The Viewing Window Paradigm: A novel tool to assess visual-motor functioning.

By

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University of Manitoba

A Thesis submitted to the Faculty of Graduate Studies of The

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in partial fulfillment of the requirements of the degree of

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In the

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Abstract

To interact with the world around us, we must accomplish three tasks that typically occur in parallel. We attend to visual regions of interest surrounding us, and then bring each area of interest into our central visual field. We identify and retrieve information about objects in sight related to our current task and we program and control actions directed at those objects. In order to accomplish these tasks, two primary visual cortical pathways have developed. Much research has focused on the roles each of these streams play in our perceptions of the world and our interactions within it, but the extent of collaboration between the two is often overlooked. The presented experiments served to quantify and assess the function of a major site of visual integration, the parietal lobe, in a number of different scenarios. First, an assessment of a new tool for visuomotor research, the viewing window paradigm was undertaken (Project 1). Following a successful demonstration of utility, the viewing window paradigm was employed in a series of experiments aimed at answering questions related to the natural aging process and the visual system (Project 2). Lastly, an examination of the neurological correlates of the viewing window was sought (Project 3). A diverse research approach was utilized, featuring both behavioural and functional magnetic resonance imaging methodologies, which allowed for an extensive examination of the issues at hand. Knowledge gained from this research may have a direct impact on how we design and evaluate tests aimed at assessing visuomotor functioning and how we currently conceive of the natural aging process. Further, the presented research may offer a new tool to examine, and rehabilitate individuals suffering from a myriad of visuomotor impairments.

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Table of Contents

Abstract ii

Acknowledgements iii

Table of Contents iv

Figures viii

Chapter I: General Introduction 10

Cortical Streams of Visual Processing 10

The Human Visual System: Anatomical Theory 13

The Posterior Parietal Cortex 16

Coding of Eye Movements 17

Reaching Actions 18

Sensorimotor Integration 19

Contributions 21

Summary 22

Chapter II: The Viewing Window Methodology 24

Experiment 1a – The Viewing Window as a Visuomotor Tool 26

Materials and Methods 29

Results 33

Discussion 34

Experiment 1b – The Viewing Window and Eye-tracking 41

Materials and Methods 44

Results 46

Discussion 49

Chapter Summary 50

Chapter III: The Viewing Window and Natural Aging 53

Experiment 2a - Natural Aging Affects Visuomotor Transformation Ability 55

Materials and Methods 56

Results 58

Discussion 69

Experiment 2b - Natural Aging Affects Visuomotor Transformation 72

Materials and Methods 73

Results 75

Discussion 82

Chapter Summary 85

Chapter IV: Neurological Correlates of the Viewing Window 91

Experiment 3a – Behavioural measures of viewing window Effectiveness as an fMRI tool... 93

Materials and Methods 94

Results 98

Discussion 101

Experiment 3b – fMRI Evidence of Parietal Lobe involvement in Viewing Window Performance 103

Materials and Methods 105

Results 110

Discussion 111

Chapter Summary 117

Chapter V: General Discussion 119

The Viewing Window as Visuomotor Tool 119

Conclusions 119

Future Directions 120

Aging and the Viewing Window 121

Conclusions 121

Future Directions 122

Neurological Correlates of the Viewing Window 124

Conclusions 124

Future Directions 125

General Conclusions 126

References 128

APPENDIX A 140

APPENDIX B 141

APPENDIX C 142

APPENDIX D 144

APPENDIX E 145

Tables

Table 1. List of objects used as practice and experimental items in Experiment 1. 30

Table 2. Results of ANOVA by items in Experiment 1a..... 37

Table 3. List of objects used as practice and experimental items in Experiment 2. 45

Table 4. Visuomotor flip conditions in Experiment 2a..... 59

Table 5. List of objects used as practice and experimental items in Experiment 3, with associated foils. 96

Table 6. Anatomical location of observed activation in Experiment 3b..... 112

Figures

Figure 1. Viewing window illustration. 32

Figure 2. Typical visuomotor scan pattern. 35

Figure 3. Typical quadrant analysis. 36

Figure 4. Detailed quadrant analysis 38

Figure 5. Eye-based and window-based scanpaths. 47

Figure 6. Example scanpath, Experiment 2a. 60

Figure 7. Example scanpath - flip in x-axis, Experiment 2a. 62

Figure 8. Number of reversals, Experiment 2a. 63

Figure 9. Movement times, Experiment 2a 65

Figure 10. Average velocity, Experiment 2a. 67

Figure 11. Direction of movment, Experiment 2a. 68

Figure 12. Example scanpath, Experiment 2b. 76

Figure 13. Example scanpath - flip in x-axis, Experiment 2b. 77

Figure 14. Number of reversals, Experiment 2b. 78

Figure 15. Movement times, Experiment 2b. 80

zFigure 16. Proportionate movement times, Experiment 2b. 82

Figure 17. Direction of movement, Experiment 2b. 83

Figure 18. Viewing window example, Experiment 3a. 97

Figure 19. Example scanpath, Experiment 3a. 99

Figure 20. Number of reversals, Experiment 3a. 100

Figure 21. Movement times, Experiment 3a. 102

Figure 22. Slice prescription, Experiment 3b. 107

Figure 23. fMRI protocol, Experiment 3b. 109

Figure 24. Observed activation, Experiment 3b. 113

Chapter I: General Introduction

To interact with the world around us, we must accomplish three tasks that typically occur in parallel. We attend to visual regions of interest surrounding us, and then bring each area of interest into our central visual field. We identify and retrieve information about objects in sight related to our current task and we program and control actions directed at those objects. Previous research has shown that two cortical visual pathways have evolved to process the information required for these distinct tasks. The ventral (perception) stream, projecting from early visual areas to the temporal lobe, processes visual information that allows us to identify and attach meaning to our surroundings. The dorsal (action based) stream, projecting from early visual areas to the posterior parietal cortex, transforms visual information into online information that is used to mediate the visual control of action (Goodale & Milner, 1992; Goodale & Westwood, 2004). Much research has focused on the roles each of these streams plays in our perceptions of the world and our interactions within it, but the extent of collaboration between the two is often overlooked. The purpose of this series of experiments was to quantify and assess function of a major site of visual integration, the parietal lobe, utilizing the viewing window paradigm. After verifying the viewing window as an appropriate visuomotor tool (Study 1), the viewing window was used to assess visuomotor transformation abilities in an aged population (Study 2). Finally, an evaluation of the neural mechanisms behind visuomotor transformation was obtained using the viewing window paradigm in a functional magnetic resonance imaging (fMRI) environment (Study 3).

Cortical Streams of Visual Processing

We consciously experience one unitary representation of our visual world that appears to allow us to both perceive and interact with our surroundings. However, if one critically

examines these two dissociable requirements (perception vs. action), it becomes tenable that both the neurological underpinnings and eventual information processing is more specialized than our experience would suggest. The presence of such a dissociation in the primate visual system was first reported by Trevarthen (1968) and Schneider (1969), but more well known is the work conducted by Ungerleider and Mishkin (1982). When experimental lesions were introduced into the dorsal visual stream, the animals were unable to form accurate representations of the spatial relationships between objects. In contrast, when experimental lesions disrupted the ventral pathway, information about what the object was (form, colour, shape, etc.), was impaired (Ungerleider & Mishkin, 1982). Emphasis in this "what vs. where" dichotomy was placed on input processing: features of the object, and where it is located. More recently, a competing theory of duplex vision has been suggested which focuses on a perception vs. action (or "what vs. how") explanation of ventral and dorsal visual processing (Goodale & Milner, 1992). Under this framework, the distinctions between ventral and dorsal visual streams directly correspond to our perceptual representations of the world, and the information necessary to allow visuomotor control. Unlike the "what vs. where" distinction previously presented, the Milner and Goodale model places the distinction of ventral and dorsal visual streams at the level of the output systems they are subservient to, rather than the input processing for which they are responsible. Milner and Goodale suggest both the ventral and dorsal cortical visual streams process information about object properties and locations, but the dorsal stream performs calculations on that information that permit visuomotor behaviour. In comparison, the ventral stream performs the calculations necessary to form the cognitive representations of objects and their relations. To allow the accurate perception of objects, humans code information in an allocentric frame of reference (one not related to egocentric positioning in the visual world) (Milner & Goodale,

1995). This frame of reference allows humans to identify objects independent of the physical dimensions observed. For example, we can identify our coffee mug from across the room without mistaking it for a similar looking smaller version because its size, relative to the objects around it, remains proportional. In contrast, the information required by the visual system when interacting with objects, must be derived from an egocentric representation of the visual surround. An egocentric frame of reference allows the incorporation of real world metrics related to oneself (Milner & Goodale, 1995).

Even though there is a clear division of labour between the perception and action systems, this dichotomy represents the complementary roles that the two systems play in the production of meaningful behaviour rather than two solitary systems functioning in isolation (Marotta, Behrmann, & Goodale, 1997; Marotta, Desouza, Haffenden, & Goodale, 1998; Marotta & Goodale, 1998, 2001; Marotta, Kruyer, & Goodale, 1998; Marotta, Medendorp, & Crawford, 2003). A prime example can be found in our daily lives; there are many instances where learned information about an object's properties, most likely a product of the ventral stream, influences the way a person's actions are directed towards that object. Properties inherent to an object such as friction, compliance and weight can affect grasp kinematics and are not fully known when interacting with novel objects. Rather, this information has to be learned from direct experience in manipulating objects (Dubrowski, Proteau, & Carnahan, 2004), and is stored and retrieved as a function of object properties within in the ventral visual stream. In more controlled settings, research has also demonstrated that when objects are perceived as larger based on surrounding visual information (the Ponzo illusion), a known ventral stream product, these objects are subjected to greater grip force when being manipulated (Brenner &

Smeets, 1996). It is apparent that, at least when dealing with previously encountered stimuli, the dorsal and ventral cortical visual streams do not act in isolation.

The Human Visual System: Anatomical Theory

Despite the ease with which humans interact with our visual environment, the human visual system is an incredibly complex network of cortical and subcortical regions, with extensive interconnections amongst them. In fact, in the macaque monkey, there have been 32 distinct cortical areas associated with visual processing, connected by approximately 300 distinct pathways (Van Essen, Anderson, & Felleman, 1992).

As information travels through the visual system, functional specializations become apparent early on with four classes of specialized photoreceptors transforming different spectrums of light into chemical energy. This chemical signal is summed at the retinal ganglion cells and then propagated to the lateral geniculate nucleus (LGN), a structure within the thalamus. Connections from the LGN relay information from the retina to both primary and secondary visual areas, making up the geniculostriate path. Despite the classification of the geniculostriate path as a single unit, there are three separate channels between the LGN and primary visual cortex (V1). The magnocellular layer is widely held to be a "colour blind" system with a low spatial resolution, but high contrast sensitivity. The magnocellular system has a higher temporal resolution than the parvo- and konio-cellular layers, and contains visibly larger cell bodies (Lee, 2004; Swanson & Cohen, 2003). The parvocellular system is largely attributed the function of red/green colour opponency, with a high spatial resolution and a comparatively lower contrast sensitivity than found in the magnocellular system. The parvocellular layer is comparatively slow, and is composed of smaller cell bodies than those seen in the magnocellular layer (Lee, 2004; Swanson & Cohen, 2003). The koniocellular layer is perhaps the least studied

of specialized cells within geniculostriate pathway. The konio channel is thought to provide a blue-yellow colour opponency that has been likened to a phylogenically ancient colour vision system, thought to predate the other channels of the LGN (Lee, 2004; Swanson & Cohen, 2003). Information from the LGN converges, via the optic radiations, to V1. All three strata of the LGN feed to V1 "blobs", so named due to their darkening when exposed to a cytochrome oxidase stain (Wong-Riley, 1979). These regions within primary visual cortex are the basis for much of our ability to perceive colour, and as such are specialized to extract spectral information with a relatively low spatial acuity. In comparison, the "interblob" regions of primary visual cortex (so named for their positioning between blobs), receive signals from the magnocellular and parvocellular layers of the LGN. Interblobs are identified from the surrounding blobs by an absence of staining by cytochrome oxidase and can be functionally identified using single-cell recordings, with interblobs demonstrating distinct orientation specificity and high spatial processing abilities (Shipp, 2006; Swanson & Cohen, 2003). Information from the blob and interblob regions remains segregated in prestriate cortex (V2) - output from the blobs innervates the thin stripes, and the interblobs innervate both the thick stripes and pale stripes. The combined purpose of V1 and V2 is to form the basis of colour, form, and motion perception before distributing information to higher visual regions (Shipp, 2006). It is not until information has passed through V2 that the separation of the ventral and dorsal visual pathways previously discussed is observable. Information within the ventral stream is passed to extrastriate visual cortex area 4 (V4), an area that is highly sensitive to properties such as orientation, spatial frequency, simple geometric shapes, and color. Visual area 4 sends information to both the middle temporal visual area (V5/MT), and the posterior inferior temporal lobe (PIT) (Braddick, 2001). Most ventral stream information is processed within PIT, anterior regions of the inferior

temporal lobe, and the central inferior temporal lobe (CIT). As visual information progresses along the ventral pathway, two general trends are reported. First, the specificity required for activation seems to increase (for example, one sees differential activation for similar stimuli organized in different configurations) (Culham et al., 2003). Second, the receptive fields for cells within the temporal lobe are comparatively larger than earlier visual regions. This expansion of the visual field allows for a generalization of activation across its entirety, and thus, an effective coding of intrinsic object features irrespective of object location (Milner & Goodale, 1995). Activations along the ventral pathway are readily observed during numerous perceptual based tasks such as the recognition of colour, form, or texture and during object recognition (Grill-Spector, 2003).

In contrast to the ventral stream, the dorsal cortical visual stream is commonly associated with interpreting motion, representing the location of objects, and allowing for the skilled control of movements. Following V2, information that is dorsal stream bound is sent to the third visual complex (V3). Within V3, information related to global motion is processed before sending the information to visual area MT (middle temporal). Similar to V3, MT is primarily activated by moving stimuli, although it is believed to process more complicated visual motions, and to integrate local visual motion signals into the perception of global motion (Beauchamp, Lee, Haxby, & Martin, 2002). The dorsal visual stream ends with information being sent from area MT to the posterior parietal cortex (PPC). As the parietal cortex is a substantial topic of discussion, it is presented in isolation in the following section (The Posterior Parietal Lobe). Activation along the dorsal pathway is commonly reported in neuroimaging studies of visually guided reaching, grasping, and pointing tasks (for example, (Grafton, Fagg, Woods, & Arbib, 1996; Grafton et al., 1992; James, Culham, Humphrey, Milner, & Goodale, 2003)).

An important caveat regarding area MT is warranted. Even though increased activation in area MT in response to moving stimuli is undeniable (a dorsal stream characteristic), recent anatomical evidence has demonstrated that MT has substantial connections to both the ventral and dorsal visual streams. These connections have led some researchers to re-classify area MT as being an extension of the ventral stream that contributes to perceptual representations of action and of the spatial relations among objects (Milner & Goodale, 2006). Other researchers (Rizzolatti & Matelli, 2003) have even suggested the existence of an entirely separate second dorsal stream.

Although the ventral and dorsal visual streams are often presented as dissociable entities, there is increasing evidence for "cross-talk" between the two systems (Van Essen et al., 1992; Webster, Bachevalier, & Ungerleider, 1994), with the parietal lobe being a likely candidate for the site of integration (Jeannerod & Jacob, 2005). In the following section a more focused discussion involving the parietal lobe, using both human and non-human primate research, is offered as further support of the important role the parietal lobe plays as a site of visual-motor integration.

The Posterior Parietal Cortex

The parietal lobe is ideally located to receive both visual and somatosensory information, and to then send output to both premotor and motor areas within the frontal cortex. Located between the visual cortex and the somatosensory cortex, the posterior parietal cortex (PPC) has long been classified as association cortex, integrating information from multi-modal sources. Based upon descriptions of neural activity within the PPC during simple movements of the eyes and limbs (Mountcastle & et al., 1975), researchers began to explore the higher order sensory and attentional processes attributed to the parietal lobe (Robinson, Goldberg, & Stanton, 1978).

Further study revealed that the PPC was not a unimodal system, but rather had both sensory and motor properties (Andersen, Essick, & Siegel, 1987). Anatomically, the PPC is divided into the superior parietal lobe (SPL) and the inferior parietal lobe (IPL) by the intraparietal sulcus (IPS). Further description includes the precuneus (PCu) anterior to the parieto-occipital sulcus (Damasio, 2005). Electrophysiological studies performed on macaques have identified a number of sensorimotor areas around the IPS. These areas of IPS are often related to the control of specific body parts such as: the hands (anterior intraparietal area, AIP), arms (parietal reach region, PRR), head (ventral intraparietal area, VIP), and eyes (lateral intraparietal area, LIP). A description of parietal lobe involvement in tasks requiring both visual and motor systems is presented by focusing on both human and non-human primate neuropsychological descriptions of PPC functioning in the coding of eye movements, reaching actions, and sensorimotor integration.

Coding of Eye Movements

Non-human primate neurophysiology. Neurons have been identified within the LIP region that activate when a monkey makes specific movements of the eyes, such as a saccade. However, LIP can also show increased levels of activation when the monkey attends to a specific visual location in the absence of a saccade (Colby & Duhamel, 1996; Colby, Duhamel, & Goldberg, 1995; Colby & Goldberg, 1999; Duhamel, Colby, & Goldberg, 1994). Other relevant properties identified in area LIP are a coding of space in coordinates directly related to the eye (Andersen, Bracewell, Barash, Gnadt, & Fogassi, 1990), and that spatial information within area LIP is updated in anticipation of upcoming eye movements (Duhamel et al., 1994). This anticipatory updating of the reference frame is likely required to maintain a stable perception of

the space around us as we explore our visual environment (Culham, Cavina-Pratesi, & Singhal, 2006).

Human neuropsychology. Monkey research examining the parietal lobe's involvement in the execution, programming, and coding of eye movements has largely been confirmed in human populations. Bilateral damage to the human homologue of area LIP, located midway along the anterior-posterior axis of the IPS, has been associated with various eye movement problems. Examples of such problems include gaze paralysis, difficulties with vergence and accommodation, problems with maintain target fixations, and deficits in smooth pursuit (Culham et al., 2006). The role of the parietal lobe in the planning and execution of eye movements has been further confirmed using neuroimaging techniques, with activation typically observed medial to the IPS, in the SPL during the performance of tasks designed to elicit saccades (Medendorp, Goltz, Vilis, & Crawford, 2003; Sereno, Pitzalis, & Martinez, 2001) and smooth pursuit (Petit & Haxby, 1999). Smooth pursuit movements are also known to result in additional PCu activation not seen during other eye movements (Berman et al., 1999).

Reaching Actions

Non-human primate neurophysiology. The role of the PPC in reaching has previously been examined using single-unit recordings in performing monkeys. This physiological research has demonstrated that subdivisions of the PPC contain cells that are selective for reaching, such as area 5 (Ferraina et al., 2001), area V6a (Fattori, Gamberini, Kutz, & Galletti, 2001), areas 7a and 7m (Battaglia Mayer et al., 2000), and the medial intraparietal area (MIP) (Johnson, Ferraina, Bianchi, & Caminiti, 1996). When examining functional properties of neurons, a parietal reach region (PRR) is identifiable including MIP and V6a (Andersen & Buneo, 2002), extending to the lateral bank of the IPS (Calton, Dickinson, & Snyder, 2002).

Human neuropsychology. Patients with posterior parietal lobe damage can suffer from optic ataxia, a disorder of visually-guided limb movements not related to motor, somatosensory, visual field or visual acuity deficits (Battaglia-Mayer & Caminiti, 2002; Ferro, 1984; Ferro, Bravo-Marques, Castro-Caldas, & Antunes, 1983; M.T. Perenin, 1997; M. T. Perenin & Vighetto, 1988; Rossetti, Pisella, & Vighetto, 2003). The damaged regions of parietal cortex associated with optic ataxia always include the IPS, and at times extend to IPL or SPL. Recent investigations have been able to identify additional areas of damage by contrasting the parietal lesions observed in optic ataxic patients, with lesions observed in parietal patients without the disorder (Karnath & Perenin, 2005). This dissociative comparison reveals that optic ataxia is commonly observed after damage to several foci in the parietal cortex: the parietal occipital junction (POJ), the superior occipital gyrus, IPS, SPL, or IPL. These patterns of damage have been verified in studies using fMRI to investigate visually-guided reaching (Culham et al., 2006).

Sensorimotor Integration

Non-human primate neurophysiology. In macaque monkeys, area VIP has been identified as a major site of multimodal encoding. Area VIP has displayed single-cell recording activation to visual, tactile, and auditory stimuli (Bremmer, Schlack, Duhamel, Graf, & Fink, 2001), with the receptive fields of VIP neurons often maintaining a congruency across modality (Duhamel, Colby, & Goldberg, 1998). VIP neurons also encode a multi-modal representation of the space and motion around the head. For example, neurons in VIP are direction selective for motion, receive input from MT, and respond well to optic flow patterns (Colby, Duhamel, & Goldberg, 1996; Culham et al., 2006; Zhang, Heuer, & Britten, 2004). Based on these experimental findings, researchers have suggested area VIP serves a number of different

functions. The most relevant of these, to the present discussion, is the role as a centre for sensorimotor integration between multiple sensory modalities.

Human neuropsychological research. Much of our knowledge concerning posterior parietal lobe involvement in human sensorimotor integration has been gained from the use of transcranial magnetic stimulation (TMS) and traditional neuroimaging techniques. TMS allows the creation of temporary "lesions" within the parietal lobe, offering a perspective previously available solely in patient case studies. In an influential investigation, Desmurget et al. (1999) examined the effects of single pulse TMS on a subject's ability to update a motion plan when a target unexpectedly changed location. Utilizing a double-step reaching paradigm in which the target jumps to a new location during a subject's saccade to fixate on it, it was observed that the trajectory of the subject's reach is corrected to the new target position. The observed correction in a subject's reach occurred even though she does not report consciously perceiving the target's displacement. When TMS was applied over the parietal cortex, this online correction to target movement was not evident in the subject's reach kinematics. This result is evidence for the parietal lobe's involvement in the online correction of limb movement. Later work (Tunik, Frey, & Grafton, 2005) had participants respond to online perturbations during a grasping task as opposed to a reaching task, since the neurological components of reaching and grasping are thought to be fundamentally different (Jeannerod, 1997). During a trial, the target object could vary in its orientation, requiring an online correction to either grip aperture or wrist orientation. When TMS was applied over the posterior parietal cortex, effective online corrections were not performed by subjects. However, both grip aperture and wrist orientation trials demonstrated this lack of online kinematic modification, suggesting an absent or loose somatotopic organization of posterior parietal cortex in humans. Online modifications to the control of limb

movement, as opposed to ballistic reaching and grasping motions, is thought to reflect sensorimotor integration as the minimization of errors in these paradigms depends on rapid, online comparisons between the issued motor command and currently available sensory information of target position and body position. Though it is true that typical reaching and grasping tasks require sensorimotor integration, without manipulating target position, the evaluation of parietal involvement is unclear.

Contributions

Typically, viewing window paradigms present participants with degraded pictures of objects on a computer monitor. A small user controlled area (the "window") displays the underlying images with normal clarity. Participants are asked to identify a presented image or perform a similar perceptual task, while the movements of the viewing window are monitored. By tracking the movements of the window, viewing window tasks have been used to identify perceptual features that capture attention in a similar manner as eye-tracking. Though often used as a proxy for eye-tracking, viewing window tasks inherently require visuomotor processing in addition to what is necessary when making eye-movements alone: calculating the arm movements that are needed to move the viewing window into the desired region of the image. Unlike eye-tracking paradigms where the speed of programming and executing planned movements makes experimental manipulation difficult, by manipulating the manner in which the window is controlled, a detailed assessment of visuomotor performance in varying conditions is possible.

In the presented work, the efficacy of the viewing window paradigm was successfully evaluated as a visuomotor tool, demonstrating an ability to detect a well-documented sex-difference in task performance. Following this demonstration of utility, the viewing window

paradigm was used in a series of experiments examining the natural aging process and the visual system. In these experiments, visuomotor transformation ability was assessed by introducing a "flipped" relationship between the participant's body movement and the resultant movement of the viewing window: If a participant moved their arm to the left, the viewing window moved to the right. When taken in their entirety, this series of experiments demonstrated older participants did indeed show deficits in performance, though the root cause of this deficit was not established. As previously discussed, the posterior parietal cortex is known site of visual integration, and though its involvement in the viewing window task was predicted, this assumption was verified in a final series of experiments examining the neurological correlates of performing the viewing window task under a visuomotor flip condition. This thesis has provided a new tool for visuomotor research, added to our understanding of the natural aging process, and verified the viewing window recruits parietal cortex in its successful completion.

Summary

This chapter has presented the background information necessary to understand the scope and potential applications of the viewing window methodology. First, a two-stream theory of cortical vision was presented. This section highlighted a theory in which visual information is processed in two cortical visual streams, with an emphasis on the eventual output of the system. Information coming from the ventral stream, projecting from primary visual cortex to inferior temporal lobe allows for the perception of the world around us and the attachment of meaning. The dorsal stream, projecting from primary visual cortex to the posterior parietal lobe, outputs information necessary for the control of skilled movements. Second, the physiological and behavioural evidence for this segregation, and the steps leading up to it, were provided. Third, a discussion specific to the parietal lobe, a neurological region of specific interest to the present

study. was provided reviewing relevant human and non-human primate research. Finding a way to explore the two-stream theory led to the development of the viewing window paradigm. an experimental procedure in which visual information restricted and linked to body movements.

