

REPRESENTATIONS OF VISUAL MOTION INFORMATION:  
INTERPRETATION OF BACKGROUND VISUAL MOTION IN THE MOTION-INDUCED  
BLINDNESS PHENOMENON

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## **ABSTRACT**

This thesis investigates different interpretations of visual background motion with regards to the visual awareness of objects. Motion-induced blindness (MIB) is a phenomenon in which stimuli superimposed on a moving background spontaneously disappear. Does MIB depend on how background motion is interpreted? York University's Tumbling Room is a full-size room that rotates around an observer. Within this room, the disappearance of static targets (MIB) was measured under two interpretations of background motion: 1) perceived self-motion 2) external motion. The speed of the room, eccentricity of targets, and physical self-motion were also manipulated. Visual background motion that induced the sensation of self-motion, regardless of whether it was illusory or physical rotation —unlike when background motion was perceived as external — did not generate MIB. I conclude that MIB depends on the way the brain processes visual motion information.

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# 1. Introduction

This thesis addresses the consequences of how visual motion is processed in the brain. I look at the effect of background visual motion and its effect on other aspects of vision. Is there a fundamental difference in the processing of full-field visual motion (evoked by self-motion) compared to the processing of other types of movement?

## 1.1. Motion perception

The environment is full of people, objects and structures and it is our interactions with these that guide our actions and shape our behaviours within the world. Any changes in our interactions, movements or representations, provide an abundance of new information that may alter the way we interact with the world. The brain uses visual information to create a percept about motion. Self-motion perception is typically generated from large amounts of visual information that comes in the form of optic flow. Optic flow, a distinctive visual pattern of motion created by a moving observer, provides rich information about the relative motion between the observer and their environment (Gibson, 1950, 1954, 1966).

### 1.1.1. *Interpretations of visual motion.*

Motion in a visual scene can be interpreted as corresponding to two separate sources of motion perception: 1) objects within the world moving relative to the observer (external motion) or 2) the observer (or at least their eye) moving relative to the world (self-motion). These motion perceptions are not biologically equivalent in nature: the importance of optic flow in the sense of self-motion estimation allows for the control of heading and visual navigation, whereas external motion allows us to catch a ball or predict where a moving animal is going. The detection of self-motion is biologically embedded

early in human development (Gilmore, Hou, Pettet, & Norcia, 2007) and uses specialized areas of the brain in its processing (see below).

### **1.1.2. *What makes visual self-motion cues distinct from other visual motion?***

#### **1.1.2.1. *Retinal stimulation.***

Of course, there are large characteristics that distinguish self-motion from external motion. A big (visual) clue is that when the motion is caused by self-motion the whole image moves in a geometrically consistent way whereas external motion is typically local (Gibson, 1954). According to the peripheral dominance hypothesis, during self-motion this visual pattern or flow of images across the retina will extend into the visual periphery: in contrast objects moving externally move against a stationary background. Therefore, perceived self-motion and body orientation in space may rely mainly on coherent peripheral retinal information consistent with self-motion (Brandt, Dichgans, & Koenig, 1973). However, this concept is now outdated and studies have found that central vision also produces compelling illusions of self-motion (Andersen & Braunstein, 1985; Warren & Kurtz, 1992). Illusory self-motion, also known asvection, can be created artificially in a lab by moving large parts of the visual field consistent with the optic flow generated during real self-motion. Again, an exception to the peripheral dominance hypothesis is when a small area of retinal stimulation produces a sensation of self-motion such as when you look through an airplane window and have a strong feeling ofvection. In this instance, the immediate surrounding is static while a small area of one's field-of-view in which motion is seen provides information about the further-away part of the scene: if this is moving – independent of whether central or peripheral retina are involved, it produces a strong sensation ofvection. This is because the view seen through the window is perceived as furthest away and therefore is taken as representing the stable world (Howard & Heckmann, 1989).



### **1.1.2.2. *Depth and interaction between the foreground and background of a moving pattern***

Vection experiences are evoked when external visual motion is interpreted as being caused by one's own movement. The background of a visual scene is that part of the scene that is furthest away (Howard & Heckmann, 1989). A more compelling experience of vection can be produced by adding 3-dimensional elements to the visual flow, for instance, making the radial flow appear more 3D, by adding stereoscopic depth cues leads to increased vection durations (Andersen & Braunstein, 1985; Palmisano, 1996, 2002). Motion arising in the furthest-away part of a scene generally comes from features that are not able to move themselves, such as the walls of a room, mountains or fields. Often these features fall in the peripheral field and this confusion has led to the "periphery dominance hypothesis". Yet several studies have demonstrated interaction between the foreground and background plays a role in perceived vection. A moving pattern perceived in the background behind a static foreground plays a greater influence on the direction, velocity, and latency of circularvection (the illusion of self-rotation: CV) compared to a moving foreground in front of a static background (Brandt, Wist, & Dichgans, 1975; Dichgans & Brandt, 1978; Howard, 1982; Howard & Heckmann, 1989; Ohmi & Howard, 1988; Ohmi, Howard, & Landolt, 1987).

### **1.1.2.3. *Field-of-view (FOV)***

Whether motion is interpreted as resulting from self-movement or external background-movement partially depends on the field-of-view (Held, Dichgans, & Bauer, 1975). In a study by Allison and colleagues, the effect of field-size (20, 50, 80, 100 degrees and full field) on illusory self-tilt and perceived self-motion was investigated. In a Tumbling Room, individuals remained stationary while the room was rotated around the roll axis. Individuals distinguished between when they felt only the room was moving and when they felt like they were moving in which case they reported the degree of body

tilt sensation (0-360 degrees) and their perceived self-motion (vection on a 7-point scale). The majority of individuals reported greater self-motion and increased body tilt with increasing field-of-view size (Allison, Howard, & Zacher, 1999). Therefore, the vection experience can be manipulated experimentally by varying the size of the field-of-view while keeping other factors, such as perceived distance to the background, constant (Howard & Heckmann, 1989).

#### **1.1.2.4. *Multisensory Integration***

Unlike visually detected external motion, the sensation of self-motion is normally associated with the integration of several sensory inputs from the visual, vestibular, somatosensory and proprioceptive systems, which generally reduce the ambiguity of visual motion. The vestibular system comprises a set of sensory organs in the inner ear that detect angular and linear accelerations of the head and provides information about self-movement (Mayne, 1974). The somatosensory system can sense air flow or an individual's body motion from pressure cues and shear relative to supporting surface (Lackner, 1992). Proprioception (knowledge of the position and movements of body parts) also provides information about self-motion through the perception and knowledge of where one's body is situated in space and the movements of the limbs (Hlavacka, Mergner, & Bolha, 1996). As these sensory inputs are combined together, they create the sensation of self-motion. Activity in these non-visual sensory systems can enhance or diminish the feeling of self-motion (Harris, Jenkin, & Zikovitz, 2000).

### **1.2. Neural correlates and visual motion perception**

A large amount of work discussing visual motion processing describes how neural cortical structures (e.g., middle temporal visual area, MT or V5) are involved in processing motion information. Despite area MT being assigned as the main cortical structure for motion processing, it shares many interconnections with other regions of the cortex that are implicated in selective types of motion. The

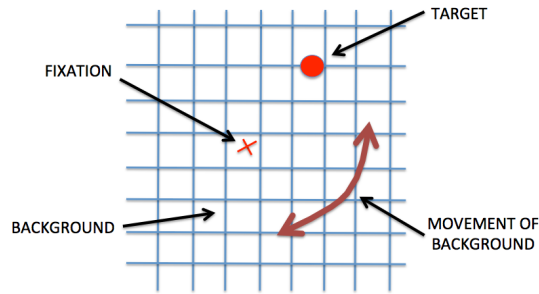
superior temporal sulcus (STS), for instance, plays a significant role in biological motion perception (the motion of animals and people (Johansson, 1973)), whereas the medial superior temporal (MST) and the ventral intraparietal (VIP) areas are fundamental in processing optic flow (for review see Born & Bradley, 2005; Britten, 2008).

Since large-field optic flow is highly affiliated with the perception of self-motion, many studies have investigated specifically the dorsal stream of the medial superior temporal (MSTd) cortex in the context of self-motion (Duffy & Wurtz, 1991a, 1991b, 1993). These visual areas, specifically the MSTd area, are sensitive to optic flow and are also tuned to vestibular signals (Duffy, 1998; Gu, Angelaki, & Deangelis, 2008; Page & Duffy, 2003). This overall, is in agreement with the idea that self-motion is a multisensory experience.

In summary, the sensation of visually induced self-motion (vection) largely depends on background motion and a large area of coherent stimulation. Under natural conditions, optic flow is combined with other sensory information (multisensory integration that binds the senses together) to provide an effective sensation of self-motion.

### **1.3. Motion-Induced Blindness**

Motion-induced blindness (MIB) is a phenomenon in which there is a spontaneous perceptual disappearance of constant visual stimuli when they are presented against a moving background (Bonneh, Cooperman, & Sagi, 2001). An example is shown in figure 1. If an observer fixates on the fixation cross but pays attention to a target a little way from fixation then, when the background moves behind the stationary fixation and target, the target will appear to dramatically disappear.



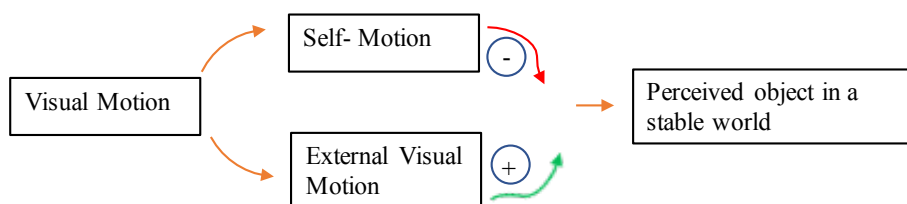
*Figure 1 A classic Motion-Induced Blindness (MIB) Display. Observers fixate at a fixation point while the large crossed-pattern background rotates behind a static target. The static target is seen to disappear as the background moves. A movie version of this stimulus can be found at <https://www.youtube.com/watch?v=Hfrb94mKCJw>*

These fluctuations of visual awareness during continuously presented stimuli have rendered the MIB a practical phenomenon for investigating underlying mechanisms of visual perception. Previous research has focused on features such as size, contrast, luminance and eccentricity of the disappearing target to understand the characteristic of the targets that make them more or less likely to disappear, but little work has considered the characteristics of the moving background. As mentioned earlier, sometimes visual background motion is due to the motion of a patch of external movement caused by when objects or large things move in our environment, but more typically, background motion in the natural world is caused by our own self-motion (Pack & Mingolla, 1998). Given that the MIB phenomenon is contingent on the motion background (Bonneh et al., 2001; Hsu, Kramer, & Yeh, 2010; Lages, Adams, & Graf, 2009; Wallis & Arnold, 2008), it is important to investigate MIB under natural real world scenarios. In reality, our environment is not limited to a computer screen with a restricted size of moving background. Under real world conditions of background motion (i.e., self-motion) does MIB occur? Close objects seen a little way off from fixation while moving should set up conditions comparable to those shown in figure 1. For example, the edges of the car windscreen while driving, or the edges of one's glasses while walking, would be fairly retinally stable and appear in front of a moving background provided by the

viewer's movement. Perhaps such objects do disappear when we move and we are just unaware of their disappearance.

#### 1.4. Statement of problem

Perceiving the moving backgrounds created by our movements is certainly not consistent with our everyday experience of looking around the world as we move around – but then we are notoriously unaware of what our sensory systems are telling us. For example, people do not appear to change size as their retinal images change size dramatically, we are unaware of changes in luminance of many orders of magnitude as we go from outside to inside illumination, and we are unaware of the almost constant smear of optic flow over the retina as we move our bodies and eyes. When a person moves through their environment the visual information created by the self-motion is interpreted differently from externally created motion such that the self-motion-generated information enables an individual to navigate and orient themselves in space (Gibson, 1954). As far as perception is concerned, this self-motion generated visual information appears to be largely removed from the perceptual pathway, leaving only motion that arises from external motion to be visible to an observer, as indicated in the simple model shown in figure 2. Thus, I expect that the visual background motion created by self-motion will not induce a MIB phenomenon because it is not part of the perceptual experience.



