE was observed that varied in strength across the length of a 30s MIB trial. In line with several researchers (Raymond et al, 1996; Van Wezel et al., 2002), we found that the DMAE was direction selective, producing only a shift in the perceived coherence when the motion direction of the coherent MIB mask and the DMAE test stimuli matched. When we restricted our data to include only the combinations where the motion direction of the MIB mask and DMAE test stimuli were equal, we found evidence that the strength of the DMAE predicted the amount of MIB reported during the trial.

The finding that the DMAE following the MIB trial was direction selective hints at the possibility that MIB is the result of an attentional mechanism. Studies of the motion aftereffect in area MT showed that the DMAE response both psychometrically and physiologically was significantly biased towards the adapting direction (Lankheet & Verstraten, 1995; Van Wezel & Britten, 2002) and may be the result of attentional tuning to a particular direction (Rezec, Krekelberg, & Dobkins, 2004). When participants view an ambiguous motion stimulus containing two radial gratings flickering with opposing motion energies, the DMAE experienced differed depending on whether they viewed the stimulus passively or attentively (Culham, Verstraten, Ashida, & Cavanagh, 2000). When viewing the stimulus passively, no DMAE was experienced. However, attentively tracking one of the component motion directions produced a sizeable DMAE.

Since the first report on MIB, an attentional mechanism has been contemplated as a possible driving force for the illusion with the selected object obtaining the competitive edge, thereby suppressing the other object from awareness (Bonneh et al., 2001). This seems a reasonable proposal given the similarity of MIB to other forms of bistable phenomenon, such as binocular rivalry (Carter & Pettigrew, 2003), known to possess an attentional component (Mitchell, Stoner, & Reynolds, 2004; Paffen, Alais, & Verstraten, 2006). In MIB, spatially dividing attention towards two targets versus focusing attention on only one target resulted in more MIB for the focused attention condition (Geng, Song, Li, Xu, & Zhu, 2007). Other reports have observed the same counterintuitive bias in disappearance towards the attended target compared to the unattended target (Carter, Luedeman, Mitroff, & Nakayama, 2008). However, it is possible that attending to two targets only succeeds in drawing the attention away from the mask, reducing the competitive interaction between the mask and target. Support for this possibility is revealed in a study where the inclusion of a demanding central fixation task significantly reduced MIB (Scholvinck & Rees, 2010). In the domain of motion adaptation, diversion away from motion processing results in comparable effects, specifically the reduction in the DMAE (Chaudhuri, 1990). Therefore, it is highly likely that attention away from the mask reduces the processing resources devoted to the mask, significantly attenuating MIB

In light of the current results, an alternative explanation for why attention to the target produces greater MIB can be easily tested. The results from our present study suggest that the amount of motion processing given to the MIB mask modulates disappearance. When motion adaptation was higher, MIB increased compared to the when motion adaptation was low. Therefore, motion adaptation is also a useful tool to explore the influence of attention on motion processing during MIB. When attention is directed to two targets the competitive forces must now be divided between three objects instead of two. However, focusing on only one target can enhance the underlying competition between the mask and target. Carter and colleagues found that attention to four targets did not impact disappearance as long as they formed a perceptual group. Once again, the attention to processing the mask may increase when items are perceived as a single item.

Using the method of the DMAE would allow one to assess the amount of attention paid to the mask during conditions where there were a number of different targets in the display. If the competitive forces between the target and mask promote target adaptation then it is possible to measure the magnitude of the DMAE of the coherently moving mask as a function of the amount of MIB experienced within a trial depending on the number of attended targets. If the attention to the target was influential in determining MIB then DMAE should not change depending on the number of targets attended. However, if attending more than one target shifts attention away from the mask then the DMAE should decrease with increasing targets attended.

Conclusion

We found that the amount of motion processing in the mask determined the amount of target disappearance during the visual illusion of MIB. We suggest that attention, specifically towards the mask, may underlie the phenomenon. We propose that results showing attention to the target may actually be a differential effect of motion processing influencing object competition. These hypotheses can easily be explored using the DMAE.