Chapter II: The Viewing Window Methodology

Studying perception by restricting the amount of visual information that is available to the participant has a long history within psychology. In early investigations dating back to the mid-1800's (Zollner, 1862), a cardboard aperture was used to prevent the full view of a target shape. The target shape was moved behind the aperture, giving participants only small amounts of visual information at any one time. Despite this limited view, subjects were able to perceive the whole object. Later work using aperture paradigms has confirmed previous results when using more than one geometric shape (Cattell, 1900; McCloskey & Watkins, 1978), and when using simple line drawings as stimuli (Parks, 1965). These early experiments primarily focused on determining the conditions under which the restricted view would result in a complete percept of the underlying form (Anstis & Atkinson, 1967; Haber & Nathanson, 1968; Helmholtz, 1867/1962). Factors found to prevent or alter the percept under aperture viewing included the speed of object displacement, the speed of aperture displacement, and the eye-movements that occurred during exposure (Morgan, Findlay, & Watt, 1982). Helmholtz's (1867/1962) early work was the first to suggest that a participant engages in an unconscious tracking of the visible shape with the eye, and that this tracking allowed for the effective projection of the stimulus onto the retina. The emphasis on where on the retina the visual stimulus is projected later became known as the "retinal painting" hypothesis. Nearly one-hundred years later, an alternate explanation held that the perception of form was a result of post-retinal storage and the later reassembling of visual information based on time coding (Parks, 1965), a process similar to what occurs during a saccade in natural viewing. Retinal painting only becomes important when the object underneath the aperture, or the aperture itself, is displaced at a high velocity. When the aperture or underlying object moves at a slower rate, post-retinal storage allows for the shape

to be recognized, despite the percept of small pieces of the object at any single time (Rock, Halder, DiVita, & Wheeler, 1987).

Viewing window procedures share many experimental features with earlier aperture work. Importantly, both methods involve occluding a substantial amount of visual information available to the participant. A key distinction between these two related paradigms is that in a viewing window task, coarse peripheral information outside of the viewing window is made available, whereas in typical aperture experiments no peripheral information is made available. Typically, viewing window paradigms present participants with degraded pictures of objects on a computer monitor. A small user controlled area (the "window") displays the underlying images with normal clarity. Similar to aperture-viewing work (Gosselin & Schyns, 2001; Kroliczak, Goodale, & Humphrey, 2003),viewing window tasks have been used to identify perceptual features that capture attention, or are otherwise useful in experimental tasks. Based on evidence from studies examining reading and text comprehension (Just, Carpenter, & Woolley, 1982; Osaka & Oda, 1994), and more recently natural scene exploration (van Diepen & Wampers, 1998), viewing window paradigms have been suggested as a cost effective alternative to eye-tracking procedures used to assess visual attention and visual information acquisition (Jansen, Blackwell, & Marriott, 2003). Nevertheless, despite being used as a proxy for eye-tracking, viewing window tasks inherently require visuomotor processing that is not necessary when making eye-movements alone: calculating the arm movements that are needed to move the viewing window into the desired region of the image. The added complexity of these visuomotor calculations allows viewing window tasks to manipulate somatosensory information and motor signals, without altering the presented visual information. For example, when using traditional gaze-contingent displays, separating the eye-movements from the resultant on-screen

movement of the viewing area would result in no useful, high-resolution, information being available to the participant, as the fixation location would always be within a blurred region of the image. By using the viewing window paradigm, one can manipulate perceptual components related to the presented stimuli (such as colour, degree of blur, and location of key object features) and visuomotor components (such as the relationship between body movement and window movement) of the task, assessing the unique contribution each provides. As a first step in assessing whether the viewing window could be used in later work examining this interaction between perceptual and visuomotor components, a confirmatory study assessing the viewing window as a visuomotor tool was undertaken.

Experiment 1a – The Viewing Window as a Visuomotor Tool.

Before the viewing window could be used as a tool in visuomotor studies, it was necessary to make a number of modifications and improvements. The first improvement involved the calibration of the physical size of the window. In previous reports (Jansen et al., 2003), it was suggested that the viewing area should be of sufficient size to allow the identification of a single element of the stimulus. Even though such a calibration may be useful when studying visual attention, it does not accurately represent the human visual system, a requirement when one examines visuomotor processing. The present study incorporated a viewing window that corresponded with fovea's "useful" resolution size, more naturally replicating the human visual experience. An important distinction is the choice of useful foveal resolution, rather than the physiological limit of foveal vision (which is much larger). By limiting the window size to useful foveal resolution, the amount of detailed visual information is limited to normal visual experience while the participant is following the window with her gaze. Further, if a participant looks at areas of the image outside of the viewing window, the only

information available would be low spatial frequency information, similar to that normally available in peripheral vision. Previous research has demonstrated the useful range of visual eccentricity to be between 2 and 4 degrees (Henderson, Williams, Castelhano, & Falk, 2003; Nelson & Loftus, 1980), with cone density and photopic resolution being closely related up to approximately two degrees of eccentricity (Green, 1970). Calibration of the viewing window dimensions that correspond to natural vision involves fairly simple calculations, and this calibration has previously been utilized in gaze-contingent displays (essentially a viewing window controlled solely by eye-movements) (Shiori & Ikeda, 1989), though such calculations have not been used in viewing window tasks. A second area of improvement concerns the transitional region between the blurred periphery and the central region of the viewing window. Although there is a sudden drop off in the high-resolution information provided by the cones in the human eye, this decline does not occur in bands or regions. Experientially, this drop in resolution is best represented by a smooth transition from the central high-resolution area to the lower-resolution periphery. Even though it is best to replicate the natural experience of vision where possible, research has shown that spatial discrimination decreases linearly as a function of eccentricity, and that some spatial discrimination is still possible in excess of 20-degrees of eccentricity (Westheimer, 1987). The use of such a function in the viewing window paradigm would provide too much peripheral information to the participants. During the viewing window task participants must make gross movements of the viewing window for accurate scan-path observations, while not consciously experiencing banded regions of increasing spatial discrimination. By using a Gaussian-type edge for the transitional regions, the viewing window replicates the experience of natural vision, provided that the Gaussian distribution's full-width at half-maximum has been set appropriately. The third, and perhaps most important, improvement

to contemporary viewing window paradigms concerns the method by which the participants control the movement of the window itself. When used as a tool to assess visual attention, the viewing window is typically controlled using a standard computer mouse. When used as a gaze-contingent display, the movement of the window is based on the real-time collection of eye-movement data. When controlling the viewing window via eye-movements and/or mouse, each method of control has an undesirable impact on how participants are moving the window, and the information that they are gaining throughout the task. When a standard computer mouse is used as the method of control, the complexity of calculations required to move the viewing window to a region of interest are likely greater than the calculations that would be required to move the eyes alone. Specifically, research has shown that tool use requires an extra step in motor tasks – planning must be engaged not only to calculate the correct position of our body, but also the resulting position of the critical region of the tool being used (Heath & Westwood, 2003). Alternatively, the use of eye-movements as a method of control does not allow one to examine the pooling of visual, somatosensory, and motor movements produced in the completion of goal directed tasks. First, due to the speed at which eye movements are calculated and executed, downstream manipulations of motor or perceptual consequences are limited in their scope as any calculations have to be completed before the eye-movement is initiated. Second, visuomotor manipulations (such as the reversals in movement previously discussed), would not be possible utilizing eye-movements alone, as it is impossible to separate the high-resolution fovea from the motor commands utilized to move the eye and window location. To combat these issues, a touch-screen monitor is used to reduce the amount of spatial re-mapping that the task requires (since there is a 1-1 correspondence between the participant's movements and the on-screen movements of the window), while maintaining a visuomotor component to the task.

The present experiment was designed to assess the effectiveness of the viewing window paradigm, with the modifications outlined above, as a visuomotor tool. In order to accomplish this, a well-known sex difference in visual scanning patterns was selected to test whether the viewing window paradigm was sensitive enough to detect small difference between groups. Previous research has shown that females are slower than males, though often equally accurate, when performing a visual search task (Efron, Yund, & Nichols, 1987; Feng, Spence, & Pratt, 2007; McGuinness & Courtney, 1983). Additionally, females are more deliberate in their visual search (Boersma, Muir, Wilton, & Barham, 1969) than males, and that this effect is present by the age of 5 and may be a function of impulsivity (McCluskey, Wright, & Papini, 1984).

Materials and Methods

Participants. Twelve young adults (6M; age range 17-22 years old; mean age = 18.5) were recruited from the University of Manitoba's introduction to psychology participant pool. Participants were right-handed and had normal or corrected-to-normal vision as reported in pre-test screening (Appendix A). Participants received partial course credit for their participation.

Stimuli. Forty-three common and easily identifiable objects were used for this experiment (Table 1). Five of the stimuli were used for practice trials, with the remaining thirty-eight being used for the experiment. Digital pictures (1600 X 1200 resolution) of these objects were first converted to a greyscale format and presented on a grey background, removing any diagnostic colour information that may have been present. Images were then modified using a Gaussian blur algorithm, with a blur radius two standard deviations above the object specific mean blur radius that was required for correct identification. This process ensured that all items were equally blurred (from a psychophysical standpoint), and that no object was recognizable based on peripheral information available outside of the viewing window.

Table 1. List of objects used as practice and experimental items in Experiment 1.

Practice Items:	
Clock	Harmonica
Typewriter	Telephone
Television Remote Control	
Experimental Items:	
Apple	Pushpin
Banana	Razor
Cup	Rolodex
Dice	Saw
Drill	Scissors
Fork	Screwdriver
Glasses	Shoe
Guitar	Spoon
Hardhat	Stapler
Lemon	Stethoscope
Light bulb	Strawberry
Muffin	Tambourine
Mug	Tape measure
Notebook	Teapot
Paperclip	Tomato
Pen	Toothbrush
Pencil	Top hat
Pocket Watch	Vice grips
Pumpkin	Wrench

The viewing window. All images were displayed in the centre of the monitor, and took up the entire viewable surface. The "window" was a circular region with a 51 pixel length (1.3cm) radius, covering a total of 8171 pixels. This area roughly corresponded with the size of useful foveal vision (2.98 degrees). The outermost region of the window displayed the underlying image at full blur and the innermost region displayed the image at normal clarity. A smooth, Gaussian based, transition between these two regions was used to avoid banding within the viewing window (see Figure 1). The viewing window was controlled by a touch-screen monitor, allowing participants to move the window using a stylus held in their dominant hand, with the stylus tip held under the index finger. A stylus was used to ensure adequate pressure was maintained on the touch-screen surface, and to prevent smudges to the screen.

Procedure. Participants were tested individually at a station consisting of a personal computer, keyboard, and monitor. All stimuli were displayed on a 20.1" LCD monitor running at a resolution of 1600 X 1200 (60Hz). Overlaying the monitor was a Keytec "Magictouch" touch-screen. All participants were seated approximately 50cm, at eye-level, from the monitor with both the keyboard and screen within easy reach. All experimental events were simultaneously controlled and recorded on the same 3.2GHz Pentium computer used to present the objects during the study session.

Following verbal and written instructions, participants received a demonstration of the proper use of the touchscreen and viewing window. Participants were told that moving the viewing window around the screen, using a stylus held in their right hand, would display the underlying object in perfect clarity. Participants were instructed to identify the presented object as quickly and as accurately as possible, and to signify identification by pressing the spacebar on the keyboard with their left thumb. After pressing the spacebar, the stimulus was removed from

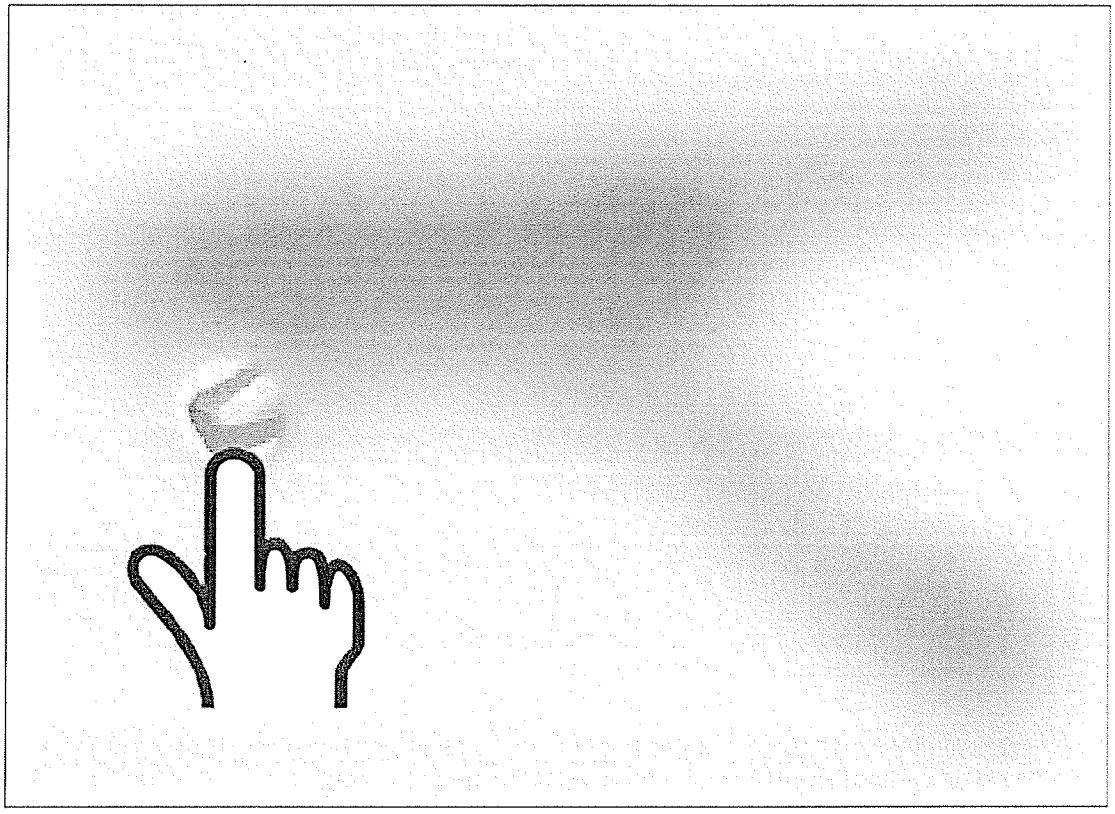


Figure 1. Viewing window illustration.

The circular viewing window displays the underlying image in normal clarity, while the remainder of the image is heavily blurred. The cartoon hand was not present during the experiment, and has been added to indicate where a participant's hand would be positioned. The target object is a pair of vice-grips.

the screen and a message appeared prompting the participant to type in her response using the keyboard. Immediately following a response, the next trial would load. Participants were given no feedback regarding their performance, and continued in this self-paced manner until all objects were presented. Object presentation order was randomized within participant, with five practice trials beginning the experiment.

Results

Main effects and interaction terms were assessed using multivariate repeated-measure analysis of variance (rMANOVA) (Barcikowski & Robey, 1984), where appropriate. When indicated as necessary by the omnibus tests, corrected (Bonferroni) pairwise comparisons were made. Incorrect responses were omitted from the analysis. This resulted in the elimination of 12.9% of trials. The response time (RT) data were separated into three distinct categories: 1) The amount of time taken before movement of the viewing window occurred (pre-movement RT); 2) The amount of time spent moving the viewing window (movement RT); 3) The total amount of time required for identifying the presented object (total RT). A correlational analysis was performed to ensure that pre-movement times were not negatively correlated with movement times, which would have been indicative of diagnostically useful information being present outside of the viewing window region. This correlation was accomplished by calculating mean pre-movement and movement times for each object, and correlating this composite score, resulting in a non-significant result ($r(36) = -.03$, $p > .05$).

Response times. Data were categorized and separated by gender, and compared using a repeated-measures ANOVA, treating items as the random effect. No main effect of gender was observed for the pre-movement RT (1411 ms versus 1249 ms, $F(1,37) = .236$, $p > .05$). A main

effect of gender was observed in the movement response time data, with females taking longer (7780ms versus 5369ms, $F(1,37) = 14.805$, $p < .001$).

Scanning pattern. A participant's individual visuomotor scanning pattern (a series of X-axis and Y-axis coordinates directly related to the arm movements used to control the viewing window) was recorded for each object, with a sampling rate of 66 Hz. A typical scanning pattern can be seen in Figure 2. Even though each individual scanning pattern is of interest in itself, a more useful measure is obtained by examining all of the participants' data at one time. To accomplish this averaging, each of the object images was parsed into four 800 X 600 pixel quadrants (see Figure 3). An item-by-item analysis was utilized to determine each object's associated scanning pattern. Twenty-one of the 38 items showed a significant effect of quadrant, after adjusting for the number of comparisons using the Bonferroni adjustment (see Table 2), demonstrating a clear dissociation in quadrant viewing times. After a quadrant of significant interest has been identified, higher resolution grids can then be applied (such as Figure 4) to determine with greater accuracy the components of the object that received the most attention.

Discussion

The results demonstrated that the viewing window methodology was highly sensitive and capable of being used to accomplish a number of important tasks required to be useful in investigating visuomotor processes. First, the correlational analysis demonstrated that the information presented outside of the viewing window was non-diagnostic in this task: participants who spent more time in the pre-movement stage did not spend significantly less time in the movement stage. Second, the analysis of response time data revealed the viewing window was able to demonstrate differences in two groups' response times required to identify the

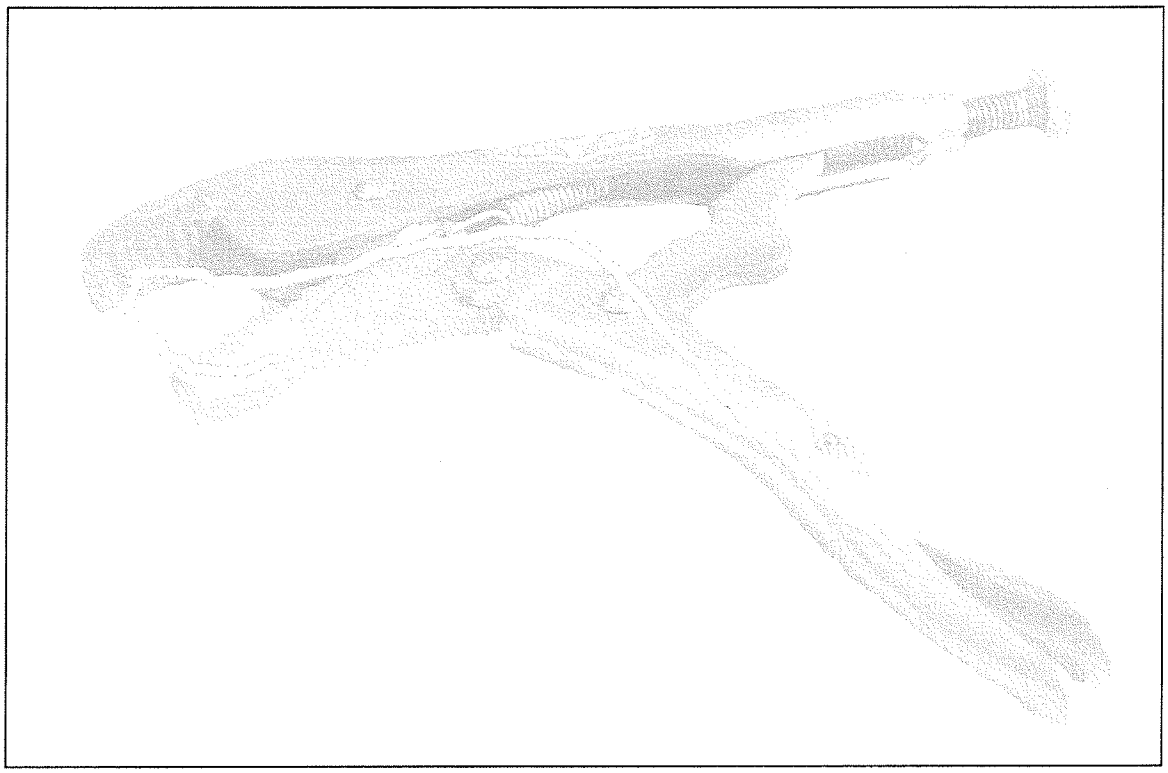


Figure 2. Typical visuomotor scan pattern.

Typical visuomotor scan pattern captured from one trial, from a single participant. The highlighted line represents the search coordinates recorded.

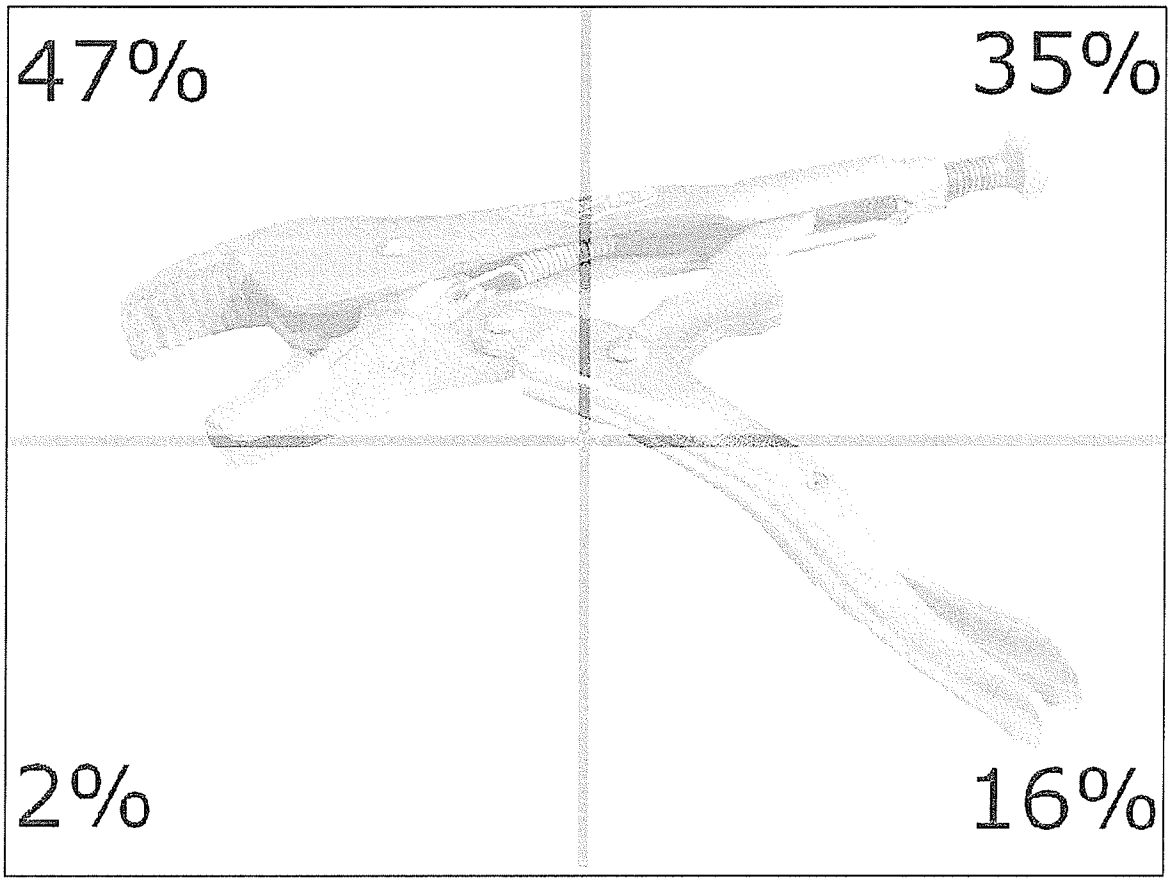


Figure 3. Typical quadrant analysis.

A typical quadrant analysis obtained from a single item across subjects. Percentages represent the ratio of movement time spent in each quadrant.

Table 2. Results of ANOVA by items in Experiment 1a.

Experimental Item:	Obtained F-Value	df1	df2	Significance	Quadrant of Interest
Apple	12.34	3	6	0.006	A
Banana	11.39	3	7	0.004	A
Cup	3.53	3	7	0.077	D
Dice	**165.37**	**3**	**8**	**<0.001**	**A**
Drill	**1243.48**	**3**	**6**	**<0.001**	**B**
Fork	**12036.09**	**3**	**9**	**<0.001**	**A**
Glasses	**202.95**	**3**	**7**	**<0.001**	**A**
Guitar	**1734.56**	**3**	**7**	**<0.001**	**A**
Hardhat	2.11	3	6	0.201	C
Lemon	**9.54**	**3**	**6**	**0.011**	**A**
Light bulb	**39.16**	**3**	**8**	**<0.001**	**C**
Muffin	0.91	3	8	0.477	A
Mug	2.67	3	9	0.111	A
Notebook	3.36	3	9	0.069	A
Paperclip	**315.45**	**3**	**7**	**<0.001**	**A**
Pen	**78.11**	**3**	**9**	**<0.001**	**A**
Pencil	**36.34**	**3**	**9**	**<0.001**	**A**
Pocket Watch	66.28	3	3	0.003	B
Pumpkin	**26.19**	**3**	**9**	**<0.001**	**B**
Pushpin	0.65	3	4	0.624	A
Razor	7.58	3	2	0.119	A
Rolodex	4.25	3	5	0.077	A
Saw	**21.29**	**3**	**6**	**0.001**	**B**
Scissors	**17.83**	**3**	**7**	**0.001**	**A**
Screwdriver	**2276.74**	**3**	**9**	**<0.001**	**D**
Shoes	10.74	3	8	0.004	A
Spoon	**1891.78**	**3**	**9**	**<0.001**	**A**
Stapler	**80.66**	**3**	**9**	**<0.001**	**C**
Stethoscope	6.07	3	5	0.040	A
Strawberry	5.70	3	7	0.027	C
Tambourine	4.24	3	4	0.098	A
Tape measure	**16.71**	**3**	**9**	**0.001**	**C**
Teapot	6.41	3	8	0.016	A
Tomato	9.33	3	7	0.008	A
Toothbrush	**948.27**	**3**	**9**	**<0.001**	**A**
Top hat	**38.99**	**3**	**6**	**<0.001**	**A**
Vice grips	**263.45**	**3**	**5**	**<0.001**	**A**
Wrench	**657.94**	**3**	**4**	**<0.001**	**C**

*The quadrant of interest column displays the quadrant (A – Top Left, B – Top Right, C – Bottom Left, and D – Bottom Right) with the highest percentage of total trial time. Those items displayed in bold demonstrated a significant main effect of quadrant (A, B, C, or D) after adjusting for multiple comparisons (Bonferroni).