*Figure 2 Relationship between perceived objects in real world and the interpretations of visual motion. Visual motion is parsed into originating from either self-motion (top channel) or external visual motion (bottom channel). Visual motion perceived as resulting from self-motion is then removed (-) from perception resulting in the perception of objects in a stable world. Visual motion interpreted as external motion is of course part of the perceived world.*

#### **1.4.1. *Self-motion: real and illusory***

Different interpretations of visual background motion may produce different amounts of MIB: visually induced self-motion (vection) and actual physical self-motion may also have different effects on MIB (even though the optic flow in both cases is the same). I hypothesize that the occurrence of MIB will be reduced if the background motion evokes vection and will be even less when a person is physically moving, in which case multiple sensory cues will be available to tell them about their movement. The difference between actual self-motion and illusory self-motion (vection) is the additional sensory cues—the self-motion is no longer illusory. Furthermore, I hypothesize that, even without peripheral visual motion, MIB will be reduced or abolished when background motion is caused by physical motion of the participant. During illusory self-motion, the visual cues are consistent with but may not be as powerful as extra-retinal cues from vestibular stimulation created during actual self-movement (Brandt et al., 1973). In the illusory self-motion condition, these additional sensory systems provide signals that are incongruent with the visual motion information – the vestibular system will correctly signal that the observer is stationary. But during physical motion, the extra feedback provided by all sensory systems will provide an unambiguous context for interpreting the background motion as being caused by self-motion independent of the size of the field of view.

#### **1.4.2. *MIB and higher-level visual processes***

Several studies have argued that the MIB visual illusion functions at a high cognitive level in the visual system (Funk & Pettigrew, 2003; Graf, Adams, & Lages, 2002; Hsieh & Tse, 2009; Sterzer, Kleinschmidt, & Rees, 2009). Examples of high-level factors on MIB include attentional competition between the target foreground and motion background (e.g., binocular rivalry) (Graf et al., 2002), as well as obeying gestalt principles such as grouping, proximity and masking effects (Bonneh et al., 2001; Hsu et al., 2010; Hsu, Yeh, & Kramer, 2004; Mitroff & Scholl, 2005).

Bonneh and colleagues evaluated the MIB phenomenon under different perceptual grouping effects. They found that MIB was subject to changes in contour smoothness, proximity and object competition. For smooth contours, MIB occurred less frequently when the contour of the object appeared more as a “whole” (e.g., a circle) compared to objects that appeared to be less connected or continuous (e.g., a circle with disconnecting lines/dots). Similarly, objects that appear closer together (therefore more likely to be grouped as a whole) disappeared less frequently than targets that were individually placed. According to these authors, mechanisms behind the illusion are reflected by shifts in attention allocated to either the moving background or to the static foreground, stimulating a winner-take-all mode. Overall, there are behavioural indicators suggesting that the visual processes underlying the MIB phenomenon occur at higher levels in the brain.

Although no consensus has been reached regarding the mechanisms driving MIB, some factors such as the saliency of the targets (e.g., high contrast) tend to increase rather decrease MIB (more easily seen targets are more likely to disappear), thus precluding the idea of inattention to static targets as an underlying cause (Bonneh et al., 2001; Geng, Song, Li, Xu, & Zhu, 2007; Hsu et al., 2004; Schölvinc & Rees, 2009). Furthermore, others have shown that fluctuations in visual awareness in MIB occur without attention (Dieter, Tadin, & Pearson, 2015) and that the periods of invisibility corresponds to a drop in sensory sensitivity (Caetta, Gorea, & Bonneh, 2007).

Many neuroimaging studies support high-level activation during MIB. Donner and colleagues (2008) showed that target- and motion-background-specific neural responses lead to activation in separate regions of the visual cortex. They measured neural activity with functional magnetic resonance imaging (fMRI) linked to reports of disappearance and reappearance of targets during MIB. They recorded neural responses during MIB and isolated target-specific and mask-specific (motion-background) neural

responses. As the salient targets perceptually disappeared, responses in Area V4 (the ventral stream of the visual cortex) decreased, and as targets reappeared responses increased. When mask-specific responses were recorded and target-specific activity was subtracted, they found large activation in the dorsal areas of the visual cortex including the medial temporal (MT), the medial superior temporal area (MST), and V3, V7 and the posterior intraparietal temporal sulcus (pIPS). Neural activation in these areas increased as targets disappeared and decreased as they reappeared (Donner, Sagi, Bonneh, & Heeger, 2008).

As outlined in the subsequent section, there are many studies supporting the involvement of later stages of visual processing, while other findings suggest that low-level influences on MIB, (Libedinsky & Livingstone, 2011; Libedinsky, Savage, & Livingstone, 2009; Schölvinnck & Rees, 2010).

### **1.5. Factors affecting motion background and MIB**

In MIB, salient stimuli may disappear as a function of changes to not only high-level components but low-level sensory ones as well. The amount of disappearance induced by background motion depends on several low-level factors, including contrast, eccentricity, background speed, and type of background motion. Manipulating some of these properties will enable me to compare the effects reported from previous studies to the outcomes in the present experiments.

#### **1.5.1. Eccentricity**

Some studies have showed that MIB increases (objects are more likely to disappear) with increasing eccentricity (Hsu, Yeh, & Kramer, 2004, 2006) whereas others suggest that varying eccentricity is a weak technique for eliminating the static stimuli from visual awareness (Kim & Blake, 2005). Hsu and colleagues used initial fading times as an indicator of the strength of MIB: shorter initial fading times indicated stronger MIB. They investigated eccentricities at 1.2°, 2.4°, and 4.8° and found that the initial



reported time of target disappearance decreased with increasing eccentricities (Hsu et al., 2004), i.e., MIB strength increased with increasing eccentricity.

An explanation for increased disappearance at larger eccentricities may be that the size of the static stimuli was not adjusted to account for the cortical magnification factor, which states that if the size of a visual stimulus is kept constant it will occupy less and less cortical area: sensitivity and visibility therefore decrease in more peripheral locations of the visual field (Anstis, 1996). Previous studies investigating MIB have not adjusted stimulus size at different eccentricities. Stronger MIB in the periphery may therefore be due in part to lower detectability in the periphery. I predict that MIB will be greater when the targets are at further eccentricities beyond  $4.8^\circ$  (which has yet to be investigated) compared to closer eccentricities ( $\sim 2.8^\circ$ , that are within the range of previous studied eccentricities), especially when the background motion is interpreted as external background motion compared to being perceived as resulting from self-motion.

### **1.5.2. *Effect of properties of background motion***

#### ***Type of motion***

Past studies report that the speed and type of motion (specifically 2D or 3D) of the background affect the disappearance rate of salient stimuli. A 3-dimensional rotating background (presented using only monocular cues) has a greater effect on making stationary stimuli disappear than a 2-dimensional translational background (Bonneh et al., 2001). Another factor affecting the disappearance of the static stimuli is the depth relationship between the static targets and the moving grid pattern. Graf and colleagues found using a stereoscopic display that when the moving grid was presented in front of the targets, participants reported much more disappearance compared to when the moving grid was in the same depth plane or behind the static targets (Graf et al., 2002; Lages et al., 2009). Other properties of

the moving mask, including the coherence of the motion have an effect (Wells, Leber, & Sparrow, 2011).

In this thesis I will test the hypothesis that the motion of a large background (that should provide more motion cues) will increase the occurrence of MIB. I will keep the targets and their immediate background at the same distance from the observer. The three-dimensional nature of motion created by motion of a three-dimensional environment might also be expected from studies using three-dimensional background movement (Bonneh et al., 2001) to create strong MIB.

### ***Speed of background motion***

Similar to the effect of increasing eccentricity, increasing speed also increases MIB (e.g.,  $6^\circ \text{ s}^{-1}$  compared to  $1^\circ \text{ s}^{-1}$ ) (Bonneh et al., 2001; Wallis & Arnold, 2008). I hypothesise that even while using a large field of background motion the effects of speed ( $36^\circ/\text{s}$  vs  $6^\circ/\text{s}$ ) will be consistent with previous studies (i.e., faster will be more effective and produce stronger MIB).

### **1.5.3. Troxler Fading**

While the MIB phenomenon is an example of the visual suppression of a constant stimulus, a similar disappearance can occur simply as an effect of prolonged steady fixation. This is known as Troxler fading and is thought to be the result of retinal adaptation (Troxler, 1804). Although MIB and Troxler fading share similar superficially similar their mechanisms are clearly different. MIB can occur with very brief observation periods and is postulated to be governed by high-level mechanisms related to the interaction between the target and background mask (Bonneh, Donner, Cooperman, Heeger, & Sagi, 2014) whereas Troxler fading is largely a low-level effect occurring at the level of the retina (Bonneh et al., 2014). Bonneh and colleagues suggest that MIB is disappearance above and beyond the

disappearance one would expect without visual background motion, as it continually persists even if the target is slowly moving or flickering over a moving background, thus preventing retinal adaptation which is the principle cause of Troxler fading (Bonneh et al., 2001).

Also, comparisons between patterns of perceptual disappearance during MIB are correlated with perceptual oscillations in binocular rivalry (Carter & Pettigrew, 2003). The rate of alternating perceptual rivalry between horizontal and vertical lines presented in corresponding left or right eyes was positively correlated to the fluctuations in disappearance and reappearance observed during MIB suggesting shared timing mechanisms between the two phenomena. Furthermore, a second experiment that involved replacing the targets from the MIB phenomenon with a two adjacent orthogonal or collinear Gabor patches. Gabor stimuli presented orthogonally corresponded to greater disappearance intervals than when the stimuli that was presented collinearly placing an emphasis on saliency and greater MIB effect (Carter & Pettigrew, 2003).

Similarly, others have extended this concept of perceptual suppression and looked at the dynamics of visible and invisible periods of MIB via the continuous flash suppression (CFS) method. The CFS method strategically suppresses static stimuli in one eye when presented with dynamic stimuli in the other, to provide a measure of saliency of the static target. Dieter and colleagues presented the MIB stimulus in one eye, and the CFS stimulus in the other eye to investigate whether MIB could be disrupted by CFS which would indicate that the fluctuations in visibility are inherent to the stimulus strength. They measured reaction times of the reappearance of the static yellow targets from the classic MIB after the removal of CFS stimulus. MIB occurs beyond perceptual suppression therefore dismissing arguments that the MIB phenomenon results from local retinal mechanisms (Dieter et al., 2015).

In other support that the MIB is not just an example of Troxler fading, Lages and colleagues exploited the disappearance of static targets after prolonged adaptation to a moving pattern that later elicits a motion-after-effect. They found that a motion-after-effect also evokes MIB, especially when the targets are presented stereoscopically beyond the moving patterned grid (Lages et al., 2009). Nevertheless, while this topic may still be debated, whenever we are looking at target disappearance Troxler fading needs to be considered (although many previous studies fail to consider the contribution of Troxler fading (e.g., (Bonneh et al., 2001; Mitroff & Scholl, 2005)). I will take Troxler fading into account in the data reported in this thesis by comparing MIB with the rate of disappearance of constant stimuli viewed against a static background.

## **1.6. STATEMENT OF HYPOTHESES**

Hypothesis 1: I hypothesize that visual motion that is interpreted as external background motion will produce greater MIB compared to a moving background that is interpreted as resulting from self-motion even though the visual motion in the central field (the part of the moving background that is adjacent to the target stimuli) is identical in both cases.