CHAPTER 7

SUMMARY AND CONCLUSIONS

The purpose of this work was to gain insight into why the visual system eliminates information in the creation of a perceptual image. The illusion of motion-induced blindness was used as an experimental tool to discern possible answers. Particular attention was paid to motion processing of the mask elements—observing the interaction between the motion parameters of the mask and target disappearance. The current methods used deviated from the typical research on MIB and have yielded intriguing results. It was found that processing motion comes with a price: the temporary exclusion of salient information from perception.

In Chapter 1, I investigated the parameters of motion that would influence MIB. The mask elements no longer moved with fixed coherent, instead varying between grouped coherent motion and ungrouped incoherent motion. Although it was reported that incoherent motion could produce disappearance (Bonneh et al., 2001; Leopold et al, 2002), a detailed account of the grouping effects of motion on MIB was absent from the literature. What surfaced suggests that awareness of the peripheral target is a direct result of the particular motion signals contained in the mask. The greater the coherence or grouping of the mask elements, the more often the target was perceived. These results point to a possible mechanism of MIB that involve how the motion in the mask is processed.

Coherent and incoherent motions are processed in different areas of the brain (Newsome & Paré, 1988) and involve different populations of neurons transmitting information with different speeds, along and within the visual stream (Ulbert et al., 2001). If motion processing determines the current state of visual awareness during MIB, one could postulate that it may be due to the interconnectivity between higher and lower visual processing areas. Although a consensus for which hierarchical area mediates target disappearance during MIB has not been reached, it appears that it may involve many areas within the processing stream. While some evidence points to the involvement of lower visual areas such as V1 (Libedinsky et al., 2008; Wallis & Arnold, 2009; Gorea & Caetta, 2009; Scholvinck et al., 2010), many believe it occurs in higher cortical areas (Donner et al., 2008; Hofstoetter, Koch, & Kiper, 2004; Funk & Pettigrew, 2003). It is quite possible, given the results from Experiment 1-4, that the ability to perceive a peripheral target in the presence of a moving mask may result from the extent of communication between lower and higher visual areas.

It is the dynamic scene that presents the greatest challenge to visual processing. One could argue that because motion is a temporally changing feature dimension in the visual scene, the local and global responses would need to be continually updated in order to account for changes in spatial location and/or changes in motion direction. As work in neurophysiology advances, the processes involved in visual perception reveal repeated activity leaving and entering different areas allowing numerous opportunities for updating and fine-tuning perception (DiLollo, Enns, & Rensink, 2000). This reentry processing of information has been noted particularly for the connections between extrastriate motion area MT and lower visual area V1 (Hupe, James, Payne, Lomber, Girard, & Bullier, 1998). Generally, reentrant processing can be seen as a Gestalt mechanism creating order from disorder and nowhere in the brain is this more important than in the areas processing motion (Hupe, et al., 1998).

If motion processing, and more specifically the reentrant processing within higher and lower visual areas, determine the phenomenon of MIB then it is no surprise that both local and global influences in MIB have been revealed. Experiments 5-8 showed that the impact of motion on target disappearance appears to be more globally derived. These results may be explained in terms of other phenomenon showing an interruption of reentrant processing when objects are suppressed from visual awareness (Fahrenfort, Scholte, & Lamme, 2007). Moreover, an increase in incoherent motion produces long-range neural inhibition that can decrease the overall motion processing signals feeding into higher motion processing areas (Chappell, 2007). Coupled with the knowledge that motion processing in one area can have a profound effect on spatially remote locations (Seanz et al., 2002; Boynton, Ciaramitaro, Arman, 2006), it is not surprising that motion far removed from the target can significantly affect target disappearance. These claims can be easily confirmed using the technique of the DMAE describe in Experiment 9. Specifically, attention could be directed to one column versus the other and the resultant MIB measured. It is possible that the amount of motion processing (or attention) would affect disappearance, independent of spatial location.

Finally, in Experiment 9, the case was made even stronger for the direct influence of motion processing on MIB. A coherent mask was shown to generate variable amounts of MIB and these were associated with comparable amounts of MIB. Therefore, the amount of motion processing resources dedicated to the mask coincided with an increase in target disappearance.

To summarize, the research presented in this dissertation help answer a number of questions that may ultimately lead to an understanding of the mechanism(s) that prompt the disappearance of a salient object during MIB. In particular, I put forth the possibility that the mechanisms instrumental in processing the mask take precedence over the mechanism devoted to the target.