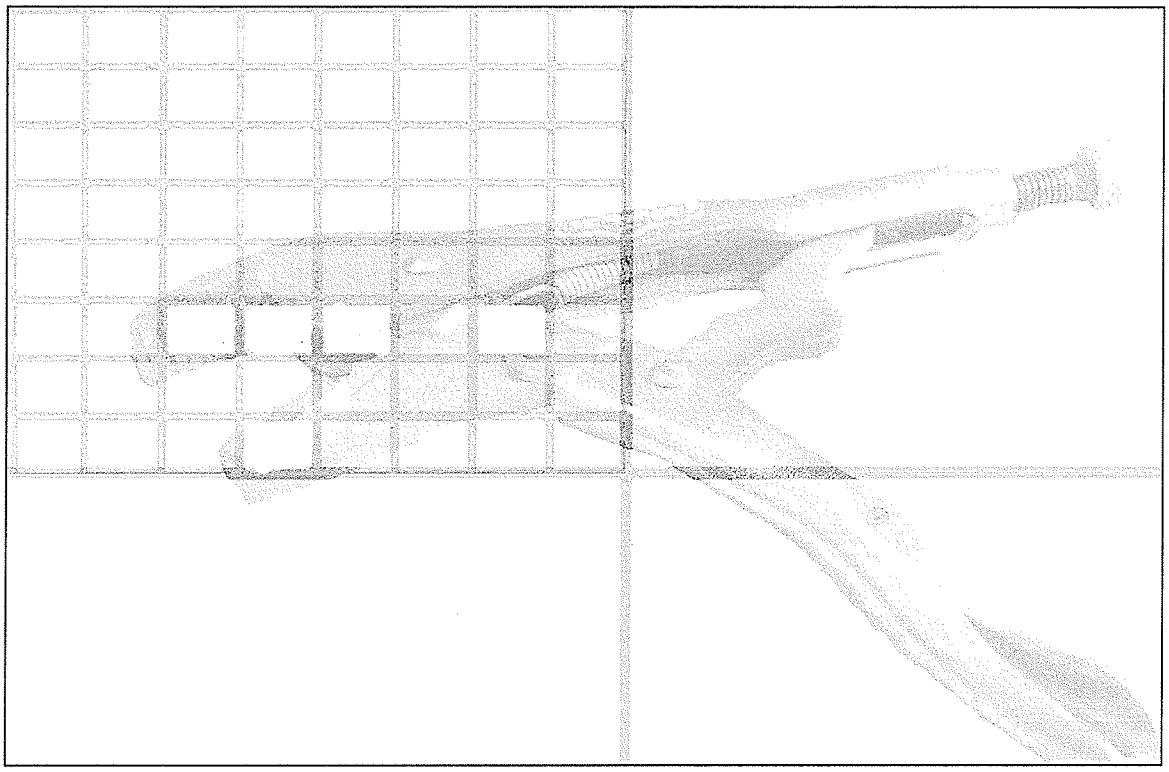


Figure 4. Detailed quadrant analysis.

Highlighted regions represented segments of the image that received five percent or more of the total object viewing time, across subjects.

presented object: a significant main effect of gender demonstrated that although both sexes spent equivalent times looking at the object before initiating window movement, males spent significantly less time in the movement phase. Third, gross discrimination between scanning patterns utilized to identify an object was possible: the individual item analysis confirms that different objects elicited different visuomotor scanning patterns.

Though not the primary focus, the results of Experiment 1a are in agreement with dominant accounts of object identification in terms of a general process. The initial categorization of an object is thought to occur at a basic level (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). Under restricted viewing conditions of greyscale images (like those used in the viewing window), an object's texture and the visible relationship among unique components are thought to be the primary source of information that determines identification (Biederman, 1987) (Tversky & Hemenway, 1984). Object identification can be further divided into sub-processes that are completed in a cascade. First, an edge extraction that is sensitive to surface characteristics such as luminance, texture, and colour occurs. Following edge extraction, non-accidental properties (such as symmetry) of edges are detected, simultaneous with object parsing based on points of deep concavity. The resulting arrangement of components is then matched to representations in memory (Biederman, 1987). The componential account of object recognition described has implications for areas of an image one would expect would attract visual attention. Areas that contain superimposed orientations or corners, and high spatial contrast would attract both visual attention and eye-movement fixations (Barth, Zetzsche, & Rentschler, 1998; Privitera & Stark, 2000; Reinagel & Zador, 1999). Similarly, one would expect areas identified as attracting visual attention in a viewing window paradigm could also be

predicted using the low-level visual saliency calculations based on the steps previously described.

The viewing window methodology is, on the surface, providing similar information to what is available through traditional eye-tracking. However, in comparison to eye-tracking, the viewing window has a number of distinct advantages when used as a tool to track visual attention. First, the viewing window requires few pieces of specialized equipment (a modern PC and an inexpensive touch-screen are all that are required). Eye-trackers are, for some, prohibitively expensive and require a substantial financial commitment. In addition to hardware costs, they require substantial expertise in calibration and adjustment which may also discourage researchers. In comparison, the viewing window requires no calibration, and is intuitive both in set-up and data interpretation. Most importantly for this thesis, the viewing window methodology allows the assessment of both motor and perceptual components of a task. Eye-tracking based paradigms do not have an easily manipulated visuomotor component that can be used to examine interactions between perception and action. In contrast, by manipulating the manner in which the window is controlled, an assessment of visuomotor performance during the viewing window task is easily accomplished.

A limitation to the presented work is we have not verified that the viewing window is being used by participants in the manner expected. Previous research (Jansen et al., 2003) has demonstrated a correlation between areas of interest identified through eye tracking and areas identified with viewing window methodologies. However, the modifications that were made to the viewing window paradigm previously (transitional blur regions, calibrated to foveal size, controlled via a touch-screen) may have an impact on the relationship between the eyes and hand. Although behavioural measures demonstrate the viewing window is able to restrict a

participant's ability to obtain diagnostically useful information without moving the window (represented by the non-significant correlation between pre-movement and movement time found in Experiment 1a), and that the viewing window methodology is sensitive to features of an object that receive visual attention (demonstrated through an identification of item specific quadrants of interest), a second experiment was conducted to validate participants were following the viewing window with their gaze in a manner consistent with previous research.

Experiment 1b – The Viewing Window and Eye-tracking

A key question that had to be answered before the viewing window could be utilized as a visuomotor tool is whether participants were interacting with the window in the expected manner. Since previous research has demonstrated strong correlations between tasks similar to the viewing window and eye-tracking (Horvath, 2003; Jansen et al., 2003), it was important to ensure that the new "modified" version of the viewing window preserved this relationship. The aim of the present experiment was to compare the tracking information obtained by analyzing the movements of the viewing window with information that was obtained by monitoring the movements of participants' eyes. Due to the complexity of the viewing window task, three rather distinct areas of research are discussed.

From studies examining eye-fixations alone, object conspicuity is known to attract visual attention. During the initial viewing of an image, a saliency map is built based on low-level visual discontinuities (such as colour, intensity and line orientation). When such a map is constructed, saliency peaks represent regions that are distinct from their surroundings and are also likely to attract attention. Once a fixation has been made, a process of inhibition is activated preventing fixations from occurring at the same location and instead for fixations to move to the next most salient region of the image (Itti & Koch, 2000; Underwood, Templeman, Lamming, &

Foulsham, 2008). Cognitive models, using low-level features of an image to make predictions about the location of initial fixations on static pictures in free-viewing tasks, perform adequately at predicting human gaze patterns (Itti, 2006; Parkhurst, Law, & Niebur, 2002; Underwood, Foulsham, van Loon, Humphreys, & Bloyce, 2006). Although fixations may initially be driven by low-level features of presented images, as participants are forced to move the viewing window to identify the presented objects, mechanisms related to hand-eye coordination must be involved.

Normal eye-hand coordination involves numerous sensorimotor systems including eye, head, and arm control systems, the visual system, the vestibular system, and components of proprioception. In addition, eye-hand coordination is also affected by cognitive factors such as attention and memory (Crawford, Medendorp, & Marotta, 2004). Despite the many systems involved in eye-hand coordination, the end goal is straightforward – using vision to guide movements of the hand. Important to the following discussion is the temporal coupling between eye and hand movements. This linking of eye and hand movements is known to vary in a task-dependent manner (Fisk & Goodale, 1985), with the general finding that temporal coupling is stronger for intentional tasks than automatic ones (U. Sailer, Eggert, Ditterich, & Straube, 2000). The site of gaze also plays an important role in eye-hand coordination, with gaze often being locked onto a target of interest until that target is reached by the hand, regardless of visual feedback (Neggers & Bekkering, 2001). Such a gaze fixation strategy allows the visual target to be projected onto the fovea, while reducing the computations that would be required if changes in gaze location were taking place. The viewing window task, as it is in essence a tool, also required the learning of novel visuomotor relationships. Depending on the nature of the task, these relationships may be simplistic (such as when a 1-1 correspondence between finger and

window movement is present) or complicated (such as when visuomotor reversals are utilized). Eye-movements are known to play a valuable role in the learning of visuomotor relationships, and are discussed next.

Studies examining eye-movements during the learning of novel visuomotor relationships have demonstrated that motor learning requires the acquisition of new maps relating motor commands to sensory outcomes (Kawato, 1999; Wolpert & Miall, 1996). In a general sense, visuomotor learning occurs in 3 stages. During the early stages of motor skill learning, performance is often uncoordinated and requires significant cognitive resources in making decisions and executing movements (Willingham, 1998). During this stage, the learner attempts to discover the basic mapping rules to relate motor and sensory signals. In tasks where only an adaptation of previously learned sensorimotor mapping is required, the exploratory stage is thought to be very brief. In a second stage, termed skill acquisition, a learner's performance demonstrates marked performance, and gaze fixations begin to precede desired hand locations, suggesting participants have established basic mapping rules between manual actions and eye movement controls. In the final stage, these established mapping rules are further refined to improve task performance (U. Sailer, Flanagan, & Johansson, 2005).

Based on what is known about initial fixations during object exploration, eye-hand coordination, and eye-movements in visuomotor learning, a concise prediction as to how a participant will interact with the viewing window is possible. First, participants should direct their gaze at areas that are visually salient on the basis of intensity and/or line orientation. Next, a participant's eye-movements should follow the window movement while a modified visuomotor relationship between hand (and window) movement and eye-movements is learned. Finally, once a participant is proficient at the task, eye-movements should precede window

movements, with gaze remaining at a location of interest until the viewing window is brought to the same area. As participants are only required to utilize previously learned sensorimotor mapping, the exploratory stage would be very brief, with participants advancing quickly into skill refinement (U. Sailer et al., 2000; U. Sailer et al., 2005).

Materials and Methods

Participants. Twelve young adults (4M; age range 18-26 years old; mean age = 19.5) were recruited from the University of Manitoba's introduction to psychology participant pool. Participants were right-handed and had normal or corrected-to-normal vision as reported in pre-test screening (Appendix B). Participants received partial course credit for their participation.

Stimuli. Eighty common and easily identifiable objects were used for this experiment (Table 3). Pilot work examined the correlation between the average time taken to identify presented objects, across participants, with the items' associated KF-word frequency (Kucera & Francis, 1967) values, where possible, and found no significant relationship ($r(45) = -.214$, $p > .05$). Five of these objects were used for practice trials, with the remaining seventy-five used as experimental trials. All items were blurred to a level two standard deviations above the object specific mean blur radius that was required to identify the

object in previous pilot work. This object calibration ensured all objects were equally difficult to identify and that no objects were recognizable based on peripheral information presented outside of the viewing window.

The viewing window. Viewing window specifications matched those previously reported in Experiment 1a.

Table 3. List of objects used as practice and experimental items in Experiment 2.

Practice Items:	
Clock	Harmonica
Typewriter	Telephone
Television Remote Control	
Experimental Items:	
Apple	Pen
Banana	Pencil
Binder Clip	Pencil sharpener
Camera	Pepper
Clamp	Piggy bank
Coffee Cup	Pills
Corkscrew	Pocket watch
Boot	Potato peeler
Dagger	Pumpkin
Ring	Pushpin
Dice	Razor
Drill	Rolodex
Guitar	Safety pin
Envelope	Saw
Eyeglasses	Scissors
Diskette	Screwdriver
Fork	Shirt
Pen	Shoes
Frying pan	Spoon
Hairbrush	Stapler
Hardhat	Stethoscope
Highlighter	Strawberry
Hole Punch	Sunglasses
Hourglass	Tambourine
Jug	Tape dispenser
Kiwi	Tape measure
Lamp	Teapot
Laptop	Three holed punch
Lemon	Toaster
Light bulb	Tomato
Lighter	Toothbrush
Lipstick	Top hat
Mallet	Vice grips
Mug	Walnut
Muffin	Watch
Notebook	Watering can
Chair	Work gloves
Paperclip	Wrench
	Yarn

Eyetracking. An Eye-link II (250 Hz sampling rate, spatial resolution < 0.5 degrees; SR Research Ltd., Osgoode, ON, Canada) was used to record eye-movements throughout the experiment. Pupil and CR-based tracking was used in a monocular (left) mode.

Procedure. The experimental procedure matched those reported in Experiment 1a, with the exception of modifications required for eye-tracking. Each participant's eye-movements were calibrated using a 9-point calibration screen and validated to less than 1-degree of error before beginning the experiment. Each trial began with a fixation point which served two purposes: 1) An object was not presented until the participant was fixating at this location, to ensure viewing window and fixation location were approximated equal and 2) it allowed the use of in-vivo drift correction, to compensate for head-band slippage or other small movements in the head-mounted eye-tracker. Participants were not given any feedback about their accuracy and continued through the entire experiment in a self-paced manner. Object presentation order was randomized across subjects.

Results

Incorrect responses and trials where eye-tracking validation failed were removed from the analyses, resulting in the elimination of 28% of all experimental trials. For the remaining items, eye and window movement data were extracted separately, so a comparison between the two methods could be made. Due to the expected complex relationship between participants' eye-movements and window movements (for example, at times fixations will precede window movements, to select regions of visual attention, while at other periods throughout the trial eye movement and window movement will overlap in time), a temporal correlation between eye-movement scanpath and window movement scanpath was not feasible (although visually inspecting these scanpaths provided a coarse measure of their alignment – see Figure 5), instead,

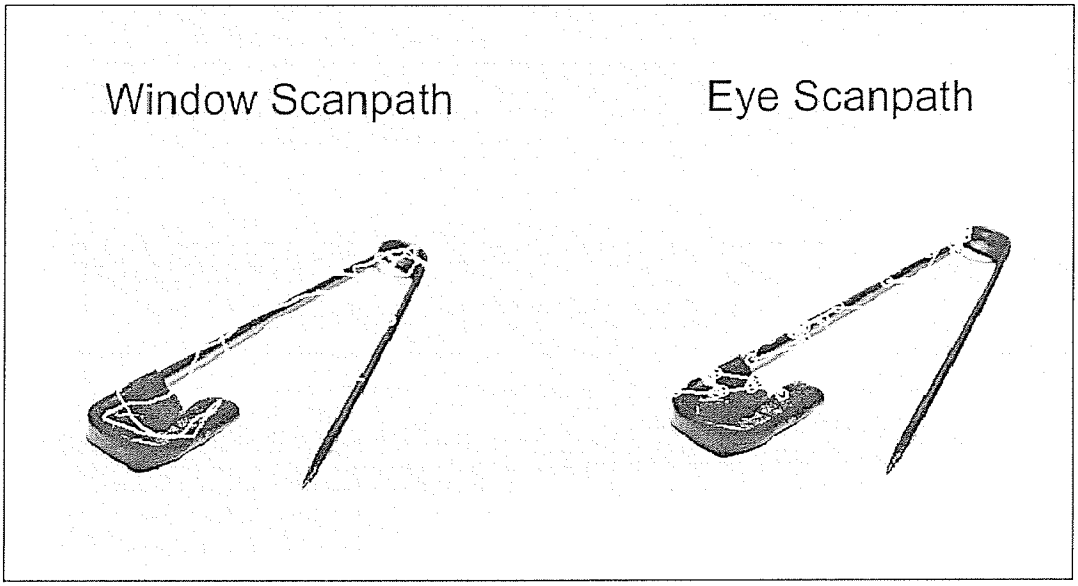


Figure 5. Eye-based and window-based scanpaths.

Right: Eye Scanpath. Circles represent fixations, swith the lines joining them the scanpath of the participant's eye-movements. Left: Window Scanpath. The solid line represents the scanpath of the window movement. Although not temporally aligned, both window and eye movement scanpaths cover the same spatial area.

a spatial alignment based on regions that captured visual attention was used. Fixations were defined as those periods that did not meet the criteria for classification as either a saccade (eye velocity greater than 30-degrees per second with an acceleration value greater than 8000) or a blink (a period of saccade detector activity with missing pupil data for three or more frames in a sequence).

Correlations between eye and window. As a cursory evaluation, both eye-movement and window-movement scanpaths were submitted to a spatial analysis, which segmented the image into sixteen x sixteen (256 total), 100 x 75 pixel rectangles. Each of the recorded eye-fixation and viewing window sample coordinates were coded as being within the appropriate spatial location, based on the segmentation of the object previously described. To ensure participants were interacting with the window in the predicted manner, the most frequent spatial location along each axis was averaged across participants for each individual item. The resultant composite X-, and Y-axis scores from both the eye-tracking and viewing window data were correlated, resulting in a significant relationship for both axes ($r(73) = .307$, $p < .01$; $r(73) = .227$, $p < .05$, respectively).

Location of initial fixations. To determine if initial fixations while using the viewing window were a result of bottom-up attentional location, a comparison between fixation locations predicted by a well established model of human behaviour based on visual saliency (Itti, Koch, & Niebur, 1998) and those observed while using the viewing window was made. To accomplish this comparison, the first 3 fixation locations for each participant's scanpath were compared to the three most salient visual regions identified by the Itti model (Itti et al., 1998). If a participant's fixation was within 2.6cm (approximate foveal vision) of the centre of the model prediction coordinates it was considered to be a correct prediction. This comparison resulted in

52% of items having at least one of the three initial fixations being correctly predicted by the model, compared to 27% when a randomized model was used.

Descriptive relationship between eye and window. To better quantify the relationship between the viewing window data and eye-movement data, a number of descriptive statistics were calculated. First, the percentage of time the viewing window was within foveal vision was found to be 45.3% of the total trial time. Additionally, the percentage of trial time the viewing window was moving towards a fixation location was calculated to be 58.5% of the total trial time. Finally, the average distance between a fixation location and the viewing window location was 295 pixels (7.52cm).

Discussion

The aim of this experiment was to determine the relationship between the manner in which participants move the viewing window, and the fixations that they make when performing the object identification task presented. Therefore, the main focus of the analysis was to ensure that areas of the image that were identified as capturing visual attention using the viewing window were also the areas capturing visual attention as indicated by eye-tracking, when no visuomotor manipulations were applied to the control of the viewing window. Significant correlations were found between eye and window data reported in both the modal X- and Y-axis spatial locations. It is not the case, however, that the participant is simply following the viewing window with their eyes. In fact, more than half of the trial time was spent with the viewing window moving towards the location of a fixation, only being within foveal view 45.3% of each trial, with an average distance between the location of a fixation and the location of the window being 7.52cm. Finally, participants are still making predictable fixations based on low-level visual features of the presented image. This result is important, as it demonstrates participants

are not unduly modifying visual strategies commonly used when identifying objects as a result of the restricted vision provided through the viewing window. These data may be reflective of a relationship between the location of eye-fixations and window location in which a participant is using the heavily blurred peripheral information to select locations of interest, and then guiding the movement of the viewing window towards these fixation locations to extract the necessary visual information to identify the presented object. Though the correlations reported are admittedly a very coarse measure, it is sufficient to verify participants are interacting with the viewing window in a logical manner, largely driven by bottom-up attentional processes. In summary, the data presented conform to previous research involving hand-eye coordination, the learning of visuomotor relationships, and eye-movements during object exploration and verifies participants are interacting with the viewing window in a predictable manner. Participants are directing their gaze at areas that are visually salient, in large part based on image intensity and line orientation. Following these initial fixations, a participant's eye-movements follow the window, in order to learn the visuomotor relationship between hand/window and eye-movements. In the later stages of the experiment, eye-movements appear to precede window movements, with gaze remaining at a location of interest until the viewing window is brought to the same region of the image. This experiment confirmed the viewing window, without visuomotor modifications, provides data comparable to that obtained through traditional eye tracking methods. With this fact confirmed, it was possible to examine visuomotor relationships not assessable with eye-tracking methodologies.

Chapter Summary

With research in lab focusing on the collaboration between the "perception" and "action" cortical visual pathways, new procedures must be designed to manipulate dorsal and ventral

pathway requirements. Traditional viewing window paradigms have very little control over visuomotor components, and a lack of a 1:1 alignment between body and window movements provides no baseline condition to compare task performance. In contrast, traditional gaze-contingent displays (where the viewing region is controlled by eye movements) do not offer a readily accessible and easily manipulated visuomotor component, required to examine the interaction of perception and action in an interesting manner. Further, gaze-contingent displays, since they rely on ballistic saccades, are much more difficult to manipulate online, requiring specialized equipment to do so effectively. By using the new viewing window procedure, the ability to discriminate any gross asymmetries in a participant's visuomotor scanpath used to identify these common objects has been demonstrated. This finding allows for many extended applications of the viewing window procedure that may have been previously overlooked (or impossible). Specifically, systematic manipulations of various task characteristics will allow for an in-depth analysis of dorsal and ventral visual interactions in performance. By manipulating visuomotor requirements while holding the "perception" utilization at a constant, a better understanding of how the perception and action systems interact will be possible. With the action system responsible for the visual control of highly skilled actions, it must compute the actual metrics of target objects or locations based on an egocentric coding. Therefore, changing features of the task that alter this egocentric frame of reference, while keeping much of the perceptual features the same, would be classified as an "action" or visuomotor manipulation. Manipulations that altered the perceptual experience of the task but kept dorsal stream information unmodified would be classified as "perception" manipulations. A simple example of each follows: By manipulating the spatial relationship between a participant's motor movement and window movement (a leftward arm movement moves the window to the right).

visuomotor manipulation is achieved: the perceptual components of the target remain unchanged, but the motor requirements necessary to achieve them have altered. In contrast, if one was to flip the object itself (so now the right side of the object is on the left), this would be an example of a perceptual manipulation: dorsal stream metrics remain valid (with relation to hand and window movements), but the perceptual features of the object (the location of areas of interest) are altered.

With the basic methodology confirmed, it was possible to extend the application of the viewing window procedure in ways that were previously overlooked or impossible. Two specific projects were undertaken to evaluate the usefulness of the viewing window paradigm in a number of different settings. First, a study designed to evaluate the viewing window paradigm as a method to assess visuomotor transformation ability in natural aging was undertaken. Following this assessment, research was conducted demonstrating that the viewing window methodology can be used to determine the neurological correlates of visuomotor transformations.

Chapter III: The Viewing Window and Natural Aging

Under normal circumstances, we have few problems using sensory information to respond to our environment. In fact, much of our ability to acquire and maintain the motor skills utilized on a daily basis capitalize on the ability to integrate and transform sensory information into a motor response. Previous research has shown that as one grows older, there is a significant decline in the ability to acquire new motor skills, and a general decline in motor skill performance (Harrington & Haaland, 1992; Seidler-Dobrin & Stelmach, 1998; Seidler, 2007). This finding is of special importance, as an aged population requires the learning of new motor skills, such as the use of a cane or wheelchair, to offset physical deterioration. Although the cause of this diminished ability is most likely multi-faceted, a necessary requirement in the learning of new skills and tool use is the ability to successfully perform visuomotor transformations. Two primary mechanisms of visuomotor adaptation have been agreed upon: *spatial realignment* and *strategic control* (Redding, Rossetti, & Wallace, 2005). Strategic control includes modifying, selecting, or learning specific movement plans that are appropriate to the task at hand. Some relevant examples would be the use of side-pointing (a deliberate reach plan that misses in the manner opposite to the perturbation), on-line corrections to the movement path when feedback demonstrates the previously calculated movement plan is erroneous, and/or a temporary recalibration of local spatial arrangements for a specific task. Relevant implicit knowledge of a novel visuomotor transformation has been construed as an internal model that approximates the transformation (the *internal model framework*). By capturing the new relationship between motor commands and their desired sensory outcomes, predictions related to the consequences of motor commands (forward model), and the motor commands required to achieve a desired output (inverse model) can be made (Flanagan & Wing, 1997; Heuer &

Hegele, 2008; Krakauer, Ghilardi, & Ghez, 1999; Wolpert & Kawato, 1998). In contrast, spatial realignment is a result of the registered difference between the performance expected from a feed-forward movement plan and the performance achieved under feedback control, signalling a discrepancy between spatial maps. This discordance, in turn, provides the impetus for an incremental realignment that serves to improve performance in the task at hand (Newport, Brown, Husain, Mort, & Jackson, 2006).

Research has demonstrated declines in a wide range of cognitive abilities as a process of natural aging. For example, there are significant declines in verbal memory, and spatial ability that are often attributed to a reduction in processing speed (Salthouse, 1996). It is likely that these declines in cognitive ability will have a substantial impact on visuomotor performance in a wide range of tasks. Previous studies examining the effect of aging on visuomotor transformation and adaptation have provided mixed results, with some studies demonstrating no age related impairments (Canavan, Passingham, Marsden, Quinn, & et al., 1990; Roller, Cohen, Kimball, & Bloomberg, 2002), though other studies have shown slower and/or reduced adaptation (Buch, Young, & Contreras Vidal, 2006; Fernandez-Ruiz et al., 2003; Seidler, 2006; Teulings, Contreras Vidal, Stelmach, & Adler, 2002). There are a number of possible explanations for this conflicting data which may be inherent in the experimental task itself, such as task transparency, participant instruction, and data analysis techniques, and others that are more a product of working with special populations, such as each participant's individual cognitive functioning. For example, a wide range of experimental tasks have been used to assess adaptation abilities, including modifying display gain (Teulings et al., 2002), prismatic adaptation (Canavan et al., 1990; Fernandez Ruiz, Hall, Vergara, & Diaz, 2000; Roller et al., 2002), sudden rotations of the stimulus display (Buch et al., 2006) (McNay & Willingham,

1998), and gradual rotations of the display (Buch et al., 2006) Even when studies are closely matched in methodology, conflicting data has been reported. For example, Roller et al. (2002) had both younger and older participants complete a throwing task while wearing displacement prisms that shifted the visual world 20-degrees to the right and found no differences in visuomotor adaptation ability between groups. In comparison, using a nearly identical task (30-degree displacement, larger target size than Roller et al. (2002)), Fernandez-Ruiz et al. (2000) found both slower adaptation rates in the elderly participant group, as well as a larger after-effect. Spawned partially by these conflicting reports and a desire to utilize the viewing window in an experimental setting, two experiments were conducted to further assess and clarify the aging brain's ability to perform visuomotor transformations.