Hypothesis 2: I hypothesize that MIB will be greater at faster speeds ( $36^\circ/\text{s}$  vs  $6^\circ/\text{s}$ ) and larger eccentricities ( $5.7^\circ$  vs  $2.8^\circ$ ) when the background motion is interpreted as external but there will be no differences in MIB when the background motion is perceived as resulting from self-motion as I predict that the motion background will no longer evoke MIB.

Hypothesis 3: I hypothesize MIB will be greater (although attenuated relative to the external background motion condition) when a person is experiencing vision-only illusory self-motion compared to when they are physically moving.

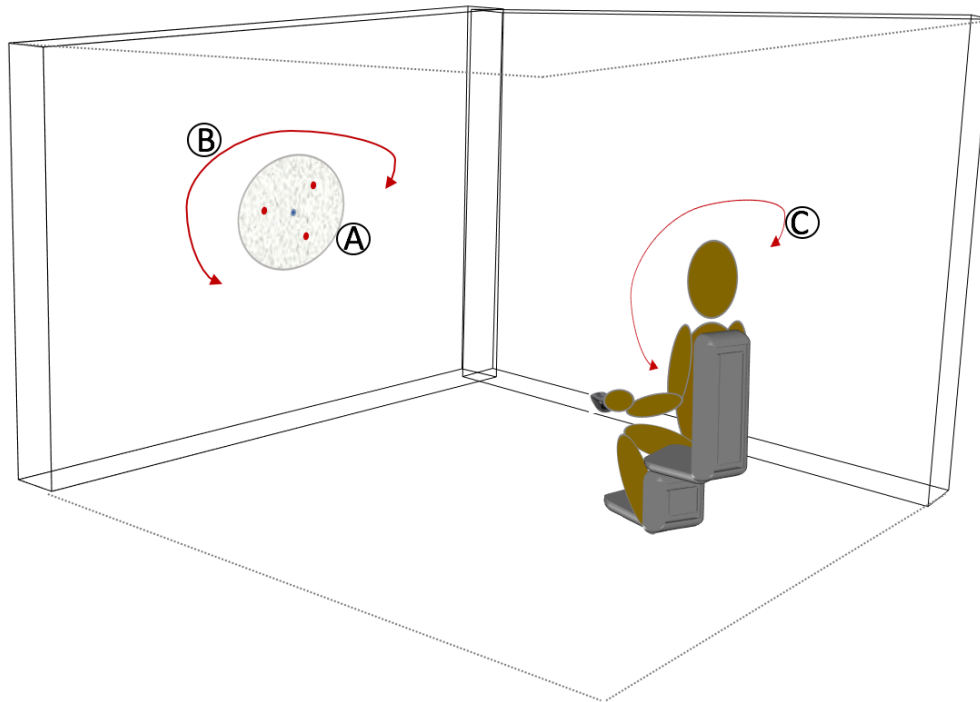
Hypothesis 4: I hypothesize that MIB will be independent of field-of-view size during physical self-motion because the extra-retinal properties experienced during physical self-motion is the same regardless of field-of-view size.

## **2. General Methodology**

### **2.1. Apparatus and Stimuli**

#### **2.1.1. *The Tumbling Room:***

In order to create a large source of global motion that can be perceived as self-motion the experiments took place in York University's Tumbling Rooms. The first experiment took place in the original York University Ian Howard Tumbling Room, an 8' x 8' x 8' fully furnished room that is able to rotate around the observer. This Tumbling Room has now been decommissioned and replaced with a 8.5' x 9.8' x 8.5' room, which is not as yet furnished but which contains many clear indications of polarity – such as a window, carpet, polarized wall paper, wall lights and a chair rail, in which the second and third experiments were conducted. While the Ian Howard Tumbling Room was operated manually, the new Tumbling Room is computer controlled using software provided by Dymech Engineering Inc. installed onto a Windows 8 desktop. The custom software was constructed using LabView. Within either room, a built-in chair can spin an individual around the same axis of rotation as the room. This is shown diagrammatically in figure 3. Figure 4 shows photographs of the interior of the new Tumbling Room.



*Figure 3 Schematic of York University's Tumbling Room. The room can rotate around the naso-occipital axis of the person. My set-up includes one to three laser targets (red dots) and a fixation laser (blue dot) superimposed on a circular textured surface, which is attached to the room (A). The room can be moved relative to the person (B) or the person can be moved relative to the room (C). The lasers are attached to the chair in which the subject sits and therefore the dots are always stationary relative to the observer.*

a) Naso-occipital rotation of Tumbling Room



b) Naso-occipital rotation of built-in Tumbling Room Chair



*Figure 4 Image of naso-occipital rotations inside New Tumbling Room. a) Illustrates individual seated stationary in a chair while the room rotates around the person. b) Stills of person moving in the same axis of rotation as the moving room: here the room is fixed.*

### **2.1.2. Motion**

The optic flow generated by movement of the Tumbling Room gives a powerful and compelling feeling of self-motion around the naso-occipital axis (roll) (Figure 4a). The newly-built room can rotate between 0-60°/second both clockwise and counter-clockwise by means of a computer controlled servomotor (Dymech Engineering Inc. software). The direction of rotation (clockwise or counter-clockwise) does not significantly alter the effectiveness of this self-movement illusion (Howard & Childerson, 1994). Therefore, I alternated between the two directions in all experiments. Optic flow was generated by

moving the room at constant velocities of between  $6^\circ/\text{second}$  and  $36^\circ/\text{second}$  for durations of 120 or 135 seconds in each data collection session.

### **3. Experiment 1- Interpretations of Visual Background Motion on MIB**

This experiment was designed to test hypothesis 1. The fact that people interpret background motion differently depending on the size of the FOV provides a method to evaluate the relationship between the application of motion cues and visual awareness. I propose that the differences in MIB may be a function of whether background motion is interpreted as resulting from self-motion or from external motion. If MIB, defined as the total duration of perceptual disappearance, were the same across the different background motion conditions, then I could conclude that MIB was independent of the interpretation of the background motion cues. If, however, MIB were larger in the condition where background motion was interpreted as external motion compared to the amount of MIB evoked when the background-motion was interpreted as resulting from self-motion, then I could conclude that the motion used to induce the phenomenon was differently processed.

#### **3.1. Methods**

##### *Participants*

Ten naïve participants (6 female, ages= 23-62, mean = 30.5) completed two parts of the study. The first part consisted of an assessment of their vection experience (illusory vision-induced self-motion) (figure 4a) before proceeding to complete the second part that consisted of reporting the disappearance of the target stimuli under a vection, no vection, and non-motion conditions. All participants had normal or corrected-to-normal vision. The experiment was approved by York University's Ethics Approval Committee. All participants gave their informed consent.

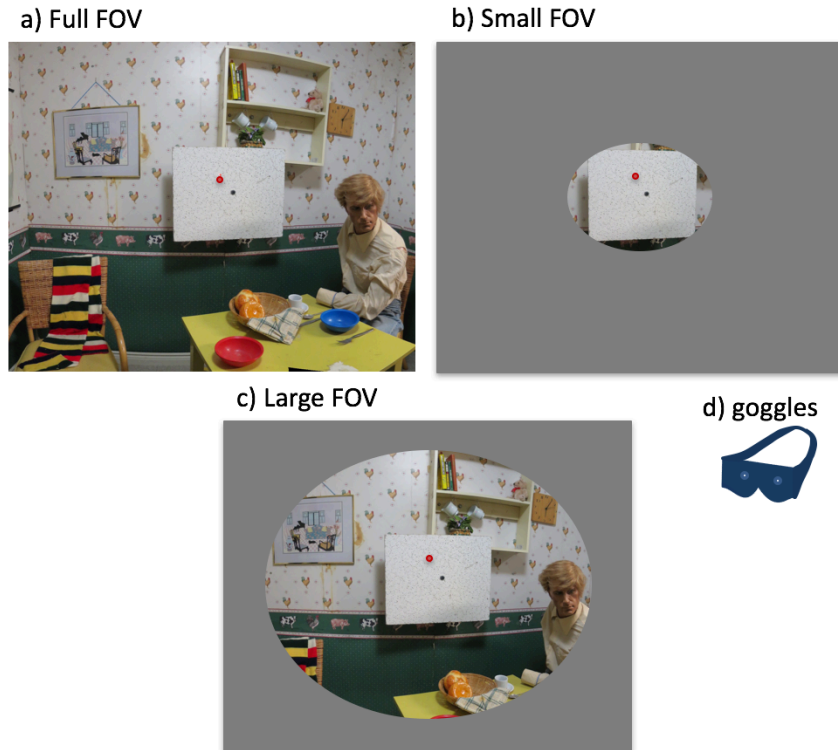


### *Stimulus and Apparatus*

The experiment took place in York University's 8' x 8' x 8' fully furnished Tumbling Room (see general methods). The optic flow generated by rotation of the Tumbling Room was at either 8°/second or 36°/second and presented for a total duration of 135s. The movement of the room was controlled manually: we counted the number of complete rotations made per minute to calculate speed. A slow speed of 8°/second was equivalent to 1 1/3 rotations per minute, and a faster speed of 36°/second corresponded to six revolutions per minute.

#### **3.1.1. FOV**

To create different types of visual motion interpretations and to test the hypothesis as to whether the interpretation of visual background motion had an impact on MIB, three different visual-field conditions were used to elicit different interpretations of the same visual moving background. (1) A full field-of-view (full FOV) where the participant could see an unobstructed view of the furnished Tumbling room (figure 5a). (2) A small field-of-view (small FOV) condition in which the field-of-view is masked-down to approximately  $\pm 14^\circ$  (figure 5b) using goggles (see below). (3) A large field-of view (large FOV) condition in which the field-of-view was masked-down to approximately  $\pm 40^\circ$  (figure 5c) also created using the goggles.



*Figure 5 Different visual fields of the visual background motion. a) the full-FOV, b) the small-FOV c) the large FOV with d) a schematic of the goggles. The edges of the viewing area were not clearly in view as they were determined by the tape on their goggles which was far too close to be in focus.*

### 3.1.2. Goggles

The small and large field-of-view (small FOV, large FOV) conditions were created using a pair of safety goggles covered in opaque electrical tape (figure 5d) that was adjusted for each eye customized for each participant so as to restrict the viewing area to only the appropriate field using feedback from the participant as what they were able to see. Individuals covered one eye while the mask of the other eye was adjusted by the researcher. Participants were instructed to fixate at the center of the display and to inform the experimenter when the tape occluded the participant's surrounding field-of-view up until the border of the display.

### **3.1.3. *Measuring vection***

Since vection experience can be induced by a moving pattern displayed even when viewed through a small window (e.g., looking through a window of an airplane (Howard & Heckmann, 1989) it was necessary to get a measure of each participant's self-motion experience under each FOV. This was done by asking participants to hold down a button whenever they experienced vection. The strength and magnitude of vection was not recorded.

### **3.1.4. *MIB Targets***

A single laser (5mW, 635nm), mounted on the elevated chair built within the Tumbling Room provided a constant target at approximately 4° from the fixation point on a 23" x 18" visually textured rectangular surface (29" diameter, 14° visual angle FOV) (Figure 5) surface. Participants sat 58" from the display. At the center of the textured surface, a black dot provided a fixation point.

## **3.2. Procedure**

*Vection Experience:* Participants sat in the chair built within the Tumbling Room (figures 3 and 4). A lap belt was secured around each participant to help convince them that they might be moving. Participants fixated a black dot at the center of an off-white textured surface. Participants were signaled verbally when the trial began and indicated by pressing and holding down the button of a wireless mouse whenever they felt they were moving (experiencing vection). Vection was defined as the total duration of perceived visually induced self-motion expressed as a percentage of total duration time (135s). Vection experience was measured at all three fields-of-view (small, large, and full- FOVs). 100% of participants reported self-motion during at least part of the trials.