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APPENDIX A—IRB FORM 2009

University of New Hampshire
Institutional Review Board for the Protection of Human Subjects in Research
Departmental Review Committee Exemption Classification Sheet

Name: **Erika Wells** **IRB #:** [illegible]
Dept: **Psychology** **Reviewer:**
Study: **Motion-induced blindness**

Exempt Review

46.101(b)(1) ______ Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as:
(i) research on regular or special educational instructional strategies, or
(ii) research on the effectiveness of or comparison among instructional techniques, curricula, or classroom management methods.

46.101(b)(2) __X__ Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior unless:
(i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and
(ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to subjects' financial standing, employability, or reputation.

46.101(b)(3) ______ Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior that is not exempt under category (b)(2) if:
(i) the human subjects are elected or appointed public officials or candidates for public office; or
(ii) federal statute(s) require(s) without exception that confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

46.101(b)(4) ______ Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

46.101(b)(5) ______ Research and demonstration projects which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.

46.101(b)(6) ______ Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the Food and Drug Administration, or approved by the Environmental Protection Agency, or the Food Safety and Inspection Service of the U.S. Department of Agriculture.

__✓__ **Protocol is approved as presented in the category checked**
______ **Protocol is approved with the following contingencies/comments (attach sheets if necessary)**
______ **Protocol is referred to the IRB for Expedited or Full Board review**
______ **Protocol cannot be approved as presented (cite reasons on separate sheet)**

DRC Reviewer: ______________________ **Date:** 9/9/07

APPENDIX B—IRB FORM 2010

University of New Hampshire
Institutional Review Board for the Protection of Human Subjects in Research
Departmental Review Committee Exemption Classification Sheet

Name: **Erika Wells** **IRB #**B-110901C
Dept: **Psychology** **Reviewer:** Ed Lemay
Study: **Assessment of Mask Parameters in Motion-induced Blindness**

Exempt Review

46.101(b)(1) ____ Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as:
(i) research on regular or special educational instructional strategies, or
(ii) research on the effectiveness of or comparison among instructional techniques, curricula, or classroom management methods.

46.101(b)(2) ✓ Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior unless:
(i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and
(ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to subjects' financial standing, employability, or reputation.

46.101(b)(3) ____ Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior that is not exempt under category (b)(2) if:
(i) the human subjects are elected or appointed public officials or candidates for public office; or
(ii) federal statute(s) require(s) without exception that confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