Experiment 2a - Natural Aging Affects Visuomotor Transformation Ability

The purpose of the present study was to further research targeting the effects of aging and visuomotor transformation. Specifically, this experiment was designed to determine whether a healthy, aged population performs at lower levels than younger controls in a visuomotor transformation task. The viewing window task was used because it has a number of benefits over previously reported visuomotor paradigms. It is a substantially more complicated task than those used in previous research, requiring an assortment of cognitive, visual, and visuomotor skills to complete. In comparison to tasks such as ball throwing, the viewing window has a more complicated visual design, spatial layout, and requires devoting cognitive resources to the identification of the object, in addition to performing the required visuomotor transformations. By increasing the task difficulty it was possible to better understand the conflicting reports of aging effects on visuomotor transformation/adaptation.

Aged participants were expected to demonstrate deficits in a number of dependent measures reflective of visuomotor transformation difficulty. When examining a participant's window movement scanpath, a more complicated pattern was expected when a visuomotor transformation was required, as evidenced by a larger number of reversals (sudden changes in movement direction) in each of the flip conditions. When examining average trial velocities, aged participants were expected to be slower overall when compared to young controls, and thus take longer on a trial by trial basis. When examining the overall direction of movement of the window aged participants were expected to demonstrate an increase in movement direction consistent with the direction of induced visuomotor distortion. This latter hypothesis is based on how participants are known to initially react when presented with a visuomotor distortion similar in nature to the one used here. Specifically, because the number of sudden reversals and zigzags in movement path are reflective of ongoing / incomplete adaptation (Roby-Brami & Burnod, 1995), such a back and forth motion would increase total movement along the same axis as the introduced visuomotor discrepancy.

Materials and Methods

Participants. The young control group consisted of twelve participants (2M, 10F; age range 18 – 33 years old, mean age = 22) recruited from the University of Manitoba's introduction to psychology participant pool and received course credit for their participation. The aged group consisted of eight participants (1M, 7F; age range 62 – 74, mean age = 68) recruited from the University of Manitoba Centre on Aging participant database and received no remuneration. Additionally, older adult participants were asked a series of questions to exclude those that had pre-existing conditions that may have affected performance (such as certain prescription medications and a history of stroke or arthritis, or the presence of neurological

disorder) and can be seen in Appendix C. Further, all aged participants were maintaining independent living status and reported their level of health to be good to excellent. Cognitive screenings were performed on all aged participants. Six of the eight aged participants completed the Mini Mental State Exam (Folstein, Folstein, & McHugh, 1975) (mean score = 29.8, standard deviation = 0.41). Two participants were unavailable for an in-person screening, and instead completed an abbreviated mental test (Hodkinson, 1972) (mean score = 10, standard deviation = 0). All cognitive screening scores were at or above normal levels (Crum, Anthony, Bassett, & Folstein, 1993). Aged participants' near point acuity (NPA) were verified using an MIS pocket vision guide (Ferris, Kassoff, Bresnick, & Bailey, 1982), and participants were required to have a NPA of 20/25 or greater (Leat, Legge, & Bullimore, 1999).

Stimuli. The same eighty common and easily identifiable objects used in Experiment 1b were used for this experiment. Pilot work had established these items as being equally identifiable in both young and aged participants, with a mean correct identification rate of 74%, while using the viewing window paradigm. Additionally, the level of image blur used for the older participants was independently established at two standard deviations above the object specific mean blur radius required for correct identification within an older participant group. Five of these objects were used for practice trials, with the remaining seventy-five used as experimental trials.

The viewing window. The viewing window specifications matched those used in previous experiments.

Procedure. The experimental procedure was similar to Experiment 1b, with the exception that three Visuomotor-flip conditions were created by varying how the participant's body movements affected the onscreen movement of the viewing window, and can be seen in

Table 4. Participants were naïve to the visuomotor manipulation. Object presentation and visuomotor-flip condition were randomized within subjects, with each visuomotor-flip condition having a 25% chance of occurring on any given trial.

Results

Due to aged participants' overall slower performance, 50% of the eight participants from this demographic were unable to complete the full set of 80 stimuli. For these participants, only data from the completed trials were included in later analyses. No significant differences in accuracy between the aged participants and the younger controls (average incorrect = 33.7%) were observed. Trials in which the target object was not correctly identified were analyzed separately from those trials in which correct identification was achieved.

Four separate examinations of the correct response data were conducted. First, participants' window movement scanpaths were visually inspected and then quantified by assessing the number of reversals present. Next, an analysis on viewing window movement time was performed. Third, an analysis on average trial velocities was performed. Finally, an examination of the direction of movement was undertaken. An initial outlier analysis was performed on the movement time data, excluding values 2.5 standard deviations from each participant's mean for that condition. This resulted in the elimination of 1.6% of trials from all statistical analyses. Unless otherwise stated, multivariate analyses of variances were used, with an alpha level equal to .05. Incorrect responses were submitted to the same four analyses previously described resulting in insignificant findings and are not reported.

Sample scanpaths. Upon visual inspection of the participants' individual scanpaths, when no visuomotor flip was required, aged participants engaged in more scanning of the object than the young controls (Figure 6). Additionally, when a visuomotor-flip was required, aged

Table 4. Visuomotor flip conditions in Experiment 2a.

Movement Type	X-Axis Body Movement	Y-Axis Body Movement
Normal	Remains veridical	Remains veridical
Full Flip	Results in opposite on-screen movement	Results in opposite on-screen movement
Flip in X-Axis	Results in opposite on-screen movement	Remains veridical
Flip in Y-Axis	Remains veridical	Results in opposite on-screen movement

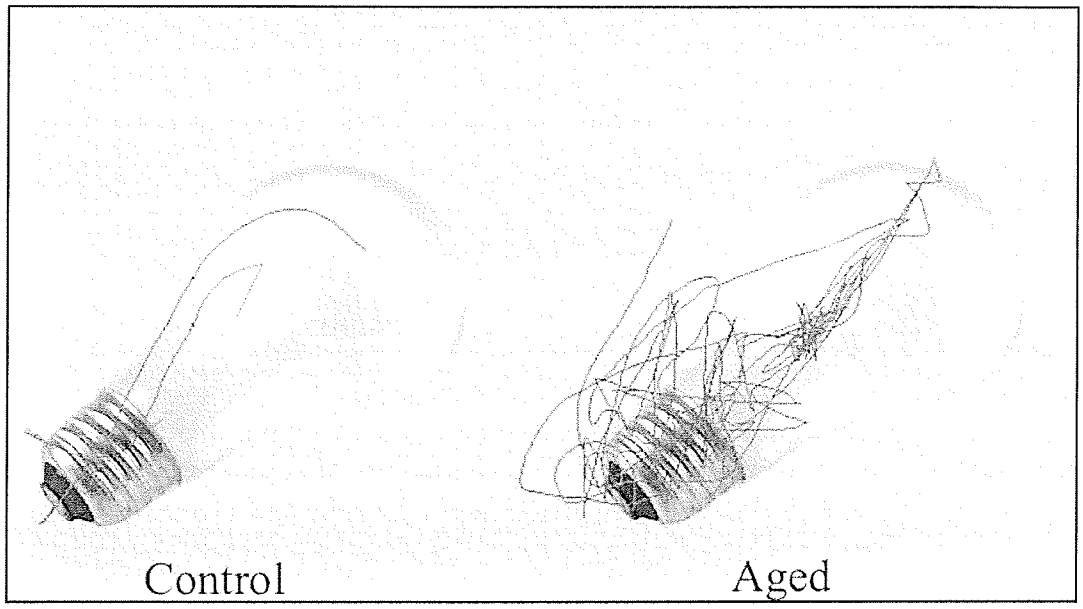


Figure 6. Example scanpath, Experiment 2a.

When no visuomotor transformation was required, aged participants engaged in more scanning of the presented object as compared to younger controls.

participants appeared to have greater difficulty adapting to the new relationship between body and window movement (Figure 7). The number of reversals of window direction per trial was used as a measure of scanpath complexity, and can be seen in Figure 8. A reversal was considered to have occurred when a change in both the X-Axis and Y-Axis direction of movement occurred within a 500ms interval. Directions were calculated on a per-sample basis by examining the change in viewing window coordinates using the equations:

$$dx = x(n+1)-x(n) \quad (1)$$

$$dy = y(n+1)-y(n) \quad (2)$$

Negative values were indicative of leftward or downward movement and positive values were indicative of a rightward or downward movement, respectively. If a change in both the horizontal and vertical direction of movement occurred within 500ms, a reversal was coded as having occurred.

Due to differences in the underlying distributions of the older and younger participants' reversal data in skewness and kurtosis revealed during the omnibus test, planned comparisons between groups was not possible. Therefore, pairwise comparisons between each of the visuomotor flip conditions to the baseline normal condition were made for both the younger and older participant groups. Significant differences were observed within the older participants between the normal and flip in x conditions ($t(7) = -2.50$, $p < .05$) and the normal and flip in y conditions ($t(7) = -2.62$, $p < .05$). No significant differences were found within the younger participant data.

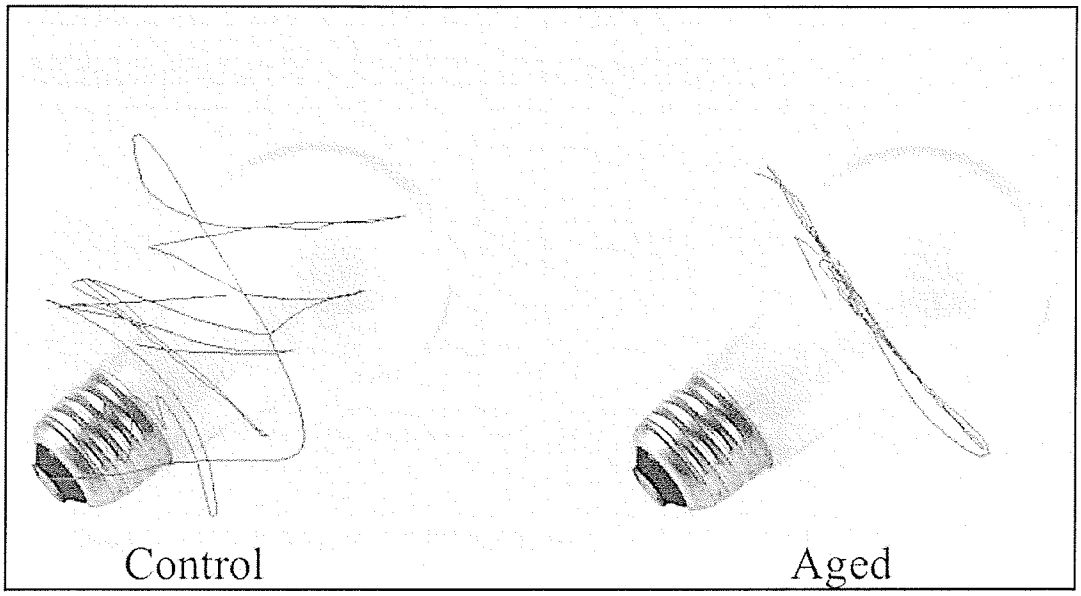


Figure 7. Example scanpath - flip in x-axis, Experiment 2a.

When a visuomotor transformation was required, aged participants seemed to have a greater difficulty in adapting to the new relationship of body movement and window movement.

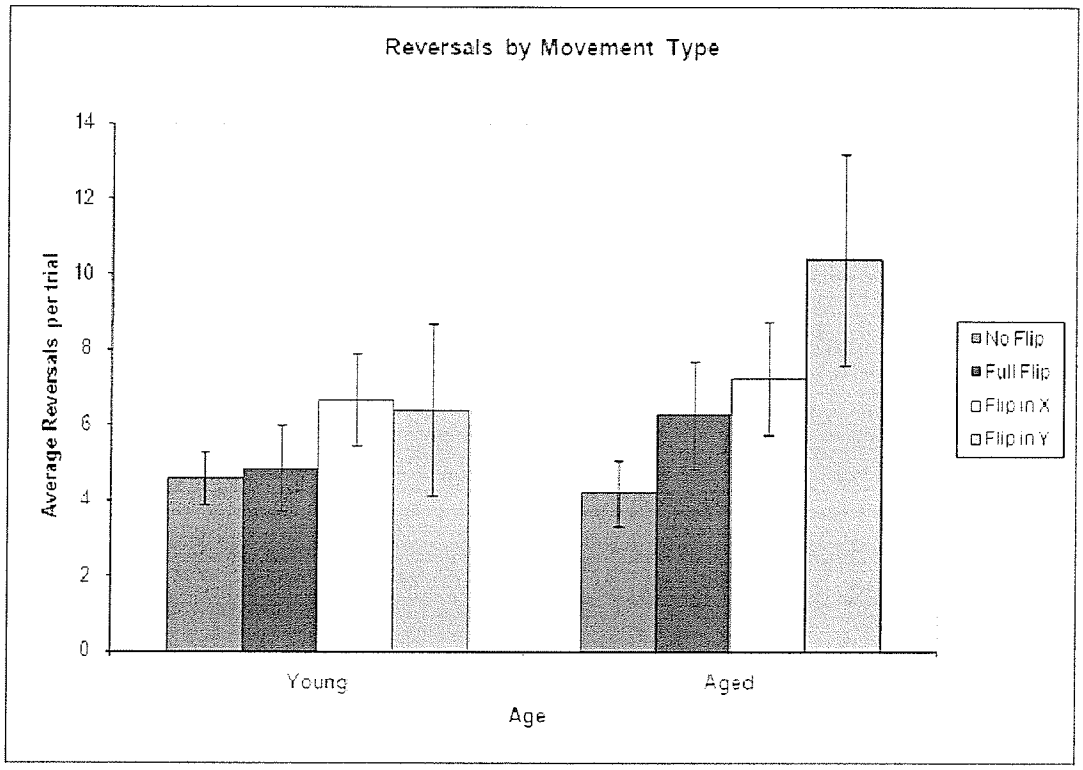


Figure 8. Number of reversals, Experiment 2a.

During an X- or Y-axis flip, the aged participants had significantly more reversals per trial than when no visuomotor transformation was required.

Total movement duration. The participant movement time data (an aggregate value of the total amount of time the participant spent moving the viewing window, excluding time spent before window movement was initiated) was separated into groups based on participant age (Young vs. Aged) and visuomotor-flip (Normal vs. Full Flip vs. Flip in X vs. Flip in Y). Data was compared using a multivariate ANOVA, treating participants as the random effect. A graphical representation of the data can be seen in Figure 9.

A main effect for visuomotor-flip was found, $F(3,16) = 8.69$, $p < 0.05$: Movement times were smallest in the normal condition, followed by the full flip, flip in X, and flip in Y, conditions respectively. Additionally, a significant effect of the between subjects variable age was found, with young controls taking less time scanning the objects than the aged participants ($F(1,18) = 48.76$, $p < .001$). Importantly, a significant interaction was observed between visuomotor-flip and age, characterized by the aged participants showing a proportionately larger effect of both a flip in X and a flip in Y, when compared to the younger control participants ($F(3,16) = 3.5$, $p < .05$). To characterize this interaction, follow up tests were conducted to evaluate pairwise differences among the means. Post hoc comparisons using the LSD test revealed there were significant differences within the older participants between the normal and each of the solitary axis flips ($M = -19.489$, $SE = 6.634$, $p < .05$; $M = -27.745$, $SE = 11.744$, $p < .05$), and between the full flip condition and the solitary flip in x ($M = -21.227$, $SE = 8.382$, $p < .05$). No post hoc comparisons amongst the younger participants were significant. Post hoc comparisons revealed there were significant differences across age in all but the solitary y-axis flip condition ($M = -20.779$, $SE = 7.614$, $p < .05$; $M = -18.516$, $SE = 5.933$, $p < .01$; $M = -35.18$, $SE = 9.171$, $p < .01$).

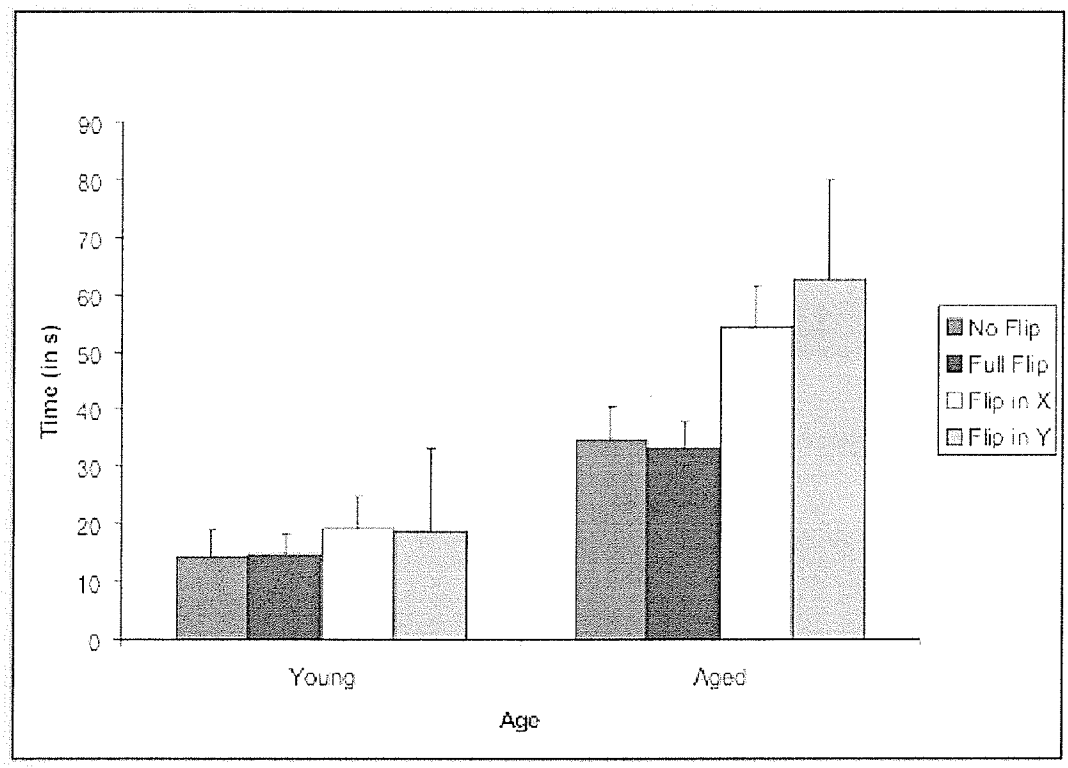


Figure 9. Movement times, Experiment 2a.

Overall, aged participants spent more time scanning the presented object as compared to the younger controls. Additionally, aged participants displayed a significantly larger effect of both a flip in the X-Axis, and a flip in the Y-Axis when compared to control participants.

Movement velocity. An analysis was conducted on the measure of movement velocity. The average velocity (calculated in pixels per second) was calculated for each trial. A graph of the means for each of the four visuomotor conditions, by age, can be seen in Figure 10. There was a significant between-subjects effect of age, consistent with the movement time analysis previously presented: Aged participants were moving significantly slower than the young controls ($F(1,18) = 6.505$, $p < .05$). There was no age by visuomotor flip interaction, and planned pairwise comparisons within the aged participants and young controls revealed no effects of visuomotor condition on movement velocity, providing evidence that the effects observed in the movement time data are not simply a result of the aged participants moving the window slower.

Movement direction. An analysis on the primary axis of movement by age in each of the four visuomotor flip conditions was conducted by taking the summed movement on the X-Axis in pixels and subtracting the summed movement from the Y-Axis in pixels. Therefore, positive values reflected a bias in moving the viewing-window along the X-Axis, whilst negative values reflected a bias towards moving the window along the Y-Axis. This data can be seen in Figure 11. Such an analysis was performed with the assumption that in order to adjust to a particular visuomotor flip, movement along the same axis as the distortion would increase.

A main effect of visuomotor-flip was found ($F(3,16) = 10.60$, $p < .001$), as was a significant Age X Visuomotor-flip interaction ($F(3,16) = 4.55$, $p < .05$). Planned comparisons were conducted between the means of the young and aged participants in both an X-Axis flip and a Y-Axis flip, resulting in non-significant differences after correcting for multiple comparisons (using a Bonferroni correction).

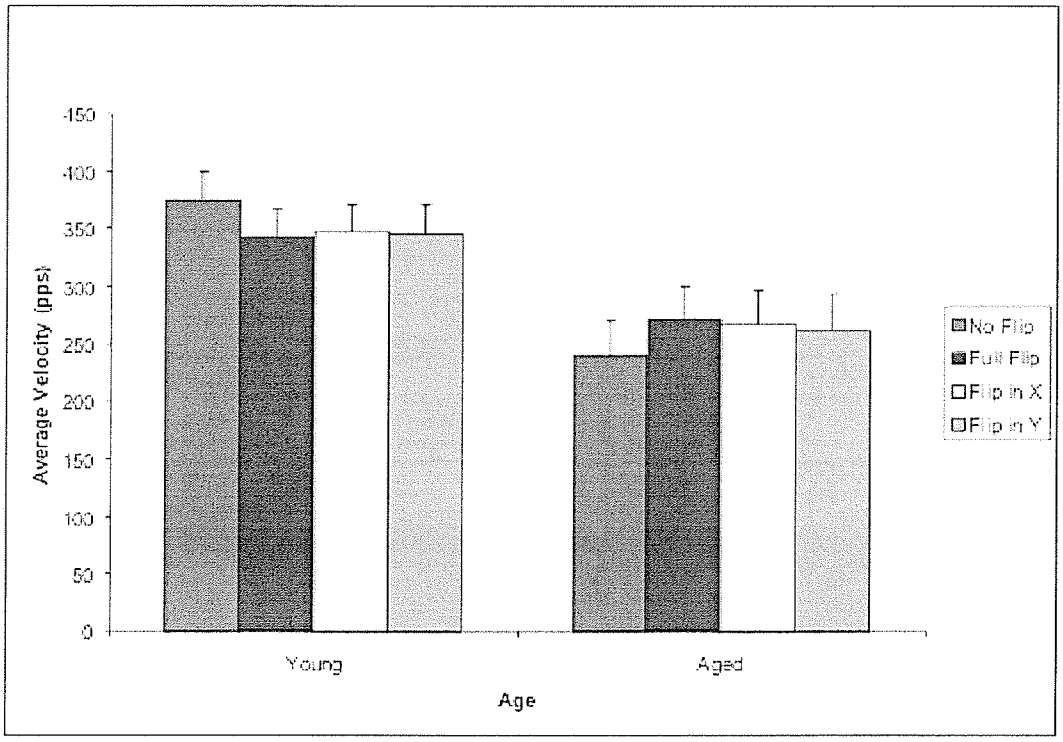


Figure 10. Average velocity, Experiment 2a.

Aged participants demonstrated an overall slower velocity when compared to the younger controls. No age by visuomotor flip interaction was present in the data.

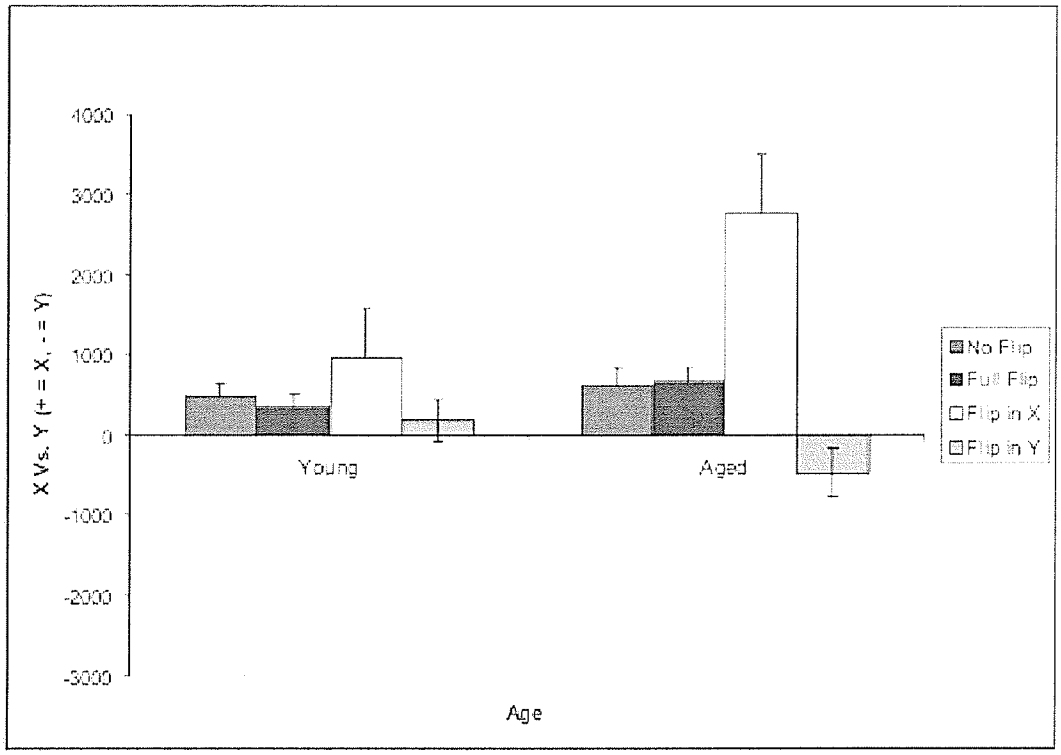


Figure 11. Direction of movment, Experiment 2a.