*Target Disappearance (MIB):* In separate trials, participants held down the button of a wireless mouse whenever the laser target dot disappeared. Target disappearance was measured in each FOV condition as

well as a non-motion (static background) condition to control for Troxler fading. Each of the moving conditions was run at two velocities: either 8°/s (slow) or 36°/s (fast) for 135s. MIB was expressed as the total duration of disappearance of the target (lasers) minus the time of Troxler disappearance divided by the total stimulus duration (135s). Participants could press the button anytime from the start of the trial when signalled by the experimenter. The order of conditions was counterbalanced using a balanced Latin Square design and responses were recorded using custom-written MATLAB (R2015) software.

### 3.3. Results

*Vection*: All participants experienced vection in at least the full-FOV condition. A 2X3 repeated-measures ANOVA was conducted to examine the effect of speed (8°/s (slow) or 36°/s (fast)) and FOV (small, large, and full) on the fraction of time that the participant reported experiencing vection. There was a statistically large significant interaction between the effects of speed and FOV on the perception of vection  $F(1.986,17.871)=5.383, p=0.015, \eta^2=0.374$  (figure 6). The analysis also revealed large significant difference in vection experience between the three types of FOV conditions  $F(1.986,17.871)=234.835, p=0.000, \eta^2=0.963$ , but no differences in vection experience between the slow and fast speeds ( $p=0.387, \eta^2=0.084$ ). Pairwise comparisons using Bonferroni corrections found that individuals reported a much longer vection experience during the full FOV and large FOV conditions compared to the small field of view condition ( $p=0.000$ ). There were no differences in the reported duration of vection between the full and the large FOV conditions ( $p=0.062$ ).

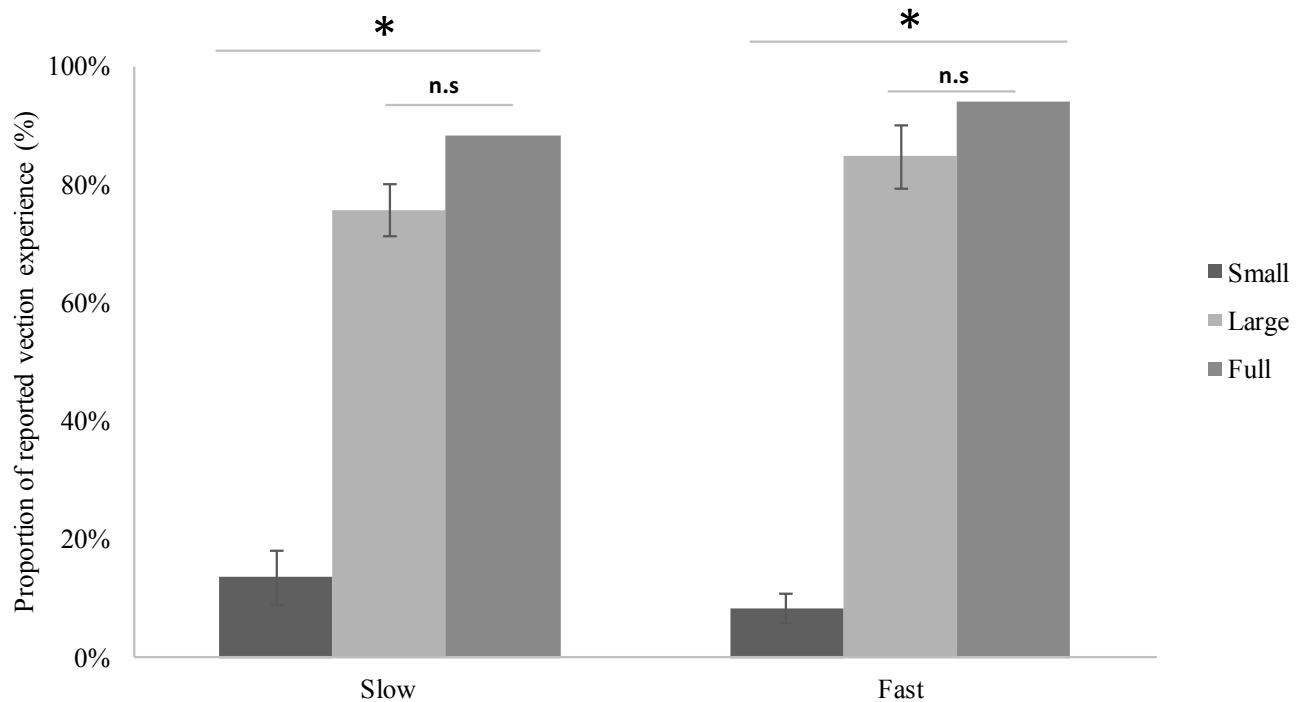
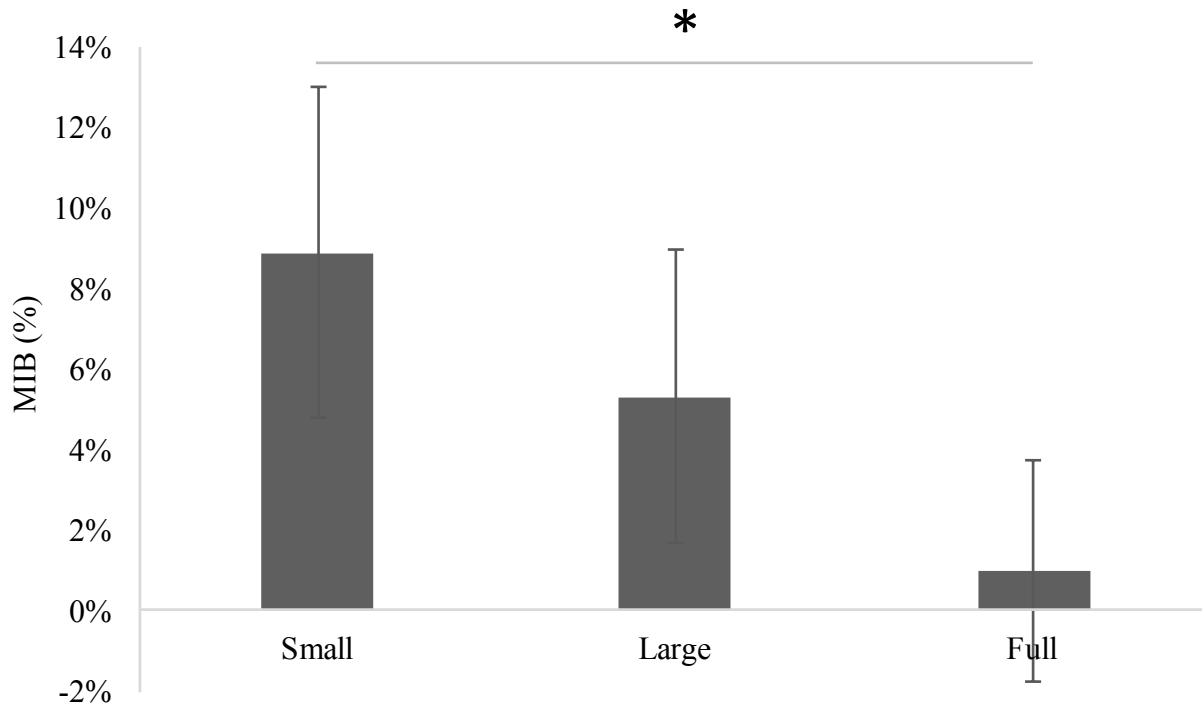


Figure 6 Experiment 1- Percent of vection out of the total duration time (135s) 8°/s (slow) and 36°/s (fast) in each field-of-view (small, large, and full – see legend). Error bars are standard errors of the mean. Asterisks indicate significant differences ( $p < 0.05$ ).

*MIB*: In each condition *MIB* was indicated by the total duration of laser (target) disappearance. *MIB* for each condition was then calculated as the difference between the total duration reported in each FOV motion condition minus the duration of disappearance in the non-motion (Troxler effect) condition. A 2X3 repeated-measures ANOVA was conducted that examined the effect of speed (8°/s (slow) or 36°/s (fast)) and FOV (small, large goggles, full no goggles) on participants' *MIB*. There was a statistically large significant main effect between the FOV conditions  $F(1.642, 14.777) = 5.994$ ,  $p = 0.016$ ,  $\eta^2 = 0.400$  (figure 7). Pairwise comparisons using a Bonferroni corrections to  $\alpha = 0.05$  found that individuals

reported more disappearance during the small FOV compared to the Full FOV condition ( $p=0.049$ ). There were no differences in MIB between the full FOV and large FOV conditions ( $p=0.293$ ), and no differences between large and small FOV( $p=0.206$ ). There were no significant interactions ( $p=0.093$ ) or simple main effects for speed ( $p=0.151$ ) (figure 8).



*Figure 7 Experiment 1-Effect of field-of-view on MIB. MIB as a percentage of the total stimulus disappearance duration (135s) for each of the three-different field-of-view (Small, Large, Full). Data from the different speeds have been collapsed. Error bars are standard errors of the mean. Asterisks indicate significant differences ( $p<0.05$ ).*

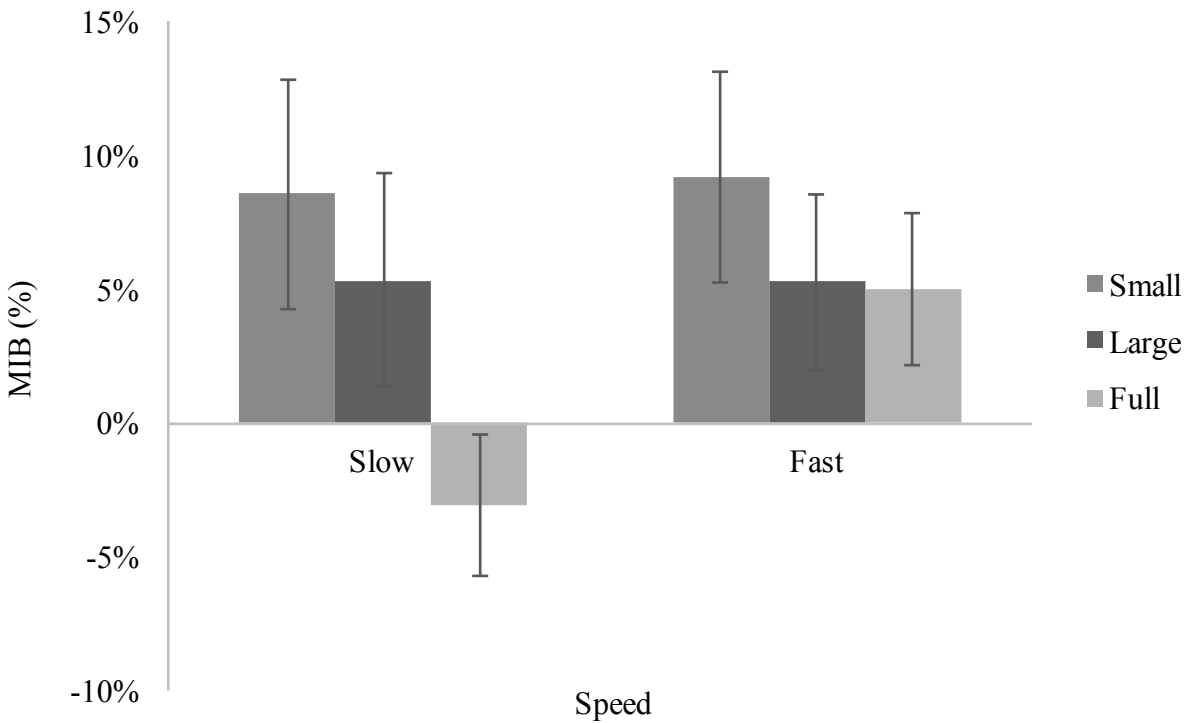


Figure 8 Experiment 1- Effect of speed on MIB. Speed ( $8^{\circ}/s$  (slow) or  $36^{\circ}/s$  (fast)) and FOV (small, large goggles, full no goggles) on participants' MIB. Error bars are standard errors of the mean.