46.101(b)(4) ____ Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

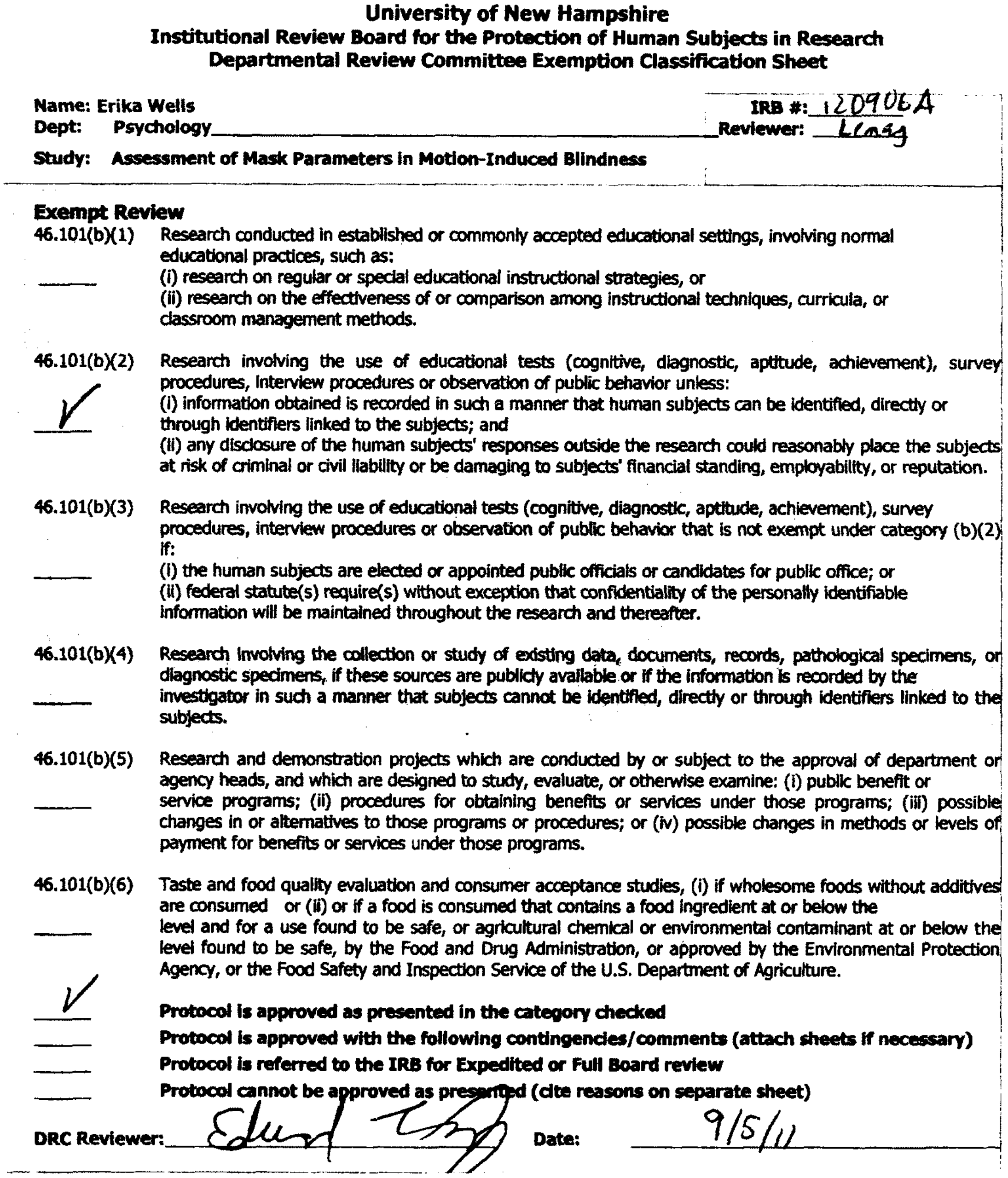
46.101(b)(5) ____ Research and demonstration projects which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.

46.101(b)(6) ____ Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed or (ii) or if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the Food and Drug Administration, or approved by the Environmental Protection Agency, or the Food Safety and Inspection Service of the U.S. Department of Agriculture.

✓ **Protocol is approved as presented in the category checked**
____ **Protocol is approved with the following contingencies/comments (attach sheets if necessary)**
____ **Protocol is referred to the IRB for Expedited or Full Board review**
____ **Protocol cannot be approved as presented (cite reasons on separate sheet)**

DRC Reviewer: ________ **Date:** 9/2/10

APPENDIX C—IRB FORM 2011



University of New Hampshire
Institutional Review Board for the Protection of Human Subjects in Research
Departmental Review Committee Exemption Classification Sheet

Name: Erika Wells
IRB #: 120906A
Dept: Psychology
Reviewer: Lcnsg
Study: **Assessment of Mask Parameters in Motion-Induced Blindness**

Exempt Review

46.101(b)(1) _____ Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as:
(i) research on regular or special educational instructional strategies, or
(ii) research on the effectiveness of or comparison among instructional techniques, curricula, or classroom management methods.

46.101(b)(2) ✓ Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior unless:
(i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and
(ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to subjects' financial standing, employability, or reputation.

46.101(b)(3) _____ Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior that is not exempt under category (b)(2) if:
(i) the human subjects are elected or appointed public officials or candidates for public office; or
(ii) federal statute(s) require(s) without exception that confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

46.101(b)(4) _____ Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

46.101(b)(5) _____ Research and demonstration projects which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.

46.101(b)(6) _____ Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed or (ii) or if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the Food and Drug Administration, or approved by the Environmental Protection Agency, or the Food Safety and Inspection Service of the U.S. Department of Agriculture.

✓ **Protocol is approved as presented in the category checked**
_____ **Protocol is approved with the following contingencies/comments (attach sheets if necessary)**
_____ **Protocol is referred to the IRB for Expedited or Full Board review**
_____ **Protocol cannot be approved as presented (cite reasons on separate sheet)**

DRC Reviewer: _____ **Date:** 9/5/11