Though not statistically significant, during an X-Axis flip, the aged participants displayed more X-Axis movement and during a Y-Axis flip, the aged participants displayed more Y-Axis movement than the younger control participants. An overall bias towards X-Axis movement was also readily observable.

Discussion

The presented results demonstrate a number of interesting findings regarding the effects of natural aging on visuomotor transformation abilities. First, natural aging does affect viewing window performance when a visuomotor transformation is required to successfully complete the task. Examination of participants' scan paths revealed a pattern and complexity not observed in the younger control participants. Specifically, aged participants had more complex scan paths when a visuomotor transformation was required, as reflected in the number of reversals, than during normal viewing window control. The increase in reversals support theories that posit the aged participants are having more difficulty than the younger control participants in adapting to the new visuomotor map, as the number of sudden reversals and zigzags in movement path are reflective of ongoing / incomplete adaptation (Roby-Brami & Burnod, 1995). Statistical analyses revealed that aged participants took longer identifying objects by moving the window and a significant interaction between age and visuomotor condition, as predicted. Additionally, an analysis of movement velocity found a significant effect of age (with the older participants moving slower), but no age by visuomotor flip interaction. Thus, although aged participants were moving more slowly, this decrease in velocity does not fully account for the pattern of results observed in the movement times. When examining the overall direction of movement (as a preference towards horizontal or vertical scanning) an overall bias towards a left-right scanning pattern was observed, based on an examination of the standard error bars plotted in Figure 11. A potential explanation for this bias is the privileged role of the horizontal axis in visual exploration (Abed, 1991; Vurpillot & Baudonniere, 1976). It could be this tendency towards left-right scanning that is responsible for an apparent axial asymmetry observed during the solitary flip conditions. In fact, the only time a left-right movement preference is substituted

with a top-bottom axial preference is in the Y-Axis flip condition in the aged participants group. However, as no true counterbalancing was performed on item presentation, and a large number of items may have been presented with the primary axis along the left-right direction, it is impossible to directly assess whether a participant tendencies or item specifics were responsible for bias observed. Surprisingly, after adjusting for multiple comparisons, aged participants did not demonstrate increased movement along the direction of the visuomotor distortion.

The relative ease at which both younger and older participants were able to adapt to the "full-flip" condition warrants further discussion. Previous research examining screen-cursor rotations have found similar results: The cost associated with a 180 degree rotation (a full-flip) is significantly less than observed in other conditions, in a number of different measures, such as reaction time and error measurement (Cunningham, 1989; Kim, Ellis, Tyler, Hannaford, & W., 1987). One explanation of this seemingly paradoxical finding relates to how feedback from visuomotor distortions may be generalized in terms of egocentric rotations (van Den Dobblesteen, Brenner, & Smeets, 2004; Vetter, Goodbody, & Wolpert, 1999). In the "full-flip" condition, an imagined 180 degree rotation of the self would result in performance equal to the "no-flip" condition. In comparison, both the "flip-x" and "flip-y" axis conditions, a single rotational strategy could not improve performance, and a more complicated process may be required. A second hypothesis explaining this effect concerns how the visuomotor system recalibrates after a discrepancy is detected. In the "full-flip" condition, all information relating hand movement to window movement is incorrect, and the system is best served by a full re-calibration. In both the "flip-x" and "flip-y" conditions, only half of the information is flawed, making it necessary to selectively discard erroneous information, while retaining veridical relationships, which may be a more intensive process. Adaptation to visuospatial distortions

appears to be implemented by learning rules that operate on separate parallel sensorimotor transformations. If enough of these rules are "broken" a gross recalibration of the visual-motor system must occur (Marotta, Keith, & Crawford, 2005). Therefore, the presented finding of no associated costs within the "full flip" condition fits well within the current body of research. Taken in sum, the presented data support previous research demonstrating the process of natural aging does affect visuomotor transformation abilities (Buch et al., 2006; Fernandez-Ruiz et al., 2003; Seidler, 2006; Teulings et al., 2002), and in opposition to those reporting no effects of aging on visuomotor transformations (Canavan et al., 1990; Roller et al., 2002). Although general slowing within the older participant group could account for the significant main effect of age reported in the analyses, such a theory is not consistent with the relative ease at which older participants could perform the full-flip condition. Previous research has not examined the impact of full visuomotor reversals similar to those reported here, so a direct comparison between the presented study and previous research is not possible.

Due to the self-paced methodology employed, there was the possibility of the two experimental groups received unequal exposure to the visuomotor distortion. However, it was only the young participant group that, on occasion, did not require the full hour to complete the task, and thus would receive a lesser amount of exposure. One would expect less practice with the visuomotor distortions used in this study would lead to decreased performance, rather than the converse, therefore any experimental confound would be weighted in favour of the aged participants' performance. Even so, this and other methodological short-comings of this experiment were corrected in Experiment 2b.

Experiment 2b - Natural Aging Affects Visuomotor Transformation

Though the results from Experiment 2a were encouraging, there were a number of methodological issues that arose that were impossible to address via post-hoc data analysis. First, the overall slower trial times demonstrated by the aged participants (and the resulting inability to provide responses to all 80 trials) created the opportunity for the truly randomized item presentation and visuomotor condition to result in slightly unequal observations for each group. More troubling than unequal participant group sizes, since each object was not presented to each participant, there was the possibility that item specific differences were responsible for some of the effects observed. To address this, a pseudo-randomized presentation order was used in Experiment 2b. A second modification thought beneficial was how responses are classified as correct or incorrect. In lieu of the experimenters coding responses as right or wrong, using the participants' own object names when coding for accuracy was thought to be an improvement. Third, contrast sensitivity was measured in the aged population. Even though below average contrast sensitivity could explain the aged participants taking longer with the task, and having increased difficulty when a visuomotor transformation is required, it is unknown how this could fully explain the findings of Experiment 1a. Specifically, aged participants' lack of difficulty with the full-flip condition would not be accounted for by such low-level visual accounts. Contrast sensitivity tests were used to verify this assumption. Fourth, because the 'full-flip' condition utilized in Experiment 2a was behaviourally indistinguishable from the normal condition, it was removed from later experiments to increase statistical power with the relatively small sample sizes obtained. Finally, it was evident that much of the aged participants' trial time was spent physically entering in a response after correct identification had been achieved. Therefore, in Experiment 2b, aged participants verbally responded, with the experimenter

recording the response (no comparisons were intended between aged participants' response times and the younger control group's). The experimenter was blind to the visuomotor condition presented to the participant, however, a participant's level of frustration or surprise could have provided an indication of trials in which a visuomotor flip was introduced.

Aged participants were again expected to demonstrate marked difficulties in measures reflective of visuomotor transformation difficulty. When examining a participant's window movement scanpath, a more complicated pattern was expected when a visuomotor transformation was required, as evidenced by a larger number of reversals in each of the flip conditions. When examining average trial velocities, aged participants were expected to be slower overall when compared to young controls, and when examining the overall direction of movement of the window aged participants were expected to demonstrate an increase in movement direction consistent with the direction of induced visuomotor distortion.

Materials and Methods

Participants. The young control group consisted of fourteen participants (4M, 10F: age range 18 – 29 years old, mean age = 21) recruited from the University of Manitoba's introduction to psychology participant pool and received partial course credit for their participation. The aged group consisted of six participants (1M, 5F: age range 64 – 74, mean age = 68) recruited from the University of Manitoba Centre on Aging participant database and received no remuneration. Aged participants were asked a series of questions to exclude those that had pre-existing conditions that may have affected performance (such as certain prescription medications, a history of stroke or arthritis, or the presence of neurological disorder).The specific questions asked can be seen in Appendix D. All aged participants were maintaining independent living status and reported their level of health to be good to excellent. Cognitive screenings were

performed on all aged participants. Five participants were tested using the Mini Mental State Exam (Folstein et al., 1975) (mean score = 29.4, standard deviation = 0.55), and one participant was tested using the Dementia Rating Scale (DRS Total Score = 141). Log CS scores were calculated for most aged participants (four out of the six) using a Robson-Pelli contrast sensitivity chart (Pelli & Robson, 1988). Due to equipment unavailability after a fire in our building, two aged participants were tested using the Freiburg contrast sensitivity test (Bach, 1996). The Freiburg test was conducted on a 20.1-inch monitor (60Hz), at a viewing distance of 2.5 m. The luminance of the monitor was linearised using the built in psychophysical calibration routine. All aged participants required a score greater than, or equal to, a log contrast score of 1.5, a cut-off thought to represent healthy aging (Leat et al., 1999). All participants were right handed as assessed using a modified Edinburgh handedness inventory (Oldfield, 1971), and had normal or corrected-to-normal vision as verified by having an MIS pocket vision guide (Ferris et al., 1982) NPA score of 20/25 or greater (Leat et al., 1999).

Stimuli. The same common and easily identifiable objects were used for this experiment as were used in Experiment 2a. Five of these objects were used for practice trials, with the remaining seventy-five used as experimental trials.

The viewing window. Images were displayed in the centre of the monitor. The viewing maintained all features described in Study 1.

Procedure. Two Visuomotor-flip conditions were created by varying how the participant's body movements affected the onscreen movement of the viewing window. During the No Flip condition, the movement of the window was matched to the participants' hand movement. During each of the X-Axis and Y-Axis Flip conditions, only one dimension (horizontal or vertical) of movement was reversed. Participants were given the same verbal and

written instructions utilized in Experiment 2a. Object presentation and visuomotor-flip condition were pseudo-randomized and counterbalanced between subjects, ensuring item specifics, and the numbers of trials per condition were matched as closely as possible across participant groups.

Results

With the modifications made to the experimental procedures, all participants were able to complete the full stimulus set of 80 trials. No significant differences in accuracy between the aged participants and the younger controls (average incorrect = 36.6%) were observed. Trials in which the target object was not correctly identified were analyzed separately from those in which correct identification was achieved. An initial outlier analysis was performed on the movement time data, excluding values 2.5 standard deviations from each participant's mean for that condition. This resulted in the elimination of 2.7% of trials from all statistical analyses. The same four examinations of the data from correct responses were conducted as was presented in Experiment 2a. Incorrect responses were submitted to these same four analyses, resulting in insignificant findings and are not reported.

Sample scanpaths. When visual scanpaths were qualitatively examined, aged participants engaged in more scanning of the object than the young controls (Figure 12). Additionally, when one of the two visuomotor distortions was introduced, aged participants appeared to have greater difficulty adapting to the new relationship between body and window movement (Figure 13). The number of reversals of window direction per trial was used as a measure of scanpath complexity, and can be seen in Figure 14.

A significant main effect of visuomotor condition was found, $F(2.17) = 7.98$, $p < .05$. Planned comparisons based on the expected effects of interest revealed a significant difference between the normal condition and the solitary flip in x-axis conditions within the aged

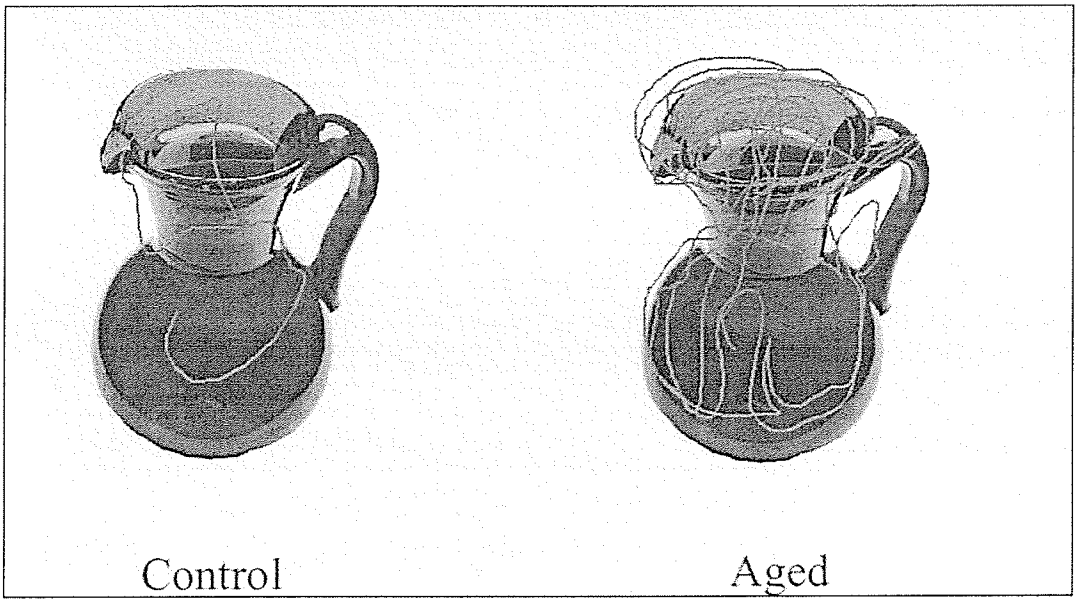


Figure 12. Example scanpath, Experiment 2b.

When no visuomotor transformation was required, aged participants engaged in more scanning of the presented object when compared to younger controls.

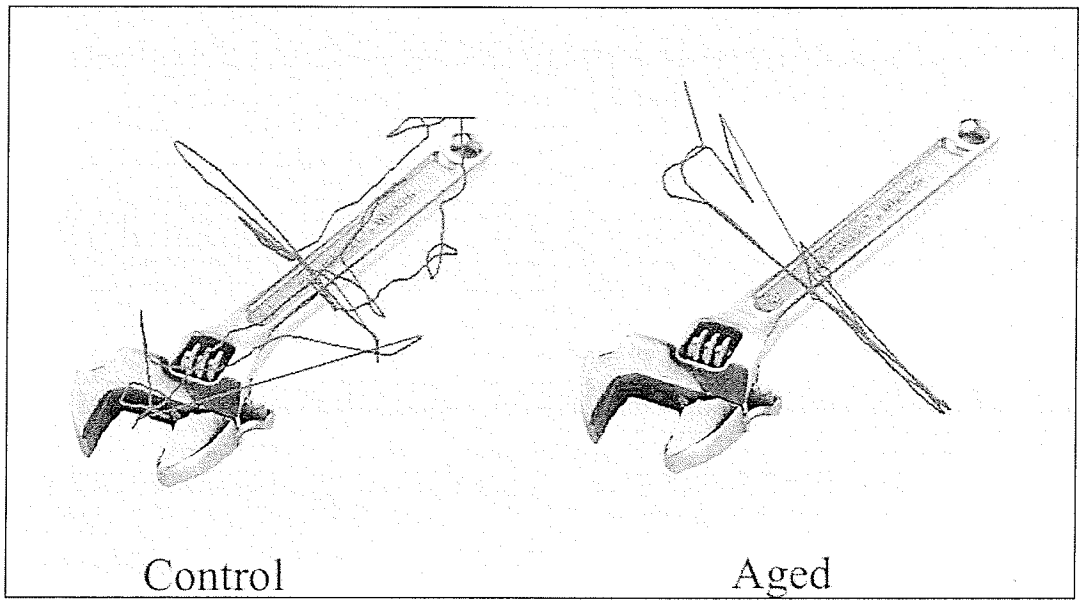


Figure 13. Example scanpath - flip in x-axis, Experiment 2b.

When a visuomotor transformation was required, aged participants seemed to have a greater difficulty in adapting to the new relationship between body movement and window movement.

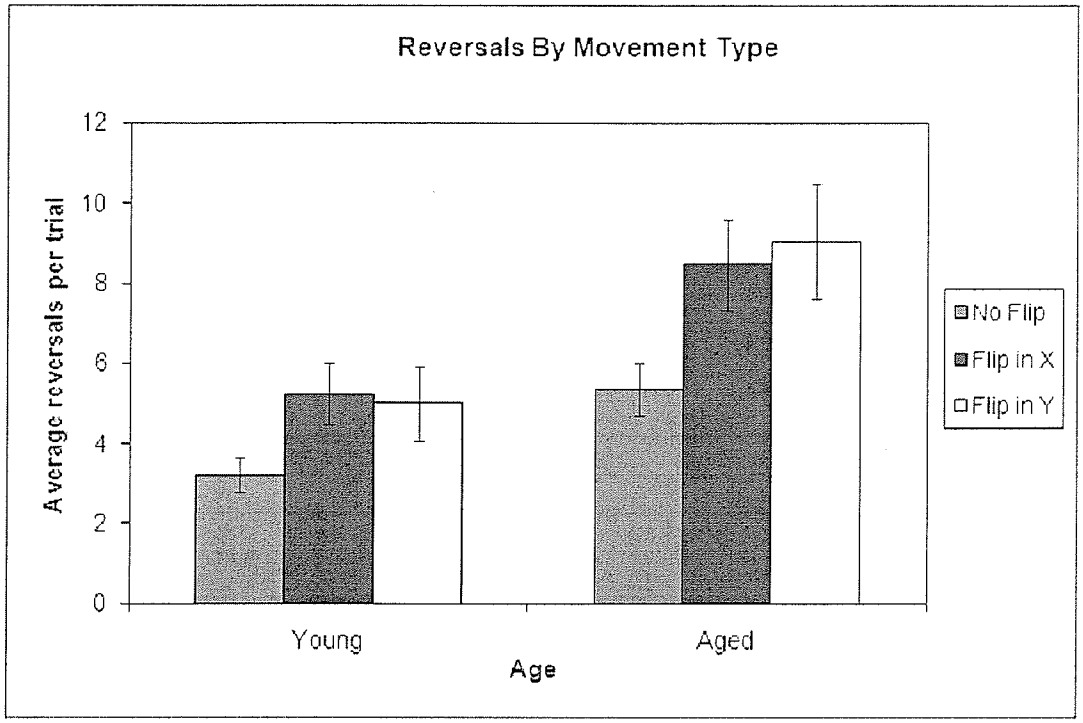


Figure 14. Number of reversals, Experiment 2b.

During an X- or Y-axis flip, the aged participants had significantly more reversals per trial than when no visuomotor transformation was required.

population (M = -3.123, SE = 1.083, $p < .05$), after adjusting for multiple corrections (Bonferroni). Comparisons between groups were not made due to the inconsistencies in the underlying groups distributions found in Experiment 2a.

Total movement duration. The participant movement time data (an aggregate value of the total amount of time the participant spent moving the viewing window, excluding time spent before window movement was initiated) was separated into groups based on participant age (Young vs. Aged) and visuomotor-flip (Normal vs. Flip in X vs. Flip in Y). Data were compared using a multivariate ANOVA, treating participants as the random effect. A graphical representation of the data can be seen in Figure 15.

A main effect for visuomotor-flip was found, $F(2,17) = 34.194$, $p < .001$. Movement times were smallest in the normal condition, followed by the flip in X and flip in Y, conditions respectively (M = 14.63, SE = 1.31; M = 28.36, SE = 2.29; M = 28.64, SE = 2.17). Importantly, a significant interaction was observed between visuomotor-flip and age, characterized by the aged participants showing a proportionately larger effect of both a flip in X and a flip in Y, as compared to the younger control participants ($F(2,17) = 22.70$, $p < .001$). To further characterize this interaction, follow up tests were conducted to evaluate pairwise differences among the means. Post hoc comparisons using the Bonferroni test revealed there were significant differences within the older participants between the normal and each of the solitary axis flips (M = -24.223, SE = 3.284, $p < .001$; M = -25.473, SE = 2.767, $p < .001$). No post hoc comparisons amongst the younger participants were significant.

An additional analysis on the movement times was performed by comparing the percentage of change from normal in each of the visuomotor flip conditions. To accomplish this, the movement times were converted into a percentage of each group's normal condition, and can

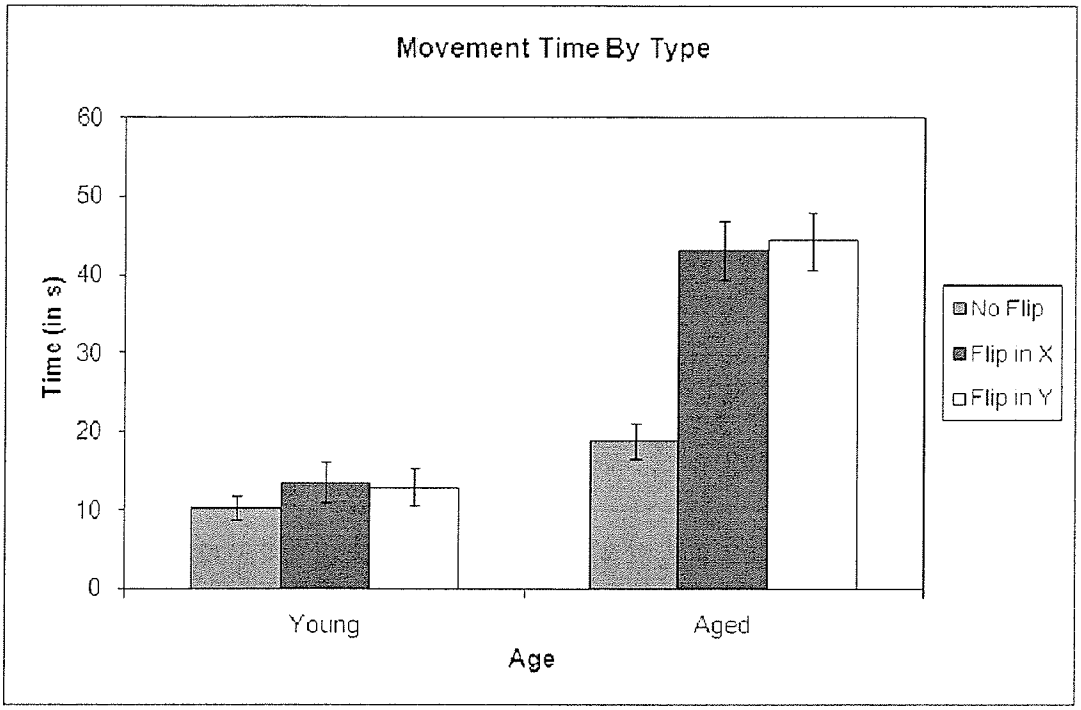


Figure 15. Movement times, Experiment 2b.

Overall, aged participants spent more time scanning the presented object when compared to the younger controls. Additionally, aged participants displayed a significantly larger effect of both a flip in the X-Axis, and a flip in the Y-Axis when compared to control participants.

be seen in Figure 16. Similar to the raw movement times, a main effect of visuomotor-flip was found ($F(2,17) = 21.13$, $p < .001$), as was a significant effect of age ($F(1,18) = 312.81$, $p < .05$) and a significant Age x Visuomotor-flip interaction ($F(2,17) = 10.42$, $p < .05$). To further characterize this interaction, follow up tests were conducted to evaluate pairwise differences among the means. Post hoc comparisons using the Bonferroni test revealed there were significant differences within the older participants between the normal and each of the solitary axis flips ($M = -1.516$, $SE = .249$, $p < .001$; $M = -1.543$, $SE = .231$, $p < .001$). No post hoc comparisons amongst the younger participants were significant. Additionally, post hoc comparisons across age in each of the visuomotor flip conditions confirmed aged participants were moving slower than the younger controls in all conditions ($M = -8.510$, $SE = 2.628$, $p < .01$; $M = -29.504$, $SE = 4.586$, $p < .001$; $M = -31.442$, $SE = 4.339$, $p < .001$).

Movement Velocity. An analysis was conducted on the measure of movement velocity. The average velocity (in pixels per second) was calculated for each trial. No significant differences were observed.

Movement Direction. An analysis on the primary axis of movement by age in each of the three visuomotor conditions was conducted in the same manner described in Experiment 2a. The resultant data can be seen in Figure 17.

A main effect of visuomotor-flip was found ($F(2,12) = 13.94$, $p < .001$), however no Age x Visuomotor-flip interaction was observed. Planned comparisons were conducted between the means of the young and aged participants in both an X-axis flip and a Y-axis flips, resulting in no significant differences.

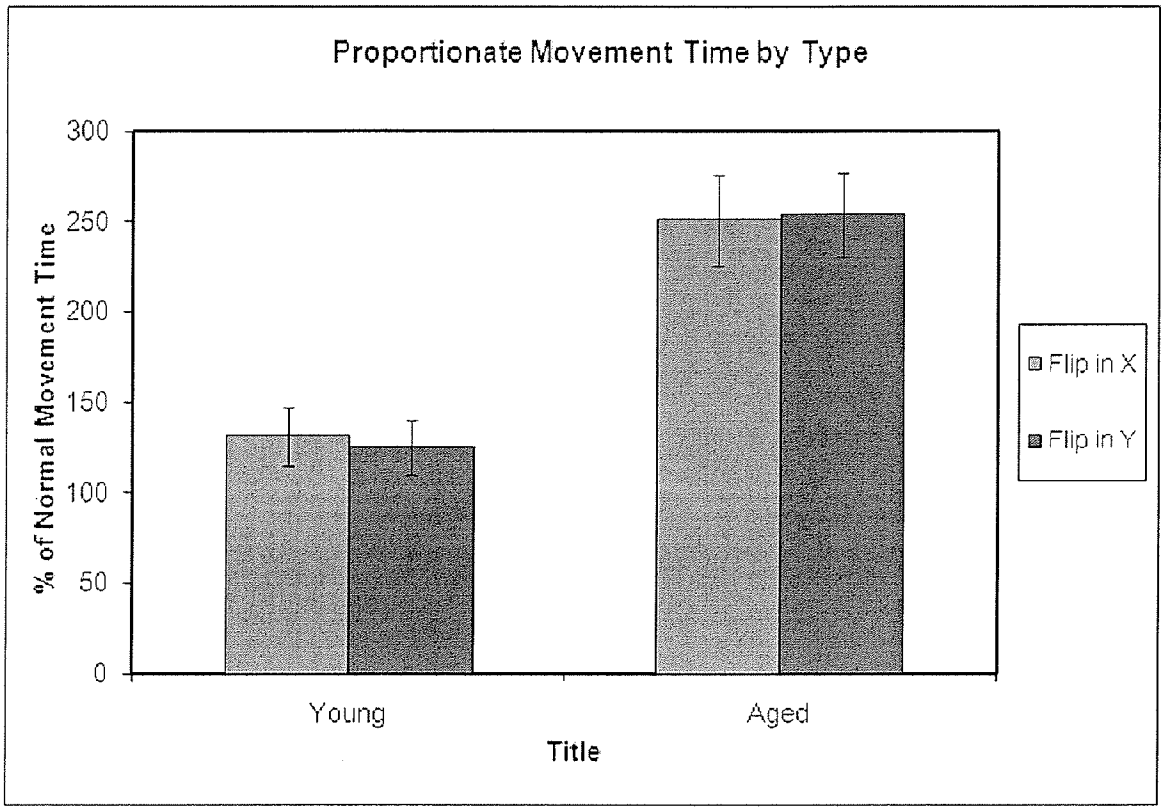


Figure 16. Proportionate movement times, Experiment 2b.