### 3.4. Discussion of Experiment 1

The duration of reported vection experience varied with field-of-view (FOV): individuals perceived themselves to be moving for a much longer duration during the full-field and large-field condition than during the small-field condition. This addresses the nature of the background motion, indicating that the same pattern of local motion (the area immediately surrounding the subject-stationary target) can be interpreted as external motion or as a result of self-motion. After this verification, I could use field-of-view as a predictor of vection and correlate that with MIB: the more the visual motion background was interpreted as self-motion the less MIB individuals reported (figure 6 and 7).

Although there was a directional trend between perceived self-motion and MIB through changes in field-of-view, the effect of the large-field-of-view was not clear. MIB reported in the large-field condition was not significantly different from MIB reported in either the small or full-FOV conditions (figure 7 and 8). The average vection experience in the “large” condition was greater than 76% for which I hypothesised less MIB than for the small field condition. One possible explanation for the large-field data not being significantly different from either the full or small field could be the small sample size. Differences between individuals may have consumed the effect, but overall group tendency of the effect of MIB was significant, therefore perhaps a larger sample size may substantiate the trends visible in figures 7 and 8.

Speed did not seem to play an important role in the disappearance of the target. However, the technical restraints in the Old Tumbling Room, such as being moved by hand, might have resulted in uneven motion and unintended changes in speed; factors that have been shown to affect the classic MIB phenomenon will be investigated more systematically in the New Tumbling Room in Experiment 2 under improved controlled speed settings.

#### **4. Experiment 2- Eccentricity and Speed in the New Tumbling Room**

As reviewed above, MIB has been shown to depend on low-level factors such as background motion speed and eccentricity of the targets. Manipulating these factors enables me to compare the effects reported in previous studies (e.g., Bonnef et al., 2001; Hsu et al., 2004) with the present results. To examine the effects of eccentricity and speed of background motion on MIB, vection and MIB were measured with the targets at two eccentricities and with two speeds of background motion. If the background motion were interpreted as external motion, then it should produce equivalent changes to MIB as in these earlier studies (i.e., MIB should increase with increasing eccentricity and speed),



whereas when motion background was interpreted as self-motion it may not be subject to these target parameter manipulations in the same way.

#### **4.1. Methods**

##### *Participants*

Thirteen naïve participants (7 female, ages= 18-32yrs, mean = 22.8yrs) provided a measure of their overall vection experience and then a measure of MIB during full field viewing, restricted field viewing and no-motion conditions under varying speeds and eccentricities. Nine of the thirteen participants were recruited from York University's Undergraduate Research Participant Pool (URPP) and were rewarded class credit, the remainder were graduate students. All participants had normal or corrected vision and completed consent forms.

##### *Stimuli and Apparatus*

Using similar methods as in Experiment 1, Experiment 2 took place in York University's newly assembled 8.5' x 9.8' x 8.5' but not yet furnished Tumbling Room that is also able to rotate around the observer's naso-occipital axis (roll). To assess the effects of eccentricity, three lasers-targets (5mW, 635nm) were mounted on the built-in chair, positioned at either 2.8° or 5.7° from a central fixation laser and projected onto a 22" diameter circular textured display (7.8° FOV visual angle) (figure 9).

Participants sat 80" from the display. Vection and MIB responses were recorded in both the small-field and the full-field view conditions (see FOV conditions from Experiment 1 methods) at two velocities of background motion (either 6°/s (slow) or 36°/s (fast)) for 120s. The stimulation of movement from the Tumbling Room for both vection and MIB conditions were sequenced using the Dymech Engineering

Inc. custom software on a Windows 8 desktop. Onset of the movement was synched manually by the experimenter to the start of the recording period on a MacBook Pro (Version 10.12.16) computer.



Figure 9 New Tumbling Room Display between different fields-of-view. Display observed through a) the small field-of-view and b) the full field-of-view.

#### 4.2. Procedure

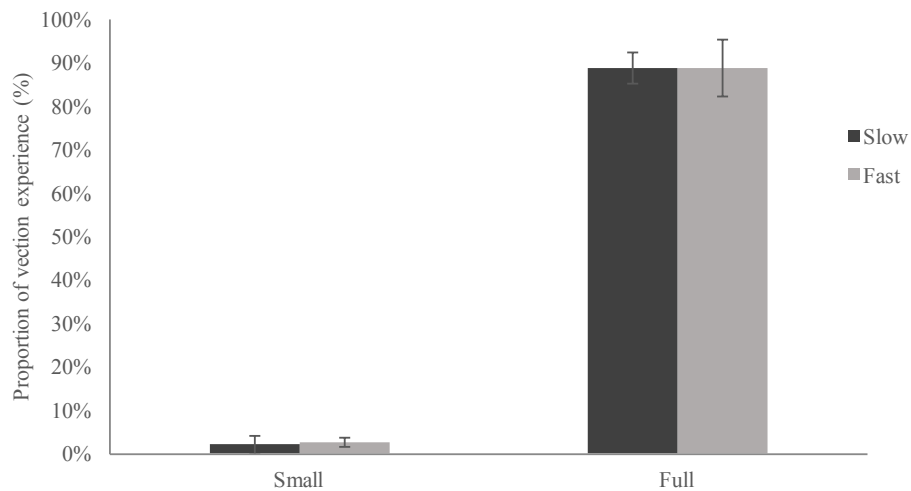
*Vection Experience:* Participants sat in the chair built within the Tumbled Room (Figure 3). As in Experiment 1, participants fixated the laser dot at the center of the textured display. By pressing and holding down a button of a wireless mouse, participants indicated whenever they felt vection as the room rotated. Vection was measured as the total duration of perceived visually induced self-motion expressed as a percentage of the total duration (120s).

*Target Disappearance (MIB):* In separate trials, participants held down the button of a wireless mouse whenever at least one of the three targets disappeared. MIB was measured at two eccentricities:  $2.8^\circ$  and  $5.7^\circ$  from the central fixation laser as well as at two velocities:  $6^\circ/\text{s}$  (slow) and  $36^\circ/\text{s}$  (fast). MIB at each eccentricity and speed was measured in each FOV condition as well as a non-motion (static background)

condition to control for spontaneous disappearance independent of the motion of the room (the Troxler effect). MIB was measured as the total duration of disappearance of any one of the three targets (lasers) minus the Troxler disappearance and expressed as a percentage of the total stimulus duration (120s). Each condition was counterbalanced using a balanced Latin Square design, and responses were recorded using MATLAB (R2015).

### **4.3. Results**

*Vection*: A 2X2 repeated-measures ANOVA was conducted to examine the effect of speed (6°/s (slow) or 36°/s (fast)) and FOV (small, full) on participants' interpretation of background motion as resulting from their own motion (vection). There was a significant difference in the reported vection experience between the FOV conditions  $F(1,9)=370.544, p=0.000, \eta^2=0.976$  (figure 10), with 86% longer vection sensation in the full-field compared to the small-field condition. There were no significant differences in self-motion experience between the two speeds ( $p=0.929, \eta^2=0.01$ ) (figure 10). Three participants reported the same vection experience for the small- and full- FOV and were excluded from the remaining trials. All participants experienced vection in at least the full-FOV condition.



*Figure 10 Experiment 2- Effect of field-of-view on vection experience at varying speeds. Proportion of reported vection experience as a fraction of total duration (120s) across two fields-of-view (small, full) at speeds of 6°/s (slow) and 36°/s (fast). Standard error bars of the mean are shown.*

*MIB:* A 2x2x2 repeated-measures ANOVA was conducted to examine the effect of speed (6°/s (slow) or 36°/s (fast)), and eccentricity (2.8° and 5.7°) among the different FOV (small, full) on participants' perception of constant stimuli disappearance (MIB). There was a significant interaction between the FOV condition (small and full) and the speed (slow vs fast),  $F(1,9)=8.655$ ,  $p=0.016$ ,  $\eta^2=0.490$  (figure 11). Further pairwise comparisons adjustments using Bonferroni correction showed that between the small and full-FOV, there was a significant difference in the fast condition ( $p=0.001$ ), where the mean difference decreased by approximately 22% within the full-FOV condition. Additionally, contrast analysis showed that there were significant differences in speed within only the small-FOV condition ( $p=0.05$ ), where there was approximately 10% increase in MIB at faster speeds (figure 12). There was a statistically significant main effect between the two FOV conditions  $F(1,9)=13.750$ ,  $p=0.005$ ,  $\eta^2=0.604$  (figure 11). There were no simple main effects for speed ( $p=0.471$ ) (figure 11) or eccentricity ( $p=0.694$ ) (figure 12).

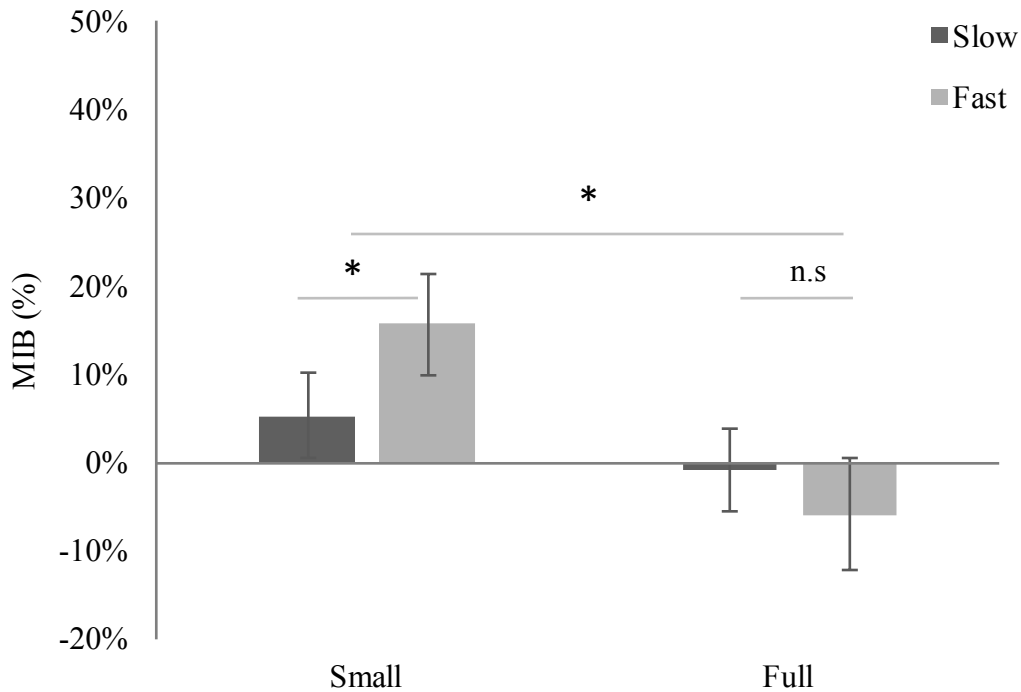


Figure 11 Experiment 2- Effect of speed on MIB under different types of field-of-view. Total duration of MIB (%) in small and full-FOV conditions at speeds of 6°/s (slow) and 36°/s (fast). Asterisks indicate significant differences of  $p < 0.05$ . Error bars are standard errors of the mean.

A second method using a 2x2x2 repeated-measures ANOVA was conducted to examine the effect of eccentricity on MIB. Here, the initial reported time of target disappearance was taken as a measure of the effect of eccentricity on MIB, in order to align with previous studies that measured the initial time of disappearance (Hsu et al., 2004). There was no significant effect  $F(1,9)=0.010$   $p=0.921$ ,  $\eta^2=0.001$  of eccentricity (2.8° and 5.7°) on MIB onset latency.