Aged participants demonstrated significant impairments in movement times as compared to young controls. Additionally, aged participants were comparatively slower in each of the flip conditions when compared to movement times in the normal condition.

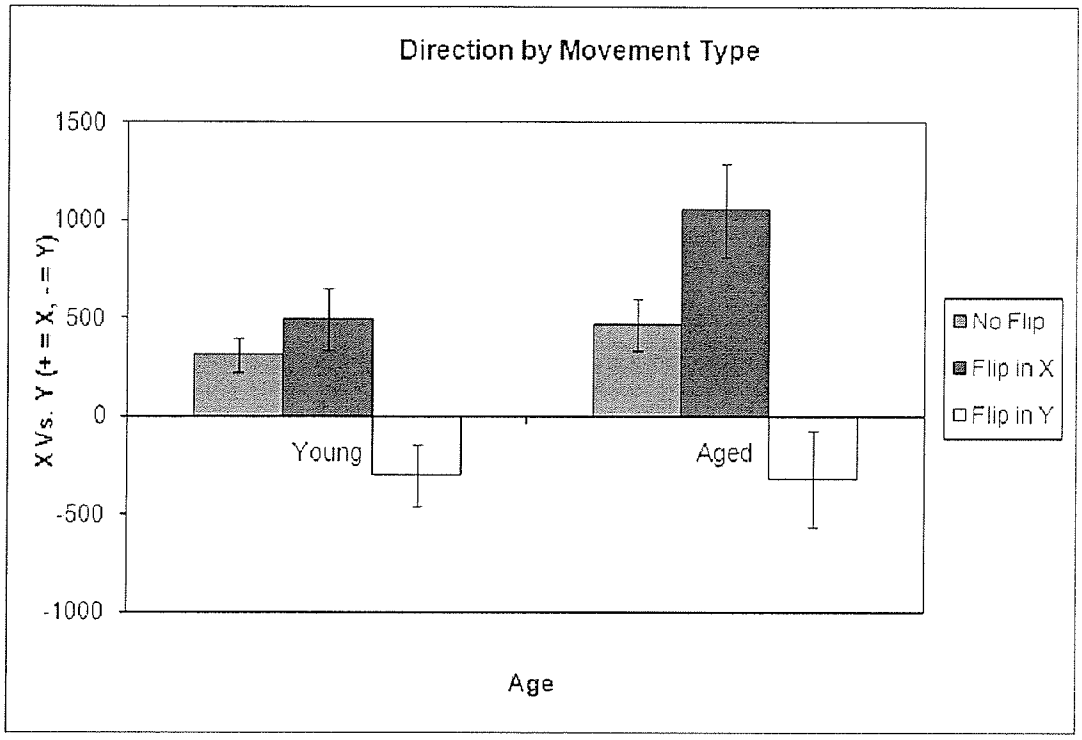


Figure 17. Direction of movement, Experiment 2b.

No significant differences were observed within the movement direction data.

Discussion

The present data confirm the natural aging process does affect visuomotor transformation abilities – verifying the results from Experiment 2a. Replicating the results of Experiment 2a, statistical analysis revealed that aged participants took longer identifying objects by moving the window when a visuomotor transformation was required when compared to the normal movement condition. In contrast to Experiment 2a, no significant differences were observed within the velocity data. When examining the overall direction of movement (as a preference towards horizontal or vertical scanning) an overall bias towards a left-right scanning pattern was observed. Similar to Experiment 2a, after adjusting for multiple comparisons, aged participants did not demonstrate increased movement along the direction of the visuomotor distortion.

The differences between Experiment 2a and 2b demonstrated a number of important conclusions for future work. First, although it is true that some older participants may be at ease when interacting with computers, it certainly appears to be the case that there is a significant increase in the time associated with computer based tasks when compared to younger participants. Modifying the method of response for the older participants allowed the entire stimulus set to be used. Second, the movement time data is the most consistent dependent measure. Although it may be possible to further refine measures of scan path complexity or velocity, at present, the data is somewhat inconsistent across experiments.

Current theories, derived in large part from behavioural data, indicate that much of the cognitive decline with aging is due to deficiencies in cognitive resources, task-switching tasks, inhibitory functions, and a general slowing in the speed of cognitive processing (Park et al., 2002; Salthouse, 1996). The viewing window, as it is presented here, requires the learning of a new visuomotor relationship that is effortful, explicit, and most-likely requires a conscious

strategy to successfully complete. It is possible that one or more of these features of the viewing window task are responsible for the dissociation in performance between younger and aged participants and it would require further study to distinguish which features of these effortful visuomotor transformations are involved in the age-related differences observed. It is interesting to note that the observed deficits in identifying the presented object do appear to be a result of the visuomotor system, rather than the visual system proper. Previous studies using fragmented object identification tests, in which participants attempt to identify common everyday objects initially composed of small fragments, increasing in completeness as a function of time (Snodgrass, Smith, Feenan, & Corwin, 1987), have shown no effect of age (Heindel, Salmon, & Butters, 1990).

Chapter Summary

This research provides support for previous experiments demonstrating deficits in visuomotor transformation abilities in the elderly, and extends the current body of research to include a more cognitively demanding, yet less transparent visuomotor task. This extension increases the external validity of methods of testing visuomotor performance in an aging population, while conforming to important previously established findings. Buch et al. (2003) compared aged and younger control task performance using two types of visuomotor distortion tasks: One was an explicit, effortful, strategic task, consisting of a sudden rotation of the relationship between finger movement and resultant on-screen cursor movement. The second was an implicit, non-strategic spatial readjustment task consisting of a gradual rotation. In congruence with the results reported here, aged participants demonstrated a decline in task performance in the overt strategic task. Unfortunately, within the literature many studies were not specifically designed to evaluate functioning of either strategic control OR spatial

adjustment, making dissociations between the two difficult. However, a deficit is often observed in aged participants' performance in tasks requiring controlled, effortful applications of specific movements in which the participants are overtly aware of the requirements (Fernandez Ruiz et al., 2000; Seidler, 2006; Teulings et al., 2002).

The viewing window task is unique in a number of ways that may better serve to demonstrate the effect of aging on visuomotor control. The viewing window task is both cognitive and motor in nature. A single viewing window trial requires selecting areas of the image that are of interest, adapting to a novel visuomotor relationship (if present), actively exploring the object, and ultimately engaging in decision making processes to determine the object's identity. The added complexities required for task completion may place additional demands on the aging brain making any visuomotor deficiencies apparent. Previous research has presented similar findings, with deficits in similar tasks more apparent during dual-task scenarios, as opposed to performing a sensorimotor transformation alone (Bock & Schneider, 2002). In ongoing research, our lab is examining the individual components of the viewing window task in isolation of one another to pinpoint where deficits in performance may occur, however, as real world scenarios require the utilization of these multiple systems in conjunction on a daily basis, studying the sum process was a necessity.

Two known limitations are inherent in the presented research. First, the sample size of eight participants and six participants in each of the aged groups is acknowledged as relatively small. Although the sample size was chosen based on effect-size calculations, caution in generalizing the results is prudent, and ongoing studies in our lab have increased these group sizes. Second, there was a pronounced asymmetry in sex representation within the two aged participant groups. Though in our small data sets there were no apparent sex differences,

previous research has suggested that male and female performance in spatial and visuomotor tasks may not be equal. For example, when performing complex visually guided movement, sex differences have been demonstrated at both the behavioural and cortical level of analysis (Gorbet & Sergio, 2007). Further, this result may persevere into the later years of life (Boucher, Denis, & Landriault, 1991; T. D. Parsons, Rizzo, Van Der Zaag, McGee, & Buckwalter, 2007), in behavioural tasks. Therefore, the cross group comparisons made in Experiment 2a may be heavily influenced by the asymmetrical gender representation between age groups (40% male in the young control group, and 20% male in the older participant group).

Though the current study characterized the complexity of a participant's scanpath in terms of the number of reversals, there are a number of alternate methods for characterizing complexity that could be utilized in future work. For example, monitoring changes in the trajectory of the viewing window, examining the number of peaks in viewing window velocity, or examining the type of corrective action undertaken all may provide additional insight into the manner by which older participants are attempting to adapt to the required visuomotor transformation. For example, with the algorithm used in the current study it may be possible that older participants were simply making more double-axis reversals than the younger control participants. Although this question can not be addressed with the presented data of Study 2, there is no previous literature to suggest older participants adapt to perturbations using changes in both axes of movement and younger participants adapt using just one. Additionally, the sensitive nature of the reversal algorithm used (functioning at the pixel level) would have resulted in very small reversals in both axes being picked up by the analysis software. Pilot work using a single axis to classify reversals resulted in many movements that clearly were not a product of difficulty in adapting to the visuomotor distortions introduced (such as large 'V-

shaped' movements). However, further research examining whether such differences are present, using alternate definitions of what constitutes a reversal in movement direction would be of benefit.

Even though we take the stance that it is a loss in visuomotor transformation ability that accounts for the differences observed between young and aged participants, it is important to note that natural aging is a global process that affects many systems simultaneously. Much research has shown natural aging affects specific both specific cognitive abilities and more general executive function. Research has shown that under conditions of cross-modal competition, for example attending to touch while a visual distractor is introduced, older participants have greater difficulty than younger controls (Poliakoff, Ashworth, Lowe, & Spence, 2005). The viewing window task inherently contains cross-modal competition, and part of the overall slowing observed in the older participants completion of the task could be in part due to this fact. In addition to cross-modal competition, natural aging also has on performance within a single sensory modality, with impairments in both controlling shifts in visual spatial attention (Greenwood, Parasuraman, & Alexander, 1997), and in attending to peripheral locations while attending to foveal regions (Ball & Owsley, 1993; Richards, Bennett, & Sekuler, 2006; Richardson & Vecchi, 2002). Impairments in the effective control of visual attention may also contribute to the lesser performance observed in the older participant group, especially when attention must be deployed to regions outside of the viewing window and likely increase when a visuomotor transformation was required. However, the above mentioned deficits would fail to explain the ease at which older participants could perform the full-flip condition of Experiment 2a. If difficulty in appropriately allocating visual attention or cross-modal competition were responsible for the increased difficulty in the solitary axis flips, it would stand to reason that an

equal deficit would be observed in the full-flip condition, as the requirements on visual spatial attention and the cross-modal interference would be equivocal. Natural aging is also well known to affect a number of perceptual abilities reducing older participants visuospatial memory span (Rayner, 2009), and performance during fragmented object identification tasks (Maki, Zonderman, & Weingartner, 1999). In combination, these deficits within the perceptual domain have a direct impact on older participants' visual search patterns, as revealed through eye-tracking (Cassavaugh, Kramer, & Irwin, 2003; Ho, Scialfa, Caird, & Graw, 2001; Kramer, Hahn, Irwin, & Theeuwes, 1999; Maltz & Shinar, 1999). Older participants often having higher saccadic latencies, increases in the number of saccades, tendencies to return to areas previously visited and longer overall periods of visual search. These results confirm the general increase in movement time and more complicated scan paths observed within the older participants' in Study 2. Within the motor domain, research has shown older adults may be impaired during the encoding of novel motor memories (A. Sailer, Dichgans, & Gerloff, 2000; Sawaki, Yassen, Kopylev, & Cohen, 2003), and that the root cause of this deficit may result from difficulties with working memory and general cognitive function (Langley & Madden, 2000; Rypma & D'Esposito, 2000). Age related declines in prefrontal cortex, where the neurological correlates of many executive functions including working memory reside, are well documented in both human and non-human primates(Fjell et al., 2009a, 2009b; Haug & Eggers, 1991; Heilbroner & Kemper, 1990; Raz et al., 1997). The presented research has no way of dissociating impairments resulting from difficulties in encoding new motor memories from those that would result from impairments in visuomotor transformation abilities, however such an examination could be undertaken by examining the time course of adaptation, rather than transformation abilities as a whole. If difficulties in encoding or retrieving motor memories were a primary factor in older

participants' difficulties with the viewing window task, within a single-trial (or within runs of trials requiring the same visuomotor transformation) performance should improve. However, if transformation abilities are at fault, performance would be expected to remain at a comparatively lower level than the younger control participants. Although ongoing work is addressing some of these issues, each alternative account requires modifications to the task, the control conditions, the participants, or all three. Due to the scope of such a project, this thesis focused on one possible way in which aged participants' performance may be impaired, in the performance of visuomotor transformations.

Contemporary literature involving parietal function in an aged population (Grieve, Clark, Williams, Peduto, & Gordon, 2005; Lehmbeck, Brasses, Weber-Fahr, & Braus, 2006; C. D. Smith, Chebrolu, Wekstein, Schmitt, & Markesbery, 2007), has demonstrated marked grey-matter loss within the parietal lobe, where learning visuomotor learning stratagem is thought to occur. When one considers the nature of the viewing window task as it is presented here, satisfactory performance could be achieved by modifying, selecting, or learning specific movement plans that are appropriate to the given condition. For example, alternate movement plans could be learned and selected for each of the visuomotor distortion conditions confronted by the participant. It is therefore proposed that, in the aged population, decreased parietal functioning has reduced the participant's ability to adopt appropriate stratagem to deal with the visuomotor distortion. As a first step in beginning to examine this hypothesis, it was verified that the viewing window task recruits parietal-based neurological mechanisms. This verification was the focus of Experiments 3a and 3b presented next.

Chapter IV: Neurological Correlates of the Viewing Window

Much of our knowledge regarding the neurological correlates of visuomotor transformation has come from prism adaptation studies. Until recently, prism adaptation was largely held to be a function of the cerebellum. The cerebellum receives both proprioceptive information from the limbs and visual input from the visual system, and is therefore a logical sight for any discrepancy between these two information streams to be detected and corrected. Visual information (from cerebral cortical visual areas) projects to the dorsolateral region of the pontine nuclei (Glickstein et al., 1980), and it is known that experimental lesions in monkey cerebellar mossy-fibre, where input from the pontine nuclei is received, abolishes prismatic adaptation in macaques (Baizer, Kralj Hans, & Glickstein, 1999). Further evidence supporting the role of the cerebellum, has been obtained from human patients with cerebellar lesions who display adaptation impairments (Martin et al., 1996; Morton & Bastian, 2004; Weiner, Hallett, & Funkenstein, 1983). For example, Martin et al. (1996) reported patients with damage to the inferior olive (the source of climbing fibres to the cerebellar cortex) were severely impaired when adapting to lateral displacement prisms.

Other prism work has demonstrated the importance of parietal cortex using functional neuroimaging (Clower et al., 1996; Fernandez-Ruiz, Goltz, DeSouza, Vilis, & Crawford, 2007), and lesion studies (Newport et al., 2006; Newport & Jackson, 2006; Pisella et al., 2004). For instance, Clower et al. (1996) used positron emission tomography to directly examine brain activation during a pointing task while the participant wore lateral displacement prisms. Consistent patterns of brain activation were observed in the posterior parietal cortex (PPC) contralateral to the pointing limb on trials in which vision was displaced.

Whereas prism work is perhaps most prolific, the role of parietal areas in visuomotor adaptation has been supported through other methods as well, including rotated reaching, joystick use, rotated joystick use, anti-saccades, and various egocentric transformations (Creem-Regehr, Neil, & Yeh, 2007; Ghilardi et al., 2000; Gorbet, Staines, & Sergio, 2004; Inoue et al., 1997; Marotta et al., 2005; Moon et al., 2007). That is, a discussion of prismatic adaptation is quite relevant to the type of visuomotor distortion utilized in the presented experiments, as it most likely recruits at least some of the same neurological systems in order to compensate for the visuomotor adaptation required within the posterior parietal lobe.

Two general mechanisms of adaptation, strategic control and spatial realignment, have been identified in previous research. Further, these two mechanisms are believed to recruit different brain regions. Previous studies have identified the neural basis of strategic control within the parietal lobe (Clower et al., 1996), whereas the cerebellum is a key structure in the use of spatial realignment (Seidler, Noll, & Chintalapati, 2006). As strategic control requires more cognitive action, and an evaluation of feedback error, it uses a feed-forward mechanism. These cognitive functions have been associated with several regions of the parietal lobe. The PPC is known to be involved in the online control of movement and the self-monitoring of actions (Blakemore & Sirigu, 2003; Desmurget et al., 1999). In a study of delay in visual feedback during a tracing task, temporo-parietal junction (TPJ) activity was found only in high-performing subjects, suggesting that this activation may be reflective of better generation of internal estimates (Ogawa & Inui, 2007). The IPL has been implicated in several aspects of adaptation tasks including motor error and feed-forward learning (Grafton, Schmitt, Van Horn, & Diedrichsen, 2008), and the PCu is involved in retrieval systems (M. W. Parsons, Harrington, & Rao, 2005). In contrast, spatial realignment relies on on-line updates to an internal model,

therefore involving more feed-back mechanisms (Roby-Brami & Burnod, 1995). This realignment process is associated with cerebellum activity particularly around the posterior superior fissure (Imamizu, Higuchi, Toda, & Kawato, 2007; Seidler & Noll, 2008).

Many features of the viewing window task would suggest successful adaptations to the visuomotor distortions that were introduced are, at least in part, mediated by the parietal lobe. Visuomotor conditions were randomized or pseudo-randomized within subject in the previous experiments. By preventing continuous exposure to any one of the required visuomotor transformations, there was not sufficient continuous exposure to any flip condition to allow for the cerebellar mediated spatial realignment previously discussed. Therefore, any preservation of function or adaptation to the task must have been a result of parietal lobe mediated strategic control. When one considers the nature of the viewing window task as it is presented here, satisfactory performance could be achieved by modifying, selecting, or learning specific movement plans that are appropriate to the given condition. For example, alternate movement plans could be learned and selected for each of the visuomotor distortion conditions confronted by the participant. To verify that the viewing window task is indeed recruiting parietal regions during a visuomotor transformation, Experiments 3a and 3b focused on the neuronal underpinnings of the viewing window task.

Experiment 3a – Behavioural measures of viewing window *Effectiveness as an fMRI tool.*

A number of modifications to the viewing window methodology were required to use it within an imaging environment. Due to an MRI machine's high magnetic field, any research materials within the scanner room must be either composed entirely of non-ferrous materials (such as plastics and fibre optics), or be fully shielded, to ensure the safety of the equipment, the investigator(s) and the participants. To accommodate this unique environment the viewing

window was controlled by a fibre-optic trackball, rather than by a touch-screen overlaying a monitor (a scenario that would not be possible). One drawback with the use of a trackball is the decoupling of the 1-1 relationship of the participants' body movements and the resultant movement of the window previously obtained. Though the movement of the trackball was grossly calibrated to correspond to the spatial distance the viewing window covered, during a visuomotor transformation the unexpected movement of the window may have caused participants to lose track of the clear portion of the window. To ensure participants were able to adequately track the window movement, its location was "illuminated" by increasing the RGB colour values of the image at its location. A third modification required was in how participants signalled their indication of a correct response. Since participants had no method of recording a response in the magnet, a forced-choice procedure was utilized. Finally, in previous experiments participants had moved throughout the experiments in a self-paced manner. With fMRI requiring a precise temporal synchrony between the presentation of stimuli and the collection of functional data, and strict periods to allow hemodynamic changes to be mapped (at least in slow event-related paradigms), participants were limited in both the amount of time they had to identify an object, and in the time they had to enter their responses. These enforced timings ensure areas of increased activity begin to return to baseline levels before the next trial is initiated. The purpose of Experiment 2a was to test out these required modifications in a behavioural task, before the paradigm was moved into the magnet environment.

Materials and Methods

Participants. Seven participants (3M: age range 18 – 25 years old: mean age = 20) were recruited from the University of Manitoba's introduction to psychology participant pool.

Participants were right-handed and had normal or corrected-to-normal vision as reported in pre-test screening. Participants received partial course credit for their participation.

Stimuli. The same 80 stimuli previously reported were used. An additional five stimuli were created for use as practice items (an iron, recycling box, baseball cap, skateboard and head of lettuce), bringing the total item count to 85. Response foils were chosen from items that were from the same category where possible, with a consideration for the items overall general shape, and can be seen in Table 5. Twenty-five percent of the foils were selected from the experimental items to prevent the possibility of a correct response based on item familiarity alone. When originally created, the experimental items were chosen from top responses of item categories and inherently were highly familiar. In contrast, the foils were selected from lower members of the item category. By repeating some experimental items as foils, the possibility of identifying foils based on object familiarity was reduced.

The viewing window. The viewing window and visuomotor-flip conditions were similar to what has been previously described, with the following exceptions. First, the total area of the window (8171 pixels) was increased 20 points in RGB colour space across all three channels. This gave the appearance of an "illuminated" window, making tracking easier for participants (see Figure 18). Second, control of the window was performed using a fibre-optic trackball (Current Designs, Pittsburgh) placed approximately 20cm from the right edge of the screen.

Procedure. Participants were given the same written and verbal instructions used in Study 2 prior to beginning, with the minor exceptions described below, and correct use of the trackball and viewing window were demonstrated by the experimenter. Participants were seated approximately 50cm from the monitor at eye-level, with the trackback within reach. Participants were instructed to identify the presented object as quickly but as accurately as possible, and to

Table 5. List of objects used as practice and experimental items in Experiment 3, with associated foils.

Practice (Experiment 3b) / Experimental (Experiment 3a) Items:			
ITEM	*FOIL*	*ITEM*	*FOIL*
Clock	Ashtray	Harmonica	Flute
Typewriter	Computer	Telephone	Stereo
Television Remote Control	Calculator		
Experimental Items:			
Apple	Banana	Pepper	Tomato
Banana	Clock	Piggy bank	Ball
Binder Clip	Wrench	Pills	Lipstick
Camera	Ladle	Pocket watch	Purse
Clamp	Can Opener	Potato peeler	Pizza cutter
Coffee Cup	Sandals	Pumpkin	Lettuce
Corkscrew	Gun	Pushpin	Screw
Boot	Earring	Razor	Scissors
Dagger	Yo-yo	Rolodex	Book
Ring	Hammer	Safety pin	Yarn
Dice	Violin	Saw	Planar
Drill	Magazine	Scissors	Pliers
Guitar	Headband	Screwdriver	Mallet
Envelope	Paper	Shirt	Sweater
Eyeglasses	Spoon	Shoes	Boots
Diskette	Ruler	Spoon	Fork
Fork	Paintbrush	Stapler	Hole punch
Frying pan	Sander	Stethoscope	Necklace
Hairbrush	Pencil	Strawberry	Kiwi
Hardhat	Pliers	Sunglasses	Hat
Highlighter	Blender	Tambourine	Cymbal
Hole Punch	Pot	Tape dispenser	Stapler
Hourglass	Strawberry	Tape measure	Level
Jug	Stool	Teapot	Iron
Kiwi	Lime	Three holed punch	Photocopier
Lamp	Orange	Toaster	Oven
Laptop	Typewriter	Tomato	Apple
Lemon	Knife	Toothbrush	Hairbrush
Light bulb	Perfume	Top hat	Baseball cap
Lighter	Chisel	Vice grips	Wrench
Lipstick	Bowl	Walnut	Almond
Mallet	Toolbox	Watch	Bracelet
Mug	Clamp	Watering can	Pail
Notebook	Textbook	Work gloves	Scarf
Chair	Sofa	Wrench	Vice grips
Paperclip	Ruler	Yarn	Needle
Pen	Screwdriver		
Pencil	Tape measure		
Pencil sharpener	Nail		

*Highlighted items were also used in Experiment 3b. For Experiment 3a, five newly created items were used for practice (an iron, recycling box, baseball cap, skateboard and head of lettuce).