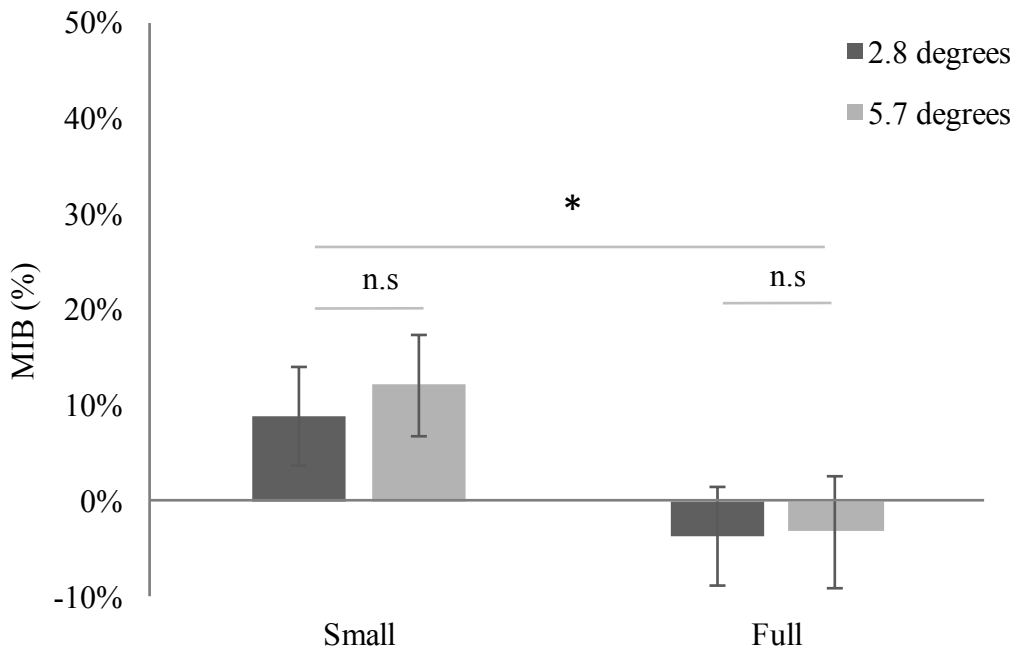


Figure 12 Experiment 2- Effect of eccentricity on MIB. Total duration of MIB (%) in small and full-FOV at eccentricities of 2.8 and 5.7 degrees. Asterisks indicate significant differences ( $p < 0.05$ ). Error bars are standard errors of the mean.

#### 4.4. Discussion of Experiment 2

The differences in MIB between the two interpretations of motion background (external-motion and self-motion perception) were consistent with the findings from Experiment 1, where MIB was greater when the motion background was believed to be external motion compared to resulting from self-motion. In Experiment 1, speed varied from 8 to 36°/s whereas in this second experiment speed varied from 6 to 36°/s, and although there were no significant main effects for speed in either study, a significant interaction in this experiment revealed that when the motion background was interpreted as resulting from external-motion (small-FOV) the greater the speed the greater the MIB, which is consistent with previous research (Bonneh et al., 2001). It is possible that the difference between speeds in the first experiment were not great enough to find a significant effect of speed with the small-FOV.

The effect of speed was completely abolished during thevection condition (full-FOV) – even with the faster speeds (that evoked more MIB), MIB was still abolished. The fact that the effect of speed on MIB was exclusive to when the background motion was perceived as external-motion and not when it was perceived as a result of self-motion, indicates that it is indeed the interpretation of visual background motion that is fundamental for generating MIB, otherwise similar effects would have been found.

However, unlike in previous studies, there were no significant effects of eccentricity on MIB even when the motion background was interpreted as resulting from external motion. Hsu and colleagues found that as the eccentricity of the targets increased, the initial fading times, a measure of MIB strength, decreased (Hsu et al., 2004; Hsu, Yeh, & Kramer, 2006). Similarly, Wells and colleagues found that eccentricity indeed affected MIB, even as the background mask changed in motion coherence (Wells et al., 2011). I used a range of eccentricities that were comparable to these previous studies. The extent of visual acuity decreases in the periphery and although my findings were different from previous study, an explanation for why there was no effect of eccentricity might lie in differences in the experimental set ups such as target features (we uniquely used lasers) or the motion background, including viewing distance, luminance and contrast of the target stimuli as well as the physical motion of the Tumbling Room itself. The lasers used in the present experiments were considerably brighter and higher contrast than the computer displays used by previous investigators (e.g., Bonnef et al., 2001) and by presenting them at larger eccentricities should have increased the likelihood of finding an effect of MIB. However, our results showed that even this combination did not produce more MIB.

So far I have looked at the effect of illusory self-motion which substantially reduced MIB compared to the effect of the same background motion when it was interpreted as external motion. What about during real physical motion? Physically rotating a person around the roll axis is a powerful experience. There

are extensive physical as well as visual cues to the rotation. For example, the otoliths report a continuously changing direction of gravity relative to the body and the semicircular canals, at least initially, will also give a strong signal. Furthermore, there are substantial and highly noticeable changes in pressure from the bottom to the side and shoulders that are picked up by the somatosensory system as the chair rotates. Under these circumstances all visual motion (whether seen through a large or small field) should be interpreted as resulting from the ongoing self-motion and according to my results so far, and my hypothesis 4, should therefore be less effective at evoking MIB.

## **5. Experiment 3- Self-motion vs Vection**

In this experiment, I compared the effects of visually induced self-motion (vection) and physical self-motion on MIB. I hypothesize that vection and physical self-motion will both attenuate MIB compared to conditions in which the background motion is interpreted as external motion. I also hypothesize that MIB will be the same independent of FOV during physical self-motion as participants will interpret the background motion as always resulting from their own motion as they rotate.

### **5.1. Methods**

#### *Participants*

Ten naïve participants (6 female, ages= 17-21yrs, MEAN = 19.3yrs) participated in the vection judgement experiment as well as completing the second part comprising reports of MIB during two types of self-motion conditions: a vection and a physical self-motion condition. Participants were recruited from York University's Undergraduate Research Participant Pool (URPP) and were rewarded class credit. All signed consent forms before commencing the experiments.



## *Stimuli and Apparatus*

Experiment 3 took place in York University's newly assembled 8.5' x 9.8' x 8.5' Tumbling Room. Within the room, a built-in chair could spin an individual around the same axis of rotation as the room (the participant's naso-occipital axis). Participants were seated in the built-in chair 80" from the 22" diameter textured display (7.8° visual angle FOV) (as described for Experiment 2) and securely strapped with a 5-point harness. The experiment consisted of a physical self-motion condition and a vision-only self-motion (vection) condition. The vection condition consisted of the individual remaining in the stationary chair while the room rotated around their naso-occipital axis as in Experiments 1 and 2 (Figure 4a). In the physical self-motion condition, participants sat in the same chair, which rotated around the same axis of rotation as in the other experiments (Figure 4b). The participant's head was stabilized during the physical self-motion condition by straps attached to the back headboard. Both self-motion and vection conditions were tested in the same participants with the small (~10° FOV) and full-field view with the room moving at 18°/second (see methods Experiment 1: FOV). The speed of rotation was matched at 18°/second for both the vection and the physical self-motion conditions. As in Experiment 2, three laser targets (5mW, 635nm) were positioned on the textured display at an eccentricity of 2.8° from a fixation laser. The laser targets were person-fixed to duplicate the display from the previous experiments. The lasers were attached to the chair and hence the targets moved with the person (remained person-stationary) in the physical self-motion condition.

## **5.2. Procedure**

*Vection Experience:* Participants were asked to keep fixation on the laser at the center of the textured surface and report when they experienced self-motion by pressing down a button of a wireless mouse during the person-stationary condition (where self-motion was visually induced). Vection experience

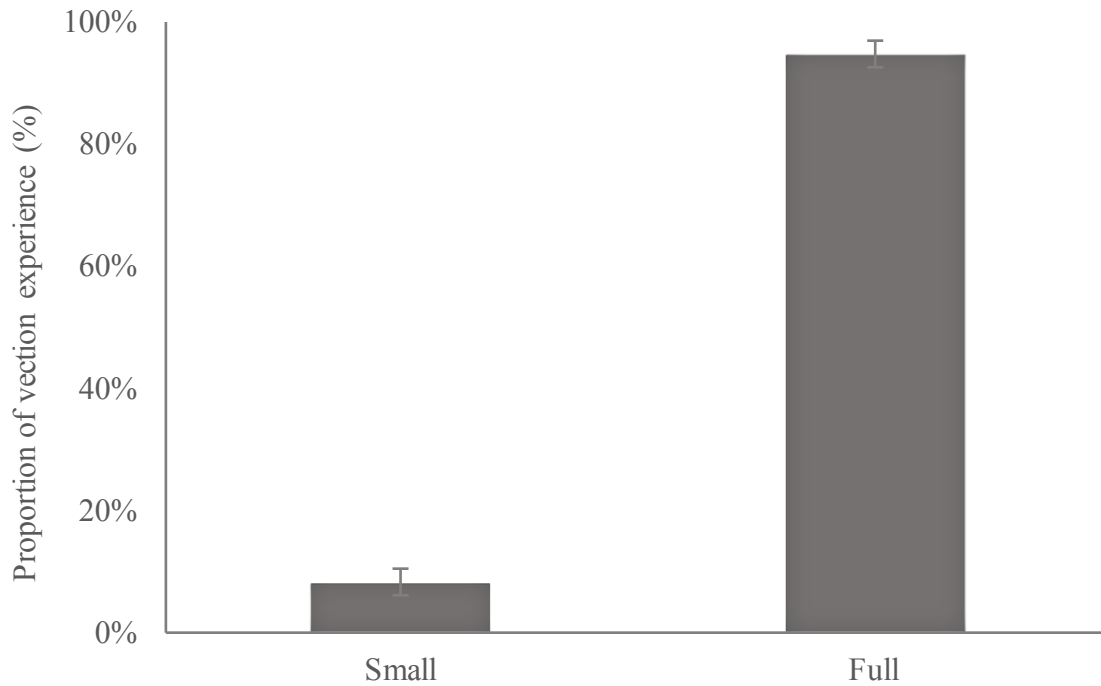
was measured in both small and full-FOV for a total duration of 120s. The feeling of self-motion was not measured in the physical rotation conditions as all participants anecdotally reported that they experienced profound and obvious self-motion.

*Target Disappearance (MIB):* Participants reported the disappearance of any one of the three target lasers by pressing and holding a button on a wireless mouse whenever one of the three laser dots disappeared. MIB was measured as the total duration of disappearance of at least one of the target lasers minus the Troxler disappearance (measured with no motion) and expressed as a percentage of the total stimulus duration (120s). MIB was measured in both small and full FOV conditions during both illusory and physical self-motion.

The stimulation of movement for bothvection and MIB conditions were sequenced using the Dymech Engineering Inc. custom software on a Windows 8 desktop. Motion onset was synched manually by the experimenter to the start of the recording of the button presses by a separate computer MacBook Pro (Version 10.12.16).

### **5.3. Results**

*Vection:* A paired-sample t-test was conducted between the two different fields-of-view, in thevection condition.  $t(9) = -29.218$ ,  $p < 0.001$ , Mean difference = 86.6% Std=9.4%, SE of Mean= 3.0%. The mean difference in reportedvection between small and full FOV was 86.6% longer for the full-FOV in theillusory vision-only self-motion condition (Figure 13).



*Figure 13 Experiment 3- Self-motion total durations. The means and standard errors of total reported self-motion durations (and percentages out of total stimulus duration  $t=120s$ ) ( $n=10$ ) during two fields-of-view (small, full) for the illusory self-motion condition.*

*MIB:* A 2x2 repeated-measures ANOVA was conducted to examine the different types of self-motion (vection, physical) and FOV (small, full) on participant's perception of constant stimuli disappearance (MIB). The data showed a significant interaction between self-motion type (vection vs physical) and FOV (small vs full)  $F(1,9)=9.195$ ,  $p=0.014$ ,  $\eta^2=0.505$  (Figure 14). When the self-motion was illusory (vection), the proportion of time MIB occurred was reduced by approximately 23% on average when the background motion was viewed under full field of view compared to the small field of view ( $p=0.008$ ). In contrast, when the self-motion was real (physical self-motion), the average proportion of MIB was not different between the different fields-of-view conditions ( $p=0.930$ ) and both were significantly lower than the conventional MIB condition (small field of view – approximately 35% subtracting the Troxler fading ( $p < 0.05$ )). The analysis revealed significant main effects between the type of self-motion

conditions on  $F(1,9)=28.826, p<0.05, \eta^2=0.762$  as well as significant main effects between the different FOV conditions on  $F(1,9)=8.331, p=0.018, \eta^2=0.481$ (figure 14). Separate t-test analyses for the physical self-motion conditions reported that MIB was significantly lower than zero  $t(9)=-4.201, p=0.02$  (Physical Small-FOV) and  $t(9)=-4.190, p=0.02$  (Physical Full-FOV) that is, even lower than the background Troxler fading.

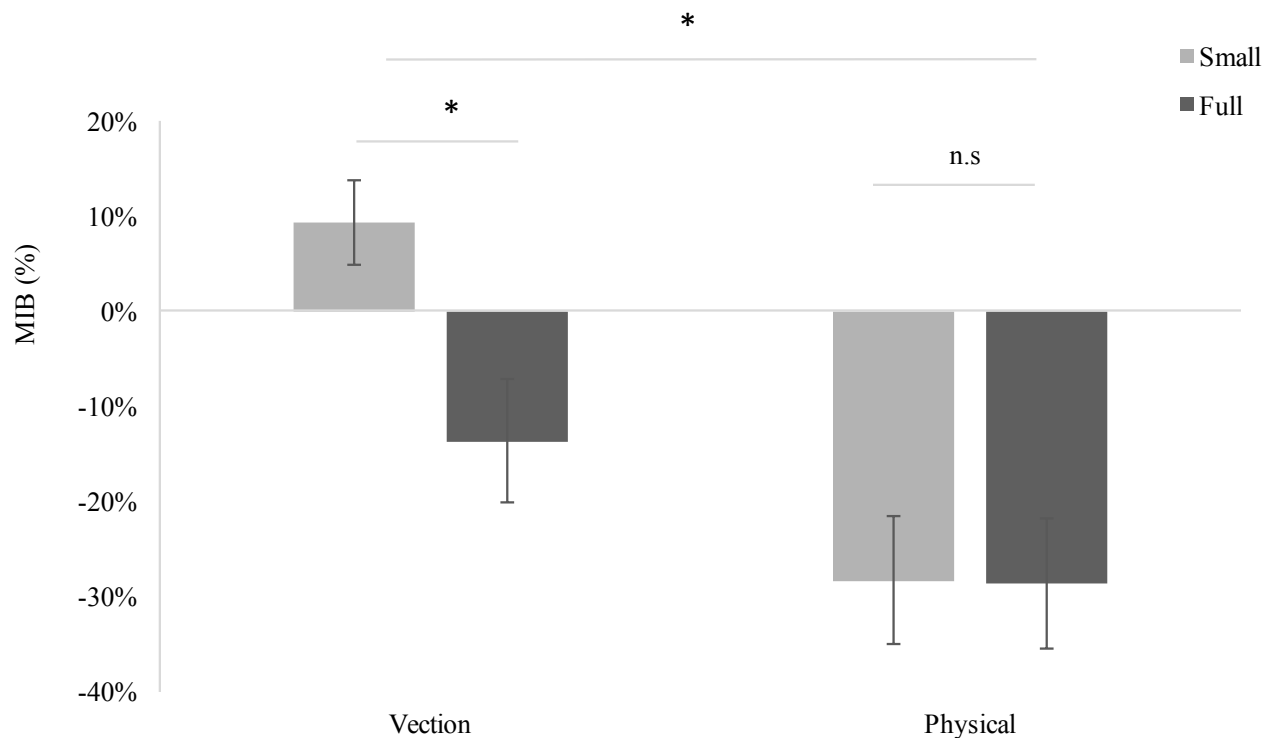


Figure 14 Experiment 3- Effect of different types of self-motion perception on MIB. Comparison of the proportion of stimuli disappearance (MIB) between vection and physical self-motion conditions with two field-of-view conditions (small and full). Error bars are standard errors of the mean. Asterisks indicate significant differences ( $p<0.05$ ).

#### **5.4. Discussion for Experiment 3**

My third experiment explored the differences in MIB during real and illusory self-motion. Similar to the findings reported in Experiments 1 and 2, when the motion background was interpreted as resulting from self-motion, regardless whether the self-motion was illusory or real, MIB was attenuated compared to when the background motion was interpreted as external motion.

Unlike in Experiments 1 and 2 where the differences between the full and small-FOV could be because of either the huge amount of visual motion information or due to the different interpretations of the background motion (vection and non-vection), here in Experiment 3, the very same retinal stimulus (small-field) has different reports in MIB. When viewed by a physically rotating participant the visual motion seen in the small-field was still attributed to the rotation of the participant. When testing during physical self-motion with both the small and full-FOV, we found the same decrease in MIB (figure 15). This suggests that the reduction in MIB was indeed due to the interpretation of the visual motion as resulting from their own movement as participants had a consistent feeling of themselves rotating independent of the size of the FOV during physical self-movement. Therefore, taken with the other results, these data provide evidence that it is the interpretation of the visual motion not the differences in the visual motion that determines whether MIB occurs or not.

Another issue that needs to be addressed in the physical self-motion condition is that MIB was significantly lower than zero (figure 14), that is the amount of Troxler fading that was reported in the stationary non-motion condition was greater than during real movement. This could be attributed to the laser dots being less stable on the retina during real movement either because of mechanical issues caused by the rotation of the device or by more eye movements being generated during physical rotation compared to when only the room moved. This point will be considered further in the general discussion.

## **6. General Discussion**

### **6.1. MIB as a tool to dissociate visual motion processes**

By using the MIB phenomenon as a tool to investigate visual perception under various interpretations of visual background motion, I have shown that the visual system treats visual motion information differently according to the type of information it contains. This study demonstrates that perception of a visual scene can change based on whether the visual information, especially motion information, is related to providing an estimate of where one is in the world compared to providing information about nearby objects.

Since the motion background changed only in the extent of the field-of-view with the central region remaining constant, one might expect that there would be no differences in visual awareness and that MIB would be the same independent of visual field area. In fact, one might even expect MIB to be greater as a larger part of the background was seen as moving because of a stronger “background motion” stimulus. However, despite having the same visual background motion across all experiments, the active ingredient that determined whether or not MIB was experienced was the interpretations of the source of the background movement. Here, I showed that when the visual background motion was interpreted as self-motion, whether illusory or real, MIB was almost completely attenuated and the target dots remained visible despite background motion.

Overall there was a correlation between the amount of vection that each condition produced and the amount of MIB (allowing for Troxler fading) as shown in Figure 15.

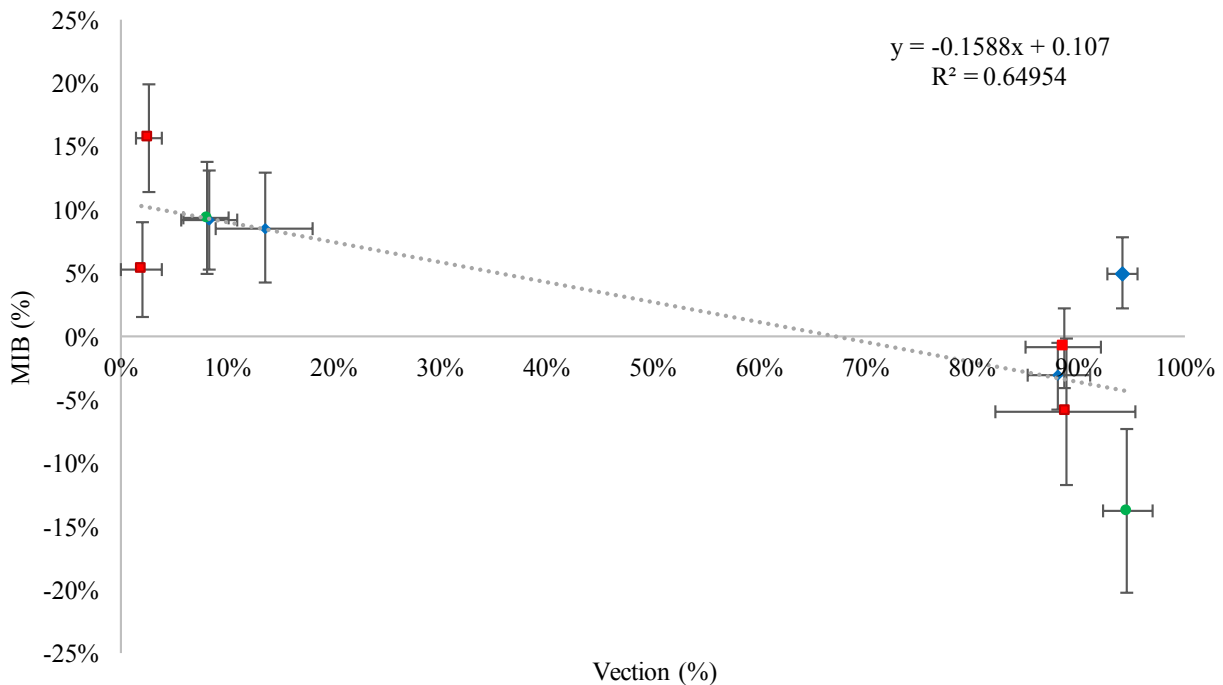


Figure 15 - Relationship of reported MIB as a function of vection experienced. The means from each of experiment with small and full- FOVs plotted with standard error bars for each measure. Blue diamond: Experiment 1; red square: Experiment 2; green circle: Experiment 3.

Although the correlation between vection and MIB is moderate ( $\rho = 0.65$ ), it is nevertheless negative and statistically different from zero. The average reported MIB decreased as longer periods of vection were experienced and approximately 65% of the variability can be explained by this relationship.

## 6.2. Perception is shaped by motion perception experience

The present study revealed that visual awareness and perception differentiates based on motion information necessary for self-movement and motion information that is not (see figure 2). In general terms, the visual system selectively processes visual information from a functional standpoint. For instance, the acclaimed two-stream model by Goodale & Milner, proposes separate visual processing streams one for action and the other for perception towards an object (Goodale & Milner, 1992).

Likewise, visual information in reference to self-motion perception is also processed independently from other visual motion (see section 1.2.). The data presented in this thesis suggest that visual motion resulting from self-motion (i.e., optic flow) is removed from perceptual processing before the point at which MIB occurs.

From a neural perspective, studies have segregated cortical regions accordingly to the features of the MIB phenomenon (i.e., background motion vs salient target) (Donner et al., 2008), while some suggest that early visual areas play a role in MIB (Libedinsky et al., 2009). My findings suggest that MIB occurs in later stages of the visual system after optic flow has been removed from the perceptual stream (figure 2).