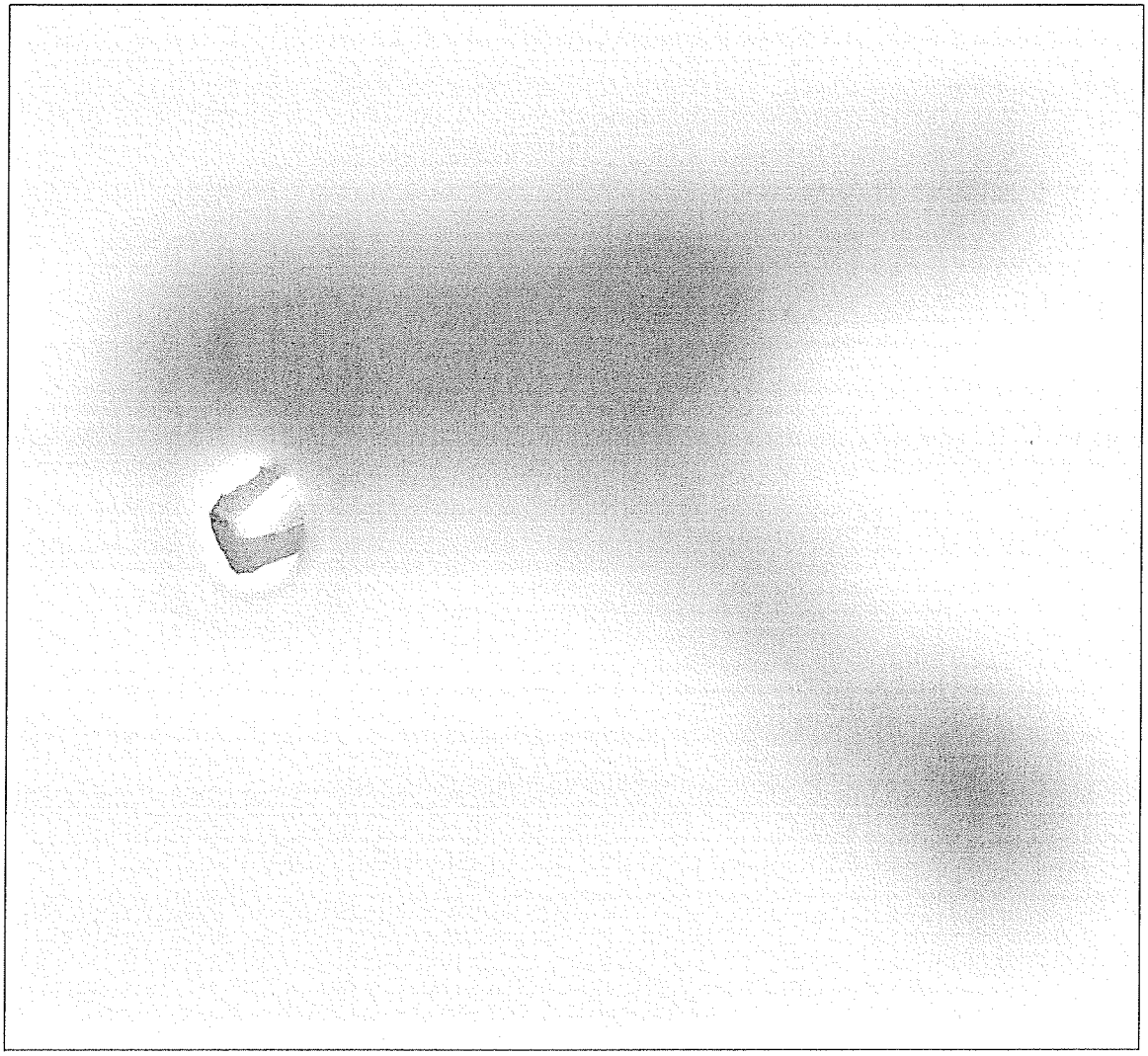


Figure 18. Viewing window example, Experiment 3a.

The circular viewing window displays the underlying image in normal clarity, while the remainder of the image is heavily blurred. The entire viewing window area has been lightened in colour by increasing the RGB values of the underlying image by 20 points in each channel. The target object is a pair of vice-grips.

signify their identification by pressing either of the two buttons located on the side of the trackball. Following the participant's indication of object identification, the stimulus was removed from the screen and two responses options were presented. Participants chose which of these two responses matched their identification by pressing the corresponding button (Left or Right) on the trackball. Each trial began with a fixation point which lasted for a minimum time of 5 seconds. Participants were given up to a maximum of 20 seconds to explore the object before being presented with response options. Participants were then given a maximum of 5 seconds to choose a response. Any time remaining in either of the response or viewing window periods of the trial were added to the fixation period. These timings ensured a new trial was initiated every 30 seconds. Participants were not given any feedback about their accuracy and continued through the entire experiment in a self-paced manner. Object presentation and visuomotor-flip condition were pseudo-randomized and counterbalanced between subjects.

Results

No significant difference in accuracy were observed in the visuomotor flip conditions (average incorrect = 34.1%). Trials in which the target object was not correctly identified were omitted from further analysis. Data were separated into two categories, early (the first 40 trials) and late (the last 40 trials). An initial outlier analysis was performed on the movement time data, excluding values 2.5 standard deviations from each participant's mean for that condition. This resulted in the elimination of 3.7% of trials from all statistical analyses.

Sample scanpaths. As experience with the novel visuomotor transformation increased, scanpaths appeared to become less complicated (see Figure 19); however, no significant differences were observed between visuomotor conditions (see Figure 20).

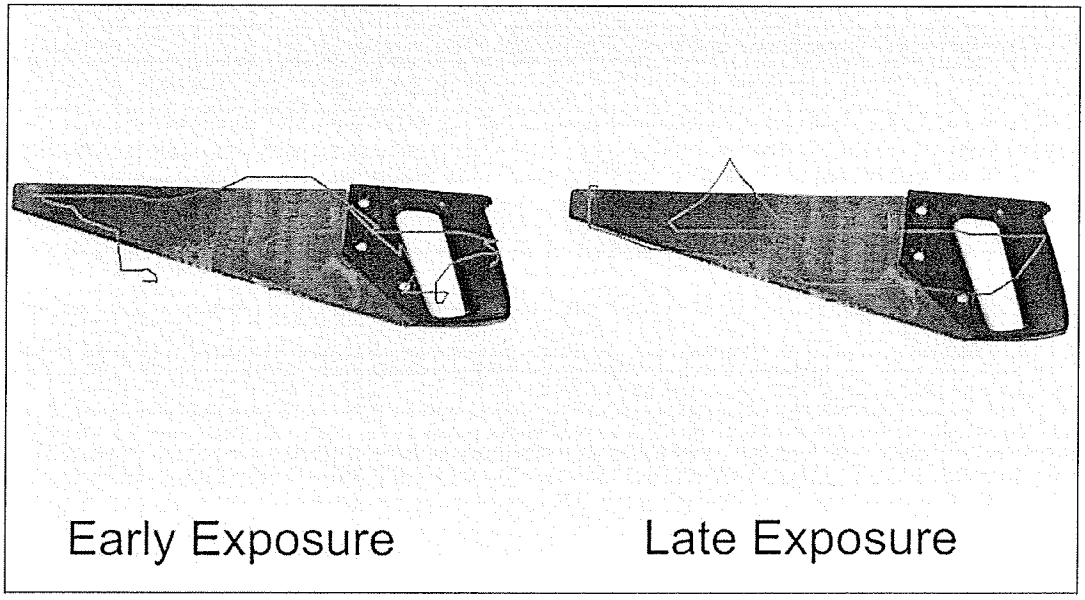


Figure 19. Example scanpath, Experiment 3a.

Earlier in a testing session, when a visuomotor transformation was required, participants displayed a greater difficulty in adapting to the new relationship of body movement and window movement as compared to later in the testing session. Note: Early and late scanpaths were obtained from different participants.

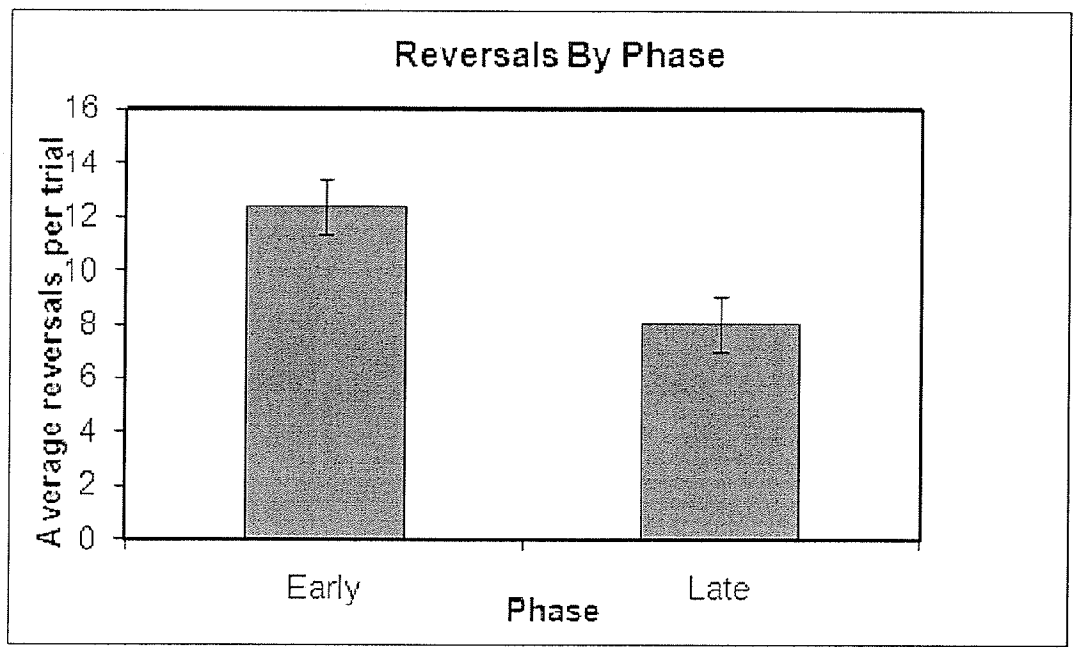


Figure 20. Number of reversals, Experiment 3a.

Experience with the viewing window resulted in an improved level of performance, as reflected in a decrease in the number of sudden reversals in movement direction.

Total movement duration. A statistical analysis on the movement time demonstrated a main effect of phase (early vs. late), characterized by participants taking considerably less time in the second half of the experiment ($F(1,6) = 17.67$, $p < .05$) (see Figure 21).

Discussion

The purpose of the present experiment was to ensure that the viewing window methodology can be adapted to suit an fMRI environment. To accomplish this, the method of controlling the window was modified, the circular viewing window region was illuminated, and the use of a forced choice response prompt and trial timings were introduced. To measure participants' adaptation abilities (as opposed to solely transformation abilities), the analysis included time as a dependent variable. An increase in participants' aptitudes with the window, as indicated by a decrease in the time required to complete the task demonstrated that participants do indeed perform visuomotor transformations with the methodology used here.

The selection of 25% of the response foils from the experimental items brings up the possibility of priming correct object identification in subsequent trials. However, when examining the mean identification time for objects that had the possibility of being primed, such an explanation seems unlikely as no significant movement time differences between the two item types was found ($t(78) = 1.12$, $p > .05$)).

One pattern of results that was not present in other variants of the viewing window is the seeming difficulty in initially controlling the window even in the normal condition, as evidenced by a non-significant main effect of visuomotor type in both the number of reversals, and in the movement time data. In fact, participants are having as much difficulty in the normal condition at the beginning of the experiment as they are with either of the visuomotor flip conditions. One

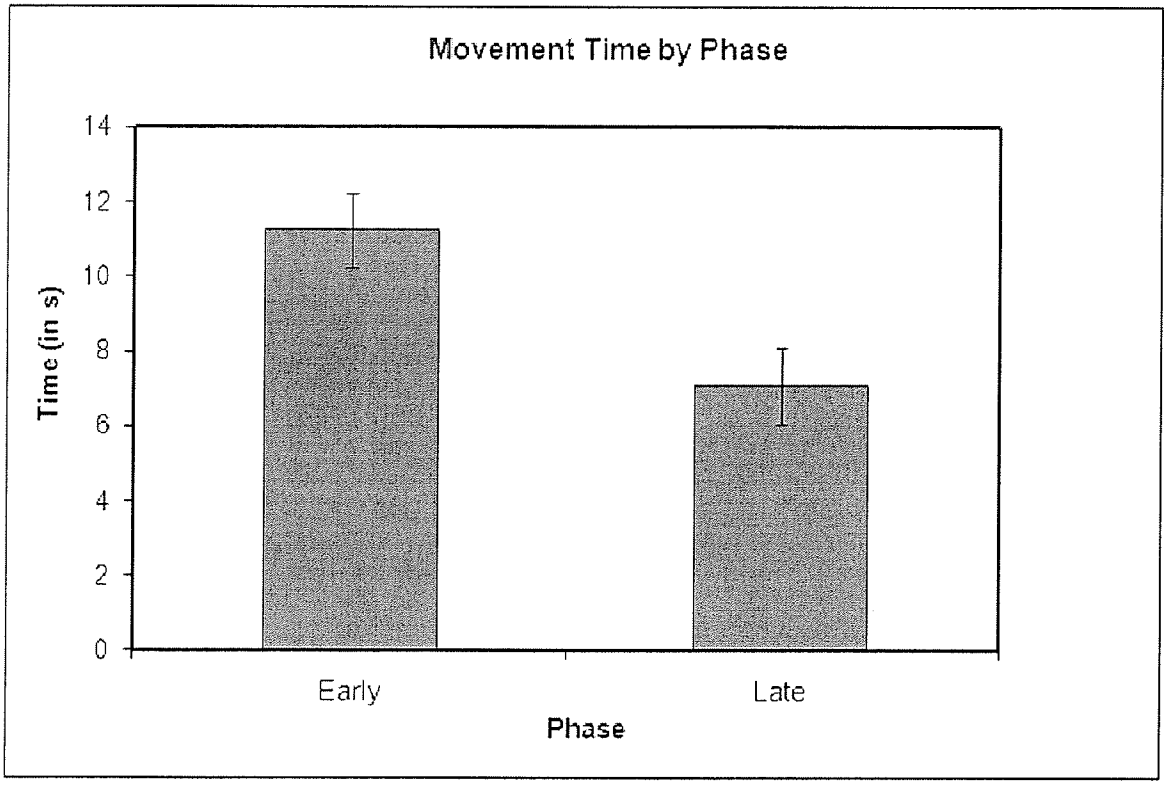


Figure 21. Movement times, Experiment 3a.

Overall, participants were significantly faster completing the viewing window task in the second half of the experiment.

plausible explanation for this is the use of a trackball in controlling the window. As discussed as the primary rationale for using a touchscreen as the controller in previous experiments, this result seems to confirm our suspicions that when a tool (such as a trackball) is used as the method of control, the complexity of calculations required to move the viewing window to a region of interest are likely greater than the calculations that would be required to move solely the fingertip. However, this explanation is purely speculative, as comparisons between Study 2 and Study 3 are not possible, due to the use of substantially different measures of effects. As it is the neuronal underpinnings that mediate visuomotor transformations that are the focus of the imaging work presented, the use of trackball, though not ideal, would suffice.

Experiment 3b – fMRI Evidence of Parietal Lobe involvement in Viewing Window Performance

With the behavioural data obtained in Experiment 3a demonstrating that the necessary modifications to bring the viewing into the magnet environment do not prevent participants from having to learn the transformations required, as evidenced by a significant effect of phase in both the movement time data and in the number of reversals, it was now possible to assess areas of neuronal activation that are related to successfully completing the task when a visuomotor perturbation (either a flip in the x-axis or flip in the y-axis) is introduced.

There have been numerous studies examining the neurological mechanisms involved in correctly performing visuomotor transformation and/or adaptation. Many of these studies have had participants execute a pointing or tracking movement under normal visual conditions and compared the obtained activation to activation observed when a perturbation was introduced. Distortions have included simple rotations (Ghilardi et al., 2000; Imamizu et al., 2007; Inoue et al., 1997, 2000; Krakauer et al., 2004), magnification (Krakauer et al., 2004), lateral shifts of

location (Clower et al., 1996), and, more similar to the present work, axis reversals (Balslev et al., 2002; Flament, Ellerman, Kim, Ugurbil, & Ebner, 1996). The adaptation related activity observed differed substantially between studies, not only in the anatomical locations of regions of activity, but also in the number of regions recruited. In a descending order of frequency, activity was observed within the posterior parietal lobe, the cerebellum, prefrontal cortex, basal ganglia, premotor areas, sensorimotor areas, temporal and occipital cortex, and the thalamus. It is important to note that the studies described can coarsely be grouped into tasks that would induce spatial realignment, strategic control, or a combination of the two. When such a categorization is made, at least some of variability in results is explained, with tasks that rely upon realignment recruiting primarily cerebellar regions, and tasks requiring strategic control recruiting a more diverse range of cortical areas, predominantly within the parietal lobe.

Due to the complex nature of the viewing window task, as previously discussed, it is important to verify that the neurological correlates of successful task compliance are in line with previous imaging work examining visuomotor transformation and adaptation using simpler experimental paradigms. If the viewing window task recruited similar neural networks as previous tasks, and it was relying upon strategic control (as behavioural evidence indicates), activity was predicted primarily within the parietal lobe. Specifically, the superior and inferior parietal lobules (BA40) (Balslev et al., 2002; Girgenrath, Bock, & Seitz, 2008; Inoue et al., 1997), the precuneus (BA7)(Gorbet et al., 2004), and the posterior cingulate gyrus (BA 23, 29, 31) (Balslev et al., 2002),were all regions of interest. Though less commonly reported in previous studies, additional regions of interest included areas of the occipital lobe, the cuneus (BA17,18) (Gorbet et al., 2004; M. W. Parsons et al., 2005), and the lingual gyrus (BA18,19) (Balslev et al., 2002). Finally, regions of interest were identified within the temporal lobes,

consisting of the temporo-parietal junction (BA39, 40) (Ogawa & Inui, 2007), and the frontal lobes consisting of the anterior insula, and anterior cingulate (BA 24, 32) (Balslev et al., 2002).

Materials and Methods

Participants. All participants completed a pre-screening form to ensure it was safe for them to participate in the experiment (see Appendix E), in addition to the demographics forms previously used (Appendix C). Twelve (5M, age range 20 – 45 years old; mean age = 27) participants were recruited from the University of Manitoba's introduction to psychology participant pool or through "word of mouth". Participants were right-handed and had normal or corrected-to-normal vision as reported in pre-test screening. Participants received $25.00 to cover travel expenses, with those recruited from the participant pool also receiving partial course credit.

Apparatus. BOLD fMRI was performed on a 3 Tesla whole-body magnet (Tim Trio, Siemens, AG). A birdcage RF coil was used. Participants were lying supine in the bore, with their heads fixed. A plastic screen was placed at the head of the magnet, with participant's viewing of the screen accomplished through the use of a rear-ward facing mirror box (11cm x 9.3cm) placed within the RF coil. Visual stimuli were back projected onto the translucent screen (122cm x 91cm) at a resolution of 1024x768, with a refresh rate of 60Hz. The distance between the participant's head and screen was 2.4m. This configuration maintained the size of the window equal to the useful resolution of the fovea (2.98 degrees). The viewing window was controlled by a MR-compatible trackball (Current Designs, Pittsburgh) placed at participant midline at the level of the thigh. This placement ensured that the trackball was within easy reach, and also minimized participant movement within the bore of the scanner. Due to the use

of a mirror, the relationship between trackball movement and the resultant movement of the window on the screen was normalized.

Training. Participants were verbally instructed outside of the magnet how to perform the task. Once inside the bore, participants were again verbally reminded how to perform each stage of the viewing window task. Finally, the first functional run for all participants was used as a practice and was not included in the reported analyses. This ensured all participants were not only familiar with the task, but also familiar with the auditory noise associated with the functional scan.

General paradigm. The experimental procedure matched the viewing window paradigm as closely as possible, with necessary modifications to accommodate the imaging environment behaviourally validated in Experiment 3a.

Stimuli. Four lists of 16 items (totalling 64 items) were randomly selected from the 80 items previously used, and can be seen in Table 5, with each list being used for one functional run. Assignment of visuomotor condition was pseudo-randomized and counter-balanced, with all participants beginning Run 1 with the normal non-flipped condition.

Data acquisition and analysis. Data were collected at the National Research Council - Institute for Biodiagnositcs (NRC-IBD) using conventional Blood Oxygen Level Dependent (BOLD) imaging techniques on a 3-T Tim Trio scanner (Siemens, AG). T2* weighted, single-shot blipped gradient-echo echo planar images were acquired with a 3mm slice thickness (field of view = 250mm, in-plane resolution 3.75mm X 3.75mm, TE = 40ms, TR = 2000ms, flip angle = 70°), slice prescriptions can be seen in Figure 22. High resolution T1-weighted images were obtained after the functional runs for overlaying the acquired functional activation.

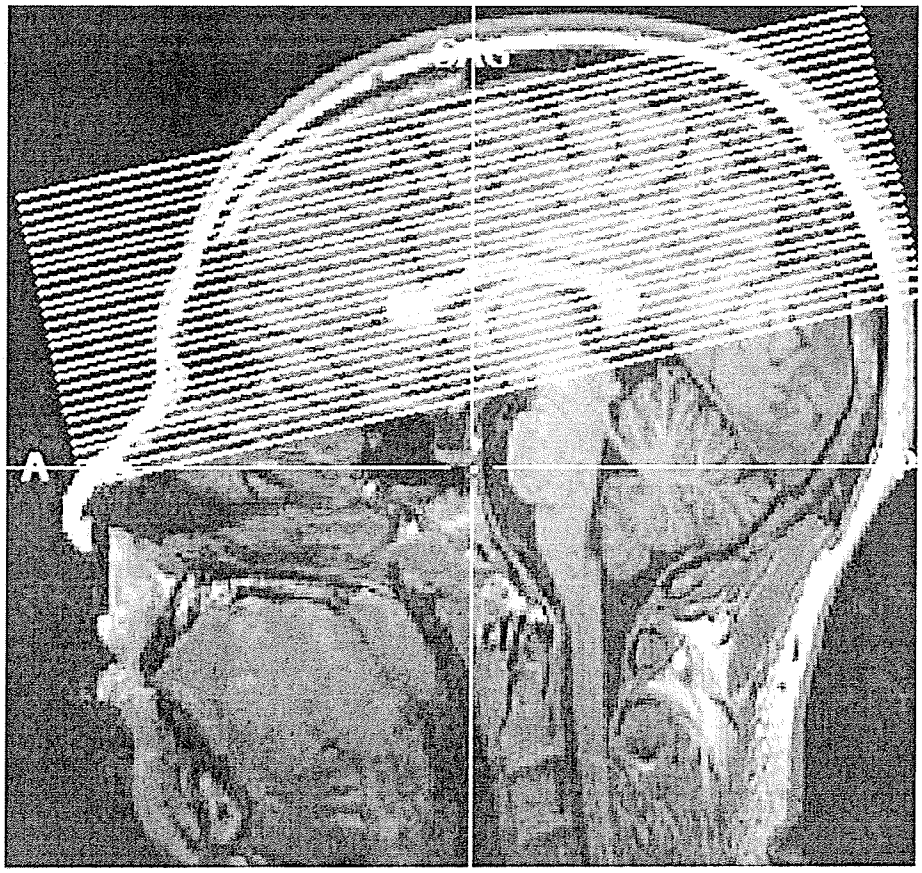


Figure 22. Slice prescription, Experiment 3b.

Each functional scan was 8 minutes in duration, and was run 4 times (with differing objects). Each trial began with a fixation point which lasted for a minimum time of 5 seconds. Participants were given up to a maximum of 20 seconds to explore the object before being presented with response options. Participants were then given a maximum of 5 seconds to choose a response. Any time remaining in either of the response or viewing window periods of the trial were added to the fixation period. These timings ensured a new trial was initiated every 30 seconds (see Figure 23), and that there was a minimum of 10 seconds between the movement phases of each trial. Since most participants did not require the full 20 seconds to identify the presented objects, most trials had 15-20 seconds of intervening time between movement phases. Thirty-two slices were acquired parallel to the AC-PC line in all participants, allowing full coverage of the frontal and parietal lobes.

Data were processed and analyzed using Brain Voyager QX software (Brain Innovation, Maastricht, The Netherlands). The first functional run was discarded as practice. The first two scans of each remaining functional run were omitted from the functional analysis to allow an equilibration of saturation effects, and were instead used to create pseudo-anatomical in-plane scans to assist in the alignment of the functional data to the high-resolution anatomical data collected. Cubic spline slice scan time correction, 3D motion correction using a trilinear/sinc interpolation algorithm, and high-pass temporal filtering using a general linear model with fourier basis set (including linear trend), with 2 cycles as the cut-off, were applied to each functional scan. Additionally, spatial smoothing, using a Gaussian filter (full-width at half-maximum equal to 8mm), was applied to the functional data. Following pre-processing, a multi-scan, fixed-effects GLM analysis with four predictors (fixation, response, normal movement, and flip in movement) was used to determine areas that were activated significantly more during a

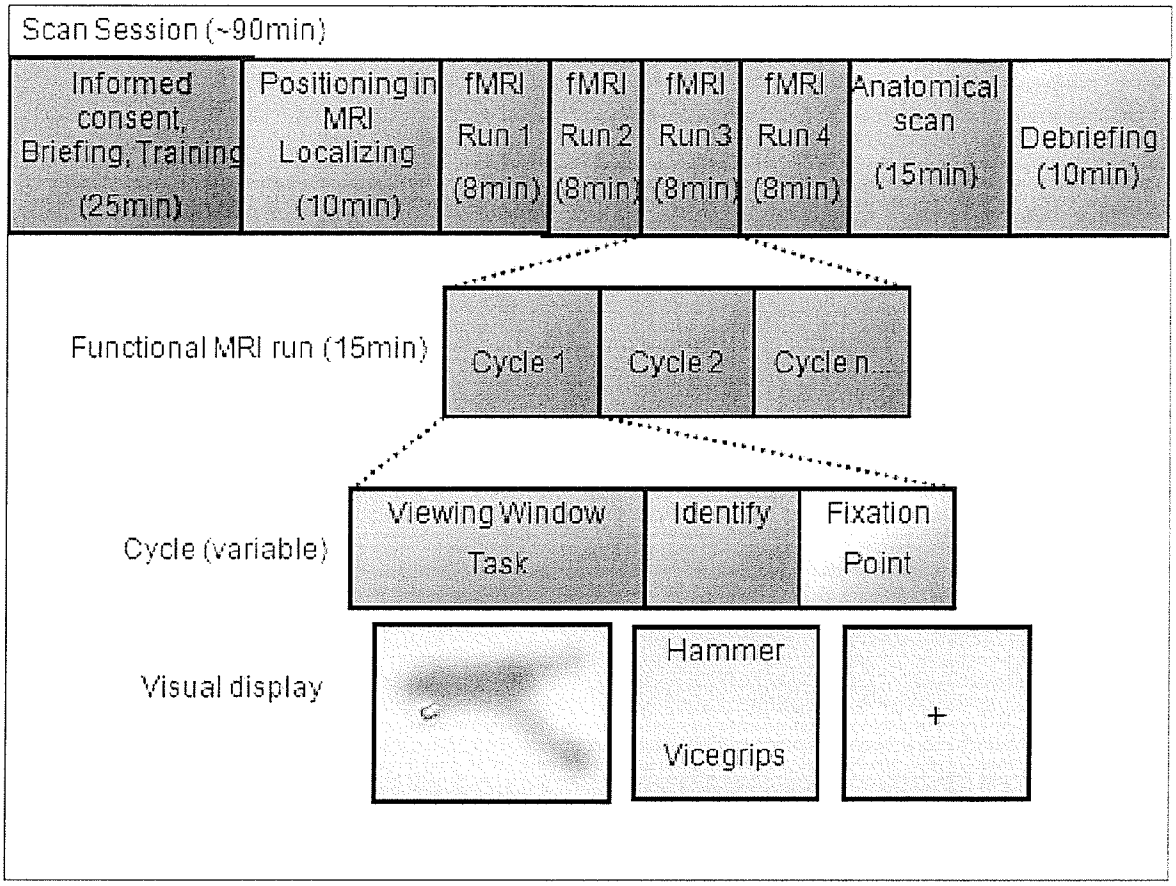


Figure 23. fMRI protocol, Experiment 3b.

flip in the x-axis or a flip in the y-axis when compared to the normal condition. A two-gamma hemodynamic response function (onset = 0; time to peak = 5s; dispersion = 1; undershoot ratio = 6; time to undershoot peak = 15s; undershoot dispersion = 1) was used to model the expected BOLD response. To correct for multiple comparisons, a cluster-threshold approach was taken (Forman et al., 1995).