Other research linking the motion experience to either self-motion or object-motion have found that how motion is interpreted does affect one's ability to function in the world. For instance, how it is interpreted affects object-tracking, and the perception of object structure. Thomas and Seiffert (2010) questioned whether active and passive self-motion interfered with object tracking accuracy compared to when individuals did not move. They found that self-motion (active and passive) reduced the accuracy of object location because individuals unconsciously updated their location and representation in space. Similarly, they had a viewpoint change condition which created optic flow (withoutvection) and they concluded that the optic flow condition that did not induce a sense of self-motion was not enough to conflict with object-tracking accuracy compared to the optic flow condition that did induced the sensation of self-motion (Thomas & Seiffert, 2010). Although Thomas and Seiffert's task was different from the present study, the overall message is that there was a reallocation of visual information necessary to updating one's location in space even though it was unintentional. Analogous to our



findings, visual motion cues signaled information about self-motion rather than providing information about object visibility.

### **6.3. Why were our MIB reporting rates so low?**

One of the unexpected findings of the study was the relative low proportion of target disappearances. Some factors that could influence the proportion of MIB include: Troxler fading, eye-movements, contrast, colour, and brightness of the targets, and field-of-view. In comparison to other research studies that looked at MIB, typical values average approximately 40% stimuli invisibility (Bonneh et al., 2001), ~40% invisible of total time (Schölvink & Rees, 2010), ~20% invisible (Wells et al., 2011) whereas our values were between -7% and 20%. However, the proportions reported in these experiments did not subtract disappearance due to Troxler Fading leading to an overestimate. When we do not take account of spontaneous fading our numbers become between ~12% and ~45% which are compatible with previous reports.

Some of the experiments in this thesis failed to confirm the effect of target eccentricity and speed of background motion (when interpreted as external motion) under conditions comparable to those used in MIB studies using a computer monitor (Hsu et al., 2004; Hsu et al., 2006; Wells et al., 2011). The apparatus used in my experiments differ widely from experiments conducted on a computer screen, which could explain many of the differences in results. Factors such as: our set-up involved a physically moving background with no computer screen edges and nothing visible (in my small FOV) in the periphery, viewing distances were different, luminance and contrast of the target stimuli etc. The targets were not the same contrast and luminance as in previous studies (which used regular computer display screens) and therefore could have been perceived differently. Distance from the moving background as well as the context (my studies were unique in using a tumbling room) could also contribute to the

differences reported here. However, the aim of the present studies was to observe changes in MIB with different interpretations in visual background motion rather than reproduce previous studies.

### **6.3.1. *Eye-movements and self-motion perception***

Self-motion whether illusory or real, provokes nystagmic eye movements referred to as ‘optokinetic’ when they are of solely visual origin (Howard 1982). These reflex movements tend to stabilize the retinal image. Thilo and colleagues recorded torsional optokinetic nystagmus (tOKN)— compensatory eye-movements that tend to stabilize the image on the retina to maintain clear vision, during egocentric and exocentric background motion around the roll axis. Participants recorded the interval times of perceived self-motion or object-motion while the proportion of oculomotor responses was calculated as the ratio between recorded tOKN slow-phase over the angular stimulus speed. The changes in the mean torsional optokinetic nystagmus between the two different perceptions of visual motion was taken at three different velocities (30, 45, and 60 degrees/second). They found there was a significant increase in torsional nystagmus when the stimulus inducedvection rather than when it was interpreted as being of external origin. They also reported that as speed increased, so did the tOKN (Thilo, Probst, Bronstein, Ito, & Gresty, 1999). Therefore, provided with a background motion that can stimulate either illusory self-motion or external-motion, torsional nystagmus eye-movements may be expected to be greater when the background motion is perceived as resulting from self-motion rather than as resulting from external-motion. If this were the case during our experiments we would expect less retinal excitation when background motion was interpreted as a resulting from self-motion (that evokes more powerful compensatory OKN), compared to when background motion was interpreted as resulting from external-motion (and evokes less eye movements). This would predict more effective MIB duringvection, which is of course the opposite of what we observed. This is important because it suggests that not only does a visual motion background interpreted as resulting from self-motion create less eye-movements, but it is

comparable to real-motion. If there is less stabilization of the image on the retina there may be more MIB caused by a simple removal of the background motion.

Although it is challenging to track the eyes or develop strategies to reduce the amount of eye torsion evoked in the present experiments, several studies have examined the relationship between eye-movements and MIB and Troxler Fading (Bonneh et al., 2010; Hsieh & Tse, 2009; Martinez-Conde, Macknik, & Hubel, 2004; Martinez-Conde, Macknik, Troncoso, & Dyar, 2006). It has been shown that both phenomena are affected by eye-movements. The Troxler Effect (the perceived disappearance or fading of stationary objects) is instantly abolished and visual perception restored with any eye-movement. Martinez-Conde and colleagues studied the probability, rate and magnitude of micro saccadic eye-movements during the Troxler Effect. They found that the probability, magnitude and rate of microsaccades tended to decrease just prior to the initial fading period and increase as perception was restored (Martinez-Conde et al., 2006).

Any explanation for the different occurrence of MIB based on different eye movements in the various conditions however seems unlikely since the relative motion between the background and the (participant stationary) target dots would be completely unaffected by any eye movements. MIB has been found when the dots move against the background (Bonneh et al., 2001) so eye movements of any amount that maintain the relative motion between the targets and the background would not be expected to influence MIB.

### **6.3.2. *Field-of-view and MIB***

Field-of-view was a varying factor that could have impacted MIB directly as well as by means of creatingvection. In order to create a large field of motion that induced interpretations of both self-motion and external-motion, the experiment took place in the York Tumbling Room. The reducing

effect of self-motion perception on MIB was ambiguous in the large-field-of-view condition (seen in Experiments 1 and 2) as it could have been caused by simply having a large field of motion – independent of whether the large field caused vection. Although MIB decreased as vection experience increased (see Figure 15), it was not possible to verify definitively that the decrease was a result of increased vection, independent of the increase in field-of-view. However, there is compelling evidence that vection can be experienced even under small field-of-view scenarios (e.g. airplane window (Howard & Heckmann, 1989)). An alternative method to differentiate between full-field motion that was interpreted as vection and one that was not is to have participants report simultaneously MIB and their experience of vection. This could reveal any actual fluctuations in MIB with patterns of vection sensation. In all the full field conditions, participants reported up to 90% vection sensation, therefore it is possible that 10% of the time, motion would be perceived as external motion. If we can determine whether MIB is greater during the time it is interpreted as external versus when it is interpreted as vection it would discriminate results from a large field-of-view. In Experiment 2, three participants had the same vection experience regardless of field-of-view (see section 4.3.) A possible resolution might be to create a large field-of-view where vection is not experienced. This could be created by for example having two superimposed large-field gratings moving in opposite directions. If the logic of the above explanation is correct, optic flow in a full FOV condition that does not elicit the sensation of self-motion should induce normal motion-induced blindness. That this is likely is suggested by the results of Experiment 3 in which identical retinal motions associated with external motion and self-motion evoked different amounts of MIB.

## **6.4. Conclusion**

Overall, the main findings in my thesis support the idea that the visual system processes visual motion information differently as a function of what it is going to be used for. When vision is used to guide and control self-motion it seems to be no longer available to contribute to visual phenomena such as MIB. These results can be related to the extensive work that has been done over the last few decades demonstrating the difference between visual information being used for action and perception (see Milner & Goodale (1992) for a review). Motion perception can be characterized in two ways; either the concept of vision used for perception which is associated to an external view-point necessary for conscious allocentric visual motion processing, or a second process that is characterized by vision used for action perception associated with egocentric visual motion processing (Milner & Goodale, 2008).

## **6.5. Future directions**

Improving and expanding these experiments would require better control of the target stimuli. For this study we used laser targets, which were essentially of fixed brightness and colour. As reviewed above, the luminance or contrast of the targets will obviously affect their visibility and therefore (presumably) their vulnerability to MIB. If more controllable targets were used I might be able to say not only that MIB was abolished by self-motion but provide a quantitative estimate of how much the thresholds were affected.

A phenomenon closely related to MIB is known as “motion silencing”. In this phenomenon – quite as extraordinary as MIB – changes made to a moving pattern (for example changes of colour, luminance, shape or size) become quite invisible (Suchow & Alvarez, 2011). You can see a convincing demonstration here: <http://visionlab.harvard.edu/silencing/>. Does motion silencing also stop happening when the motion is part of the general motion of a scene created by self-motion? In other words, if the

pattern is part the world and the whole world is rotated relative to the person (as in the experiments reported in this thesis) might motion silencing be silenced? I have already performed some preliminary studies on this phenomenon (Rushton, Elzein & Harris, 2016) but exploring the differences and similarities between these two closely related and mind-blowing illusions could reveal more fascinating information about the interaction between the perceptual and proprioceptive aspects of vision.

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## Informed Consent Form

**Date:** January 15, 2016

**Study Name:** Does optic flow make objects disappear?

**Researchers:** Laurence Harris; Yameenah Elzein

**Purpose of the Research:** Understand the nature of optic flow on our ability to detect objects in our visual field.

**What You Will Be Asked to Do in the Research:** You will be asked to look at large screen that projects a large-field background motion stimuli that may give the sensation of motion. A target will also be presented on the large screen, and you will be asked to indicate when you perceive the target to disappear. You will be asked to sit or lie in various orientations (e.g., seated upright, lying on your side, or lying on your back) and report the perceived disappearance of the target using button presses. You may be asked to report your sensations of perceived motion verbally, or with a computer mouse. The experiment will take between 30 minutes to 2 hours to complete.

**Risks and Discomforts:** We do not foresee any risks or discomfort from your participation in the research. If you feel discomfort or dizziness, tell the experimenter who will always be present with you and stimulation will be immediately stopped.

**Benefits of the Research and Benefits to You:** If you are a URPP student you will receive course credit at the rate of 1 credit/hour.

**Voluntary Participation:** Your participation in the study is completely voluntary and you may choose to stop participating at any time. If you decide to stop participating, you will still be eligible to receive the promised course credit for agreeing to be in the project rounded up to the nearest hour. Your decision not to volunteer will not influence the treatment you may be receiving or the nature of the ongoing relationship you may have with the researchers or study staff or the nature of your relationship with York University either now, or in the future.

**Withdrawal from the Study:** You can stop participating in the study at any time, for any reason, if you so decide. Your decision to stop participating, or to refuse to answer particular questions, will not affect your relationship with the researchers, York University, or any other group associated with this project. In the event you withdraw from the study, all associated data collected will be immediately destroyed. If you are a URPP participant you will still receive credit rounded up to the nearest hour.

**Confidentiality:** All information you supply during the research will be held in confidence and unless you specifically indicate your consent, your name will not appear in any report or publication of the research. Data will be collected through the experimental computer program and by the researcher. Your personal information and data will be safely stored in a locked facility on a password-protected computer and destroyed on completion of the study. Only research staff will have access to this information. Confidentiality will be provided to the fullest extent possible by the law.

**Questions About the Research:** If you have questions about the research in general or about your role in the study, please feel free to contact Dr. Harris either by telephone at 416-736-2100, extension 66108 or by e-mail ([harris@yorku.ca](mailto:harris@yorku.ca)). This research has been reviewed and approved by the Human Participants Review Sub-Committee, York University's Ethics Review Board and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines. If you have any questions about this process, or about your rights as a participant in the study, please contact the Sr. Manager & Policy Advisor for the Office of Research Ethics, 5th Floor, Kaneff Tower, York University (telephone 416-736-5914 or e-mail [ore@yorku.ca](mailto:ore@yorku.ca)).

### Legal Rights and Signatures:

I \_\_\_\_\_ consent to participate in the Project: *Does optic flow make objects disappear?* conducted by *Dr. Laurence Harris* and *Yasmeenah Elzein*. I have understood the nature of this project and wish to participate. I am not waiving any of my legal rights by signing this form. My signature below indicates my consent.

**Signature** \_\_\_\_\_ **Date:** \_\_\_\_\_

Participant

**Signature** \_\_\_\_\_ **Date:** \_\_\_\_\_

Researcher