Results

One participant was excluded from the analysis due to head movements in excess of 5mm of translation and/or 5 degrees of rotation. Additionally two-runs from separate participants were excluded for having head movements in excess of 2mm or 2 degrees. Additionally, one participant was released from the experiment early, due to investigator concerns of claustrophobia. Data analyses were performed on the remaining 9 participants. All functional scans had a signal to noise ratio of .50 or greater.

Behavioural Data. No significant difference in accuracy were observed in the visuomotor flip conditions (average incorrect = 6.2%). Trials in which the target object was not correctly identified were omitted from further analysis. Data were separated by the associated functional run (2, 3, and 4). An initial outlier analysis was performed on the movement time data, excluding values 2.5 standard deviations from each participant's mean for that condition. No trials were excluded on the basis of the outlier analysis.

Analyses were conducted on the average movement times, number of reversals, and average velocity for each trial. Only the velocity data revealed statistically significant differences with a main-effect of run ($F(2,18) = 27.528$, $p < .001$) characterised by participants moving the viewing window faster in the later runs when compared to earlier runs. A significant Run x Flip interaction ($F(2,18) = 4.609$, $p = .024$) was also observed, with the viewing window

being moved at a lower velocity when a visuomotor distortion was introduced in run 2 ($M = -72.414$, $SE = 10.656$, $p < .05$) , but at par with the no-flip condition by run 4 ($M = -23.621$, $SE = 9.223$, $p > .05$) .

Functional Data - Fixed-effects model. Cluster-thresholding was performed (27897 total voxels, 2000 iterations) at a .001 alpha level (maximum size of random cluster = 6). Visuomotor transformation-related neural activation was observed in a number of areas when the activity associated with both of the flip conditions was subtracted from the activity observed during the normal visuomotor condition. The peak activation of each activation cluster can be seen in Table 6.

Within the primary region of interest, the parietal lobes, activation was observed within the left inferior parietal lobule, the right post-central gyrus, and left precuneus. Additionally, activation was observed alone the right parieto-occipital fissure encompassing both precuneus and cuneus. Although it was not a focus of this study, substantial activation was also observed within the frontal lobes in bilateral cingulate gyrus, bilateral precentral gyrus, and the left medial frontal gyrus. Within the occipital lobe, activation was observed within the right cuneus. Finally, areas of activation were observed within the right claustrum and left insula (see Figure 24).

Discussion

The aim of the present experiment was to identify brain areas involved in performing the viewing window task with a visuomotor distortion introduced, and to confirm that parietal regions are recruited, as suggested by behavioural data and the cognitive strategies participants may use to successfully complete the task. Although not all regions of interest previously identified showed significant levels of activation, considering the variability in both the number

Table 6. Anatomical location of observed activation in Experiment 3b.

Fixed-Effects Analysis Anatomical location of Peak Voxel	Volume (voxel)	Voxel-level (T)	Talairach coordinates (x, y, z)	Corrected p-value
Right Post-Central Gyrus	260	5.034	48, -19, 28	0.000000
Right Cingulate Gyrus	16080	6.889	-3,-4,43	0.000000
Right Claustrum	882	5.401	33,-1,7	0.000000
Right Cuneus	266	4.767	15,-82,34	0.000002
Left Medial Frontal Gyrus	169	5.095	-12,50,4	0.000000
Left Precuneus	438	5.135	-18,-67,49	0.000000
Left Precentral Gyrus	4889	6.489	-30,-16,49	0.000000
Left Inferior Parietal Lobule	140	4.918	-36,-58,44	0.000001
Left Insula	96	4.867	-39,14,10	0.000001

*Anatomical location of areas significantly more active during trials when a visuomotor flip was required. The amount of significant voxels, corresponding t-values, talairach coordinates, and p values corrected on the cluster level are indicated.

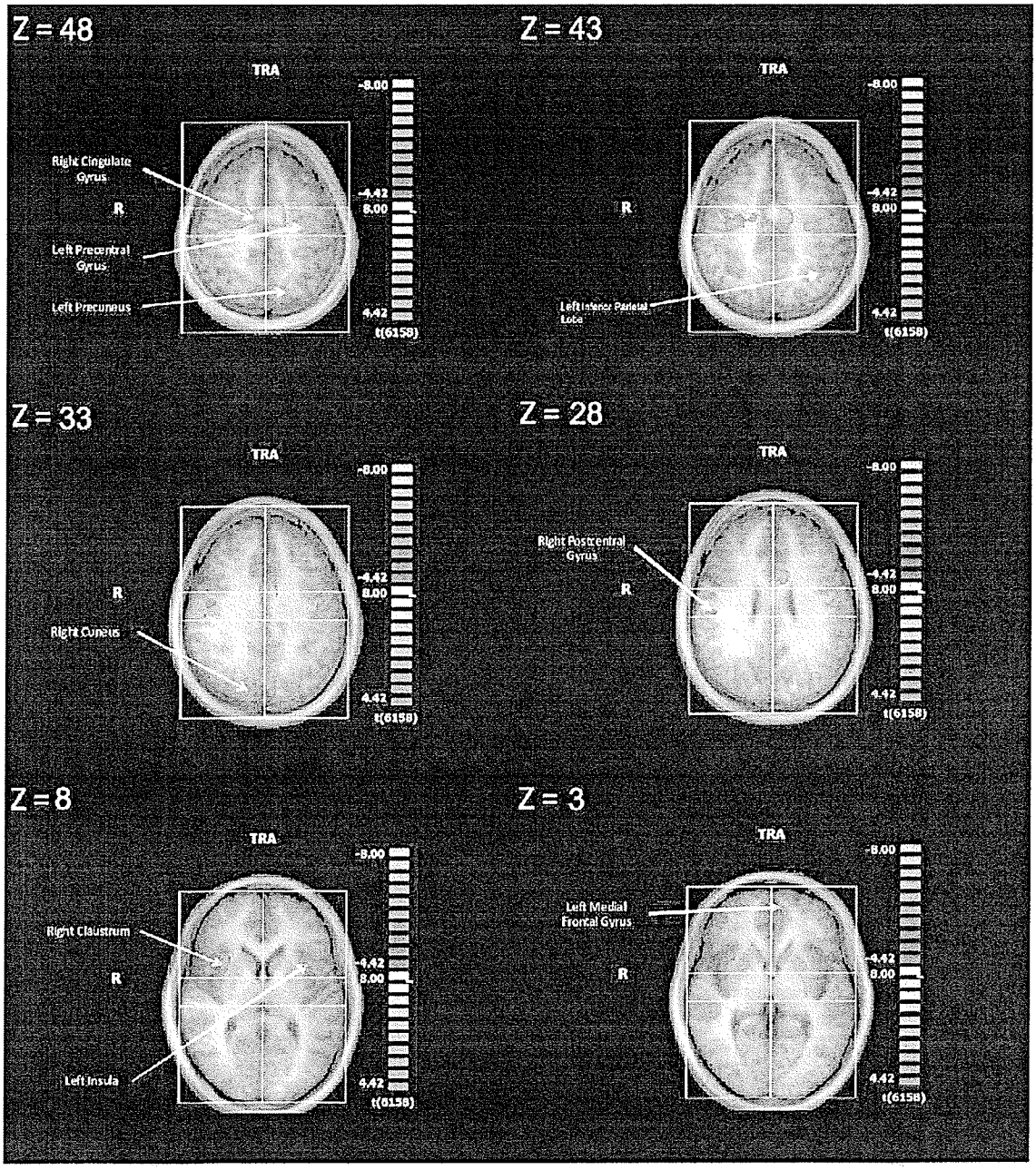


Figure 24. Observed activation, Experiment 3b.

Whole brain axial slices of the average activation from all ten participants are shown. Multiple comparisons were corrected using a cluster-threshold approach at the .001 level. Activations are the result of the fixed effects statistical GLM predictor contrast of the normal (-), and flip in x (+), flip in y (+).

and location of activation observed in a number of previous studies, it is not surprising there was only partial overlap with what has been previously reported. Importantly, significant activation was observed in a number of parietal regions previously identified as being involved in visuomotor transformations and adaptation. First, activation within the inferior parietal lobe has been previously observed both in the ipsilateral and contralateral hemisphere in relation to the hand used in studies examining visuomotor adaptation (Ghilardi et al., 2000) (Clower et al., 1996) (Girgenrath et al., 2008; Inoue et al., 1997). Additionally, similar to what was observed in this experiment, precuneus activation is often reported during visuomotor adaptation tasks (Inoue et al., 1997), especially those of a complex nature (Gorbet et al., 2004). The final area of activation observed within the parietal lobe was within the right post-central gyrus. Of the four regions of interest identified by a survey of previous literature, the present studied demonstrated significant levels of activation in three of those regions. Activation was not observed within the posterior cingulate gyrus, as may have been expected. When taken as a whole, the presented results demonstrate that the viewing window task, when used with a visuomotor motor "flip" introduced, does recruit additional parietal resources when compared to the same task completed under a normal visuomotor relationship.

Though not the focus of this experiment, the frontal regions of activation observed, including bilateral cingulate gyrus, left medial frontal gyrus, and primary motor areas have also been reported as active during similar tasks requiring a re-mapping of motor movement as related to movements within a visual scene (Balslev et al., 2002; Inoue et al., 2000; Krakauer et al., 2004) or during prismatic adaptation (Luate et al., 2009). Although these results are not the highlight of this experiment, validating these additional cortical regions is reassuring. Within the occipital lobe, cuneus activation was observed. Cuneus activation has previously been reported

in similar adaptation tasks (Gorbet et al., 2004; M. W. Parsons et al., 2005), however, it should be noted that although the peak voxel of the activated cluster was within the cuneus, this region of activation extended into parietal (crossing the parieto-occipital fissure) regions as well, making the precise location of the activation difficult to determine.

Perhaps most interesting was the activity observed within the right claustrum and left insula. The claustrum has long been known to become active during crossmodal processing (Calvert, 2001{Crick, 2005 #979), especially when integrating tactile and visual representations (Hadjikhani & Roland, 1998). Activation of the insula was also surprising, as no other visuomotor adaptation studies have shown activation within this region. The insula is known to be involved rudimentary movement (Fink, Frackowiak, Pietrzyk, & Passingham, 1997), and becomes active under conditions of spatial conflict (Meehan & Staines, 2006). Relevant to the present findings, insula activation has also been observed during sensorimotor learning (Mutschler et al., 2007). Although speculative at this time, it is possible that these additional regions of activation that are not typically observed in visuomotor adaptation studies could be a consequence of the increased complexity inherent in the viewing window task.

A discussion about what the pattern of activity actually represents is prudent. As fMRI uses contrasts to determine areas of significantly increased BOLD signal change, the employment of proper comparison conditions is crucial to ensure the observed activation result of the variable of interest. Although much effort was put into the present study to ensure this was the case, the use of the normal movement condition as a baseline for subtraction has some drawbacks. First, we are unsure if the pattern of activity observed is related to the visuomotor distortion itself, regions of cortex that are associated with error monitoring and corrections, or mechanisms involved in switching from an easier task to a more difficult one, as all of these

confounds would be present in the subtractions used. Although the current methodology serves the intended purpose of verifying that the viewing window paradigm recruits parietal regions for the successful completion of a trial in which a visuomotor remapping is required, it does not clarify which areas of activation are associated with the different components of the task. For example, the posterior parietal cortex is known to be involved in error corrections (Desmurget et al., 1999; Desmurget et al., 2001; Diedrichsen, Hashambhoy, Rane, & Shadmehr, 2005), and may therefore be involved in more than one single function, with the present data highlighting an amalgam of this processing. Second, that differences in the programming of eye-movements, or that eye-movements themselves, are responsible for the different patterns of activity observed. This latter point seems unlikely based on the regions of activation observed. However, these alternative possibilities cannot be ruled out with the presented data. Based on pilot data using eye-tracking obtained during a visuomotor distortion trial, it is known that there are more eye-movements made while adaptation is taking place. Without controlling for this confound, the net effect on the neuronal activity presented is largely unknown. Future studies should attempt to quantify this difference by performing eye-tracking during the fMRI task, or should control for eye-movements within the experimental design.

A further limitation is apparent with regards to the method of analysis used. Although common place in fMRI studies with low n-sizes, the use of a fixed-effects general linear model prevents the extrapolation of any obtained results to the target population. In future studies, the patterns of activation observed must be validated at the population level by increasing the sample size to allow such a statistical analysis to be performed.

A final limitation applies to generalizing the patterns of activation observed in the fMRI study to scenarios in which a finger (or other body part) would be used as a method of control.

Due to technical limitations inherent with high magnetic fields, the use of a trackball as opposed to direct control of the viewing window was used in Experiment 3b. This necessary substitution may have influenced the results of fMRI activity in a way specific to tool use, making the assumption that a similar pattern would be observed without tool use questionable.

Chapter Summary

The presented experiments demonstrated that the viewing window task was able to be used within a functional magnetic resonance imaging environment (Experiment 3a), and that the task activated parietal regions in the course of participants performing the visuomotor transformations required to successfully identify the presented object (Experiment 3b). To bring the viewing window paradigm into the MR environment a number of modifications to the viewing window methodology were required. Due to an MRI machine's use of a magnetic field, a fibre-optic trackball was used to control the window. To ensure participants were able to adequately track the window movement, its location was "illuminated" by increasing the RGB colour values of the image at the location of the window. Third, as participants had no method of recording a free-recall response, a forced-choice procedure was employed. Finally, participants were limited in both the amount of time they had to identify an object, and in the time to enter their response. With these modifications, the viewing window was still able to elicit visuomotor adaptation.

The imaging data presented in Experiment 3b verified that the viewing window task recruits additional parietal regions to successfully complete the task under conditions of a visuomotor reversal. Three of four parietal regions of interest were substantiated, as were regions within the frontal and occipital lobes. In addition to this confirmatory data, two additional regions (the left insula and right claustrum) were shown to be significantly more

active during a visuomotor transformation in the viewing window task. These two regions, though implicated in a number of related processes, have not yet been implicated as having a functional role in performing under visuomotor perturbations in other tasks. In sum, the results of Experiments 3a and 3b highlight the viewing window's utility as a visuomotor tool capable of functioning within the MR environment. This new methodology may provide further insight into the visuomotor adaptation process that was not possible before due to the simplicity and transparency of previously used tasks.

Chapter V: General Discussion

The Viewing Window as Visuomotor Tool

Conclusions

Traditionally, viewing window paradigms have been used to evaluate perceptual features useful in object identification. Participants are presented with a degraded picture of an object on a computer monitor and are asked to identify the object as quickly as possible. A small, user controlled area (the "window") displays the underlying image with normal clarity. Despite their traditional role, viewing window tasks require visuomotor processing, which can be manipulated to illuminate the interactions between the "perception" and "action" based cortical visual streams. The research presented in Study 1 demonstrated the feasibility of the viewing window as a method of examining the interactions between perceptual and motor information. Importantly, results confirmed that the viewing window procedure has the ability discriminate any gross asymmetries in a participant's visuomotor scanpath used to identify common objects presented as stimuli. To further ensure the viewing window methodology was suitable for visuomotor research, a comparison between movements of the window and participants' eye movements was undertaken. As suspected, it was not the case that participants are simply following the window with their eyes. In fact, more than half of the trial time was spent with the window moving towards the location of a fixation. The viewing window was only within foveal view for brief periods. These data characterize a relationship between the location of eye-fixations and window location in which a participant is using the heavily blurred peripheral information to select locations of interest, and then guiding the movement of the window towards these fixation locations to extract the necessary visual information to identify the presented object.

Future Directions

With the results of Study 1 demonstrating the viewing window's utility as a general visuomotor tool, the use of the viewing window paradigm in neurological populations now becomes a possibility. Apart from examining the natural aging process, as was done in Study 2, patients such as those who suffer from hemispatial neglect, for example, may produce diagnostically useful dissociations in performance. Hemispatial neglect is most often associated with damage to the right parietal lobe (although it can manifest after damage to the left-hemisphere), but the reasons for the correlation between parietal damage and the typical deficits observed in patients remains under debate. This question is of specific interest because traditional neglect batteries often confound many processes (e.g., visual attention, spatial representation, and motor coordination). A common clinical test for hemispatial neglect, the behavioral inattention test (BIT) is comprised of tasks such as figure copying, line bisection, picture scanning, and letter cancellation (among others). Though the BIT is quite effective at diagnosing hemispatial neglect (Hartman Maeir & Katz, 1995), one can easily identify confounded processes. In order to accurately copy a presented figure, an often-used component of the BIT, a patient must accurately scan the entire image, properly attend to regions of significance, and then utilize efficient motor control to copy what they see. Damage to any one of these systems would result in poor figure copying performance, but for distinctly different reasons. For instance, recent research has shown that severe neglect patients may suffer from simple graphical disturbances and that this may confound assumptions about the assumed visuospatial deficit (A. D. Smith, Gilchrist, Butler, & Harvey, 2006). The requirement of numerous intact visual and motor skills to successfully complete the test makes a determination as to the root cause of the deficit difficult. An inherent advantage of the viewing window task is

the ability to tease apart some of these components. For example, there has been some suggestion that damage to the lateral intraparietal region in neglect patients results in improper eye-movements, resulting in the observed deficit (Behrmann, Watt, Black, & Barton, 1997). By varying either the amount or the nature of the peripheral information in the viewing window task, one can begin to assess the role eye-movements play in the disorder. If improper ocular scanning were at fault, increasing the amount of diagnostically useful information outside of the window should have little effect (since eye-movements are not capturing that region of the image anyway). However, if visuomotor scanning patterns demonstrated an affect of diagnostically useful information being presented in neglected space, eye-movements as a solitary explanation could be ruled out. The viewing window is especially suited to determine the role of eye movements in neglect, as compared to solitary eye-tracking, as one can control the exact nature and salience of the information presented in the periphery (a feature that conventional eye-tracking cannot perform). An advantage of the viewing window task over gaze-contingent displays in studying unilateral neglect is the ability to manipulate the visuomotor properties associated with the task presented, a manipulation that may have ameliorative qualities (Harvey, Hood, North, & Robertson, 2003).

Aging and the Viewing Window

Conclusions

To date, there has been little consensus as to whether age-related visuomotor adaptation effects are readily observable. Some studies have found slower adaptation, and/or reduced overall levels. In contrast, other methodologically similar studies have found no such evidence of aging effects on visuomotor adaptation. Study 2 utilized the viewing window methodology to examine the effects of aging in a visuomotor adaption task, and posited the parietal lobe as a

likely source for the effects of aging observed. In Experiment 2a, two groups of participants, a young adult control group and an older adult group) completed a viewing window task in which four visuomotor "flip" conditions were created by varying the relationship between the participant's movement, and the resultant on-screen movement of the window: 1) No flip 2) X-Axis and Y-axis body movements resulted in the opposite direction of movement of the window. In each of the 3) Flip-X and 4) Flip-Y conditions, the solitary X- or Y-axes were reversed. Older participants demonstrated impairments in adapting to visuomotor transformations, as evidenced by more complex scanning patterns, and longer scanning times. There were, however, some methodological limitations present in Experiment 2a, which were remedied in Experiment 2b. For the most part, the results of this later experiment confirmed the pattern previously observed, providing additional evidence that the mechanisms involved in visuomotor transformation are negatively affected by age.

Future Directions

Future work regarding the use of the viewing window and an aging population should first expand upon this research by increasing the size of the participant groups, and having less of a gender bias in the sample population. Though most measures of interest obtained statistical significance, this was due to the large effect sizes observed and may not generalize to the population as a whole. Though in our small data sets there were no apparent sex differences, previous research has suggested that male and female performance in spatial and visuomotor tasks may not be equal. For example, when performing complex visually guided movements, sex differences have been demonstrated at both the behavioural and cortical level of analysis (Gorbet & Sergio, 2007). This result may persevere into the later years of life (Boucher et al., 1991; T. D. Parsons et al., 2007), at least in behavioural tasks.

Even though we take the stance that it is impairments in visuomotor transformation abilities that accounts for the differences observed between young and aged participants, it is important to note that natural aging is a global process, and affects many systems simultaneously. For instance, natural aging is known to affect cross modal selective attention (Poliakoff et al., 2005), the encoding of novel motor memories (Sawaki et al., 2003), and peripheral visual attention while attending to a foveal location (Richards et al., 2006), to name a few. Future research must be aimed at exploring whether any of these known deficits are responsible for some of the decline we have demonstrated, and if so, the relationship and extent of this process. Modifications to the viewing window task may allow for some of these examinations to take place. For example, altering the method of controlling the window from a touchscreen having a 1-1 correspondence between the participants body movements and the resultant movement of the window to something like a joystick should tease apart whether aged participants are using proprioceptive information in a unique (and conflicting) manner.

The presented research may also hold special importance to researchers addressing reduced levels of daily activity often observed in an aging population. Due to the necessity for many elderly to use tools to assist in day-to-day living, a better understanding of visuomotor functioning in this population is required, to which the viewing window may add a unique perspective. The use of a wheelchair, cane, or any other such device inherently requires a spatial transformation, and in order to provide training and support to use these tools to their maximum advantage, the ability to incorporate these devices into visual and motor computations should be further assessed. The results of Experiments 2a and 2b suggest an aged population may require special consideration when determining how effective or easy to utilize a particular assistance tool may be.

Conclusions.

The experiments conducted in Study 3 demonstrated that the viewing window task is capable of being used within a functional magnetic resonance imaging environment (Experiment 3a), and that the task activates, among others, parietal regions during participants' performance of the visuomotor transformations required to successfully identify the presented object (Experiment 3b). Precuneus activation similar to what was reported in Experiment 3b has been observed during tasks that require a retrieval of previously learned transformations (M. W. Parsons et al., 2005) and motor imagery (Stephan et al., 1995), and in performance during visuomotor distortion (Gorbet et al., 2004; Inoue et al., 1997). Inferior parietal lobe and post-central gyrus activity has also been well documented (Girgenrath et al., 2008; Inoue et al., 1997; Lauate et al., 2009), in a number of different tasks. The frontal lobe activation reported within the right cingulate gyrus, bilateral precentral gyrus, and left medial frontal gyrus have also been reported as during similar tasks requiring a re-mapping of motor movement as related to movements within a visual scene (Balslev et al., 2002; Inoue et al., 2000; Krakauer et al., 2004; Lauate et al., 2009). Novel to this study was activation within the right claustrum and left insula, regions associated with movement, spatial conflict, sensorimotor learning, and the integration of modalities (Calvert, 2001; Crick & Koch, 2005; Fink et al., 1997; Hadjikhani & Roland, 1998; Meehan & Staines, 2006; Mutschler et al., 2007). It was suggested that these additional areas of activation may be a result of the increased task complexity of the viewing window paradigm in comparison to other previously employed techniques.

Future Directions

A prudent first step in further quantifying the patterns of activation observed here is to run the study with sample sizes large enough to allow a more conservative, but appropriate random-effects statistical model. With fMRI being an expensive, time consuming method of obtaining data, larger scale projects that are required for such analysis are best left until a fixed-effects model has provided pilot data. Future research should also consider using contrasts that may disambiguate activity associated with error monitoring and task switching from the performance of the visuomotor transformation itself. This is especially important as regions neighbouring those reported here within the parietal lobe are known to be involved in error corrections (Desmurget et al., 1999; Desmurget et al., 2001; Diedrichsen et al., 2005).

With a preliminary understanding of the neuronal underpinnings of the viewing window task, a number of additional target populations and potential uses become available. Specifically, it is left to be seen if tasks such as the viewing window can fulfill a restorative role, targeting the neurological mechanisms recruited in its use. After a patient has suffered from a stroke, shaping procedures are often used to restore, or at least improve, visuomotor performance. Even though the present study does not directly rule out this line of therapy, it does suggest that the natural aging process may reduce the efficiency of such treatment regimes. Since many shaping procedures rely on explicit task instruction, and, assumingly, strategically controlled movement plan development, the viewing window may be able to serve as a computer mediated treatment regime. In fact, there have been some reports within the literature suggesting overt, explicit tasks may be less effective in fostering rehabilitation of motor skills than those that rely on implicit cues, or remove the focus from the treatment itself, lending credence to such hypotheses (Boyd and Winstein, 2003; Pohl et al, 2006). Plasticity, can simplistically be thought

of as a neuronal ability allowing sensorimotor systems to adapt to novel situations, and to maintain that adaptation for a period of time following. Research on aging has determined that plasticity remains throughout the lifespan in rat (Diamond, Johnson, Protti, Ott, & Kajisa, 1985; Ferchmin & Etorovic, 1986) although there may be a decline in advanced age. Work specific to humans has, for the most part, supported animal models, with a surprising amount of neuronal plasticity remaining throughout the lifespan (Bennett, Sekuler, McIntosh, & Della-Maggiore, 2001; Buonomano & Merzenich, 1998; Kaas, Florence, & Jain, 1999; Liepert et al., 2000). It may, therefore, be possible, due to preserved plasticity, for extensive viewing window training to have a rehabilitative role. It is currently an open question as to whether multiple and/or prolonged exposure to these visuomotor distortions increase task performance in the target populations, and if so, if practice is generalized beyond the specific task to real world scenarios leading to an increase in an overall quality of life.

General Conclusions

The studies outlined in the thesis served to quantify and assess the function of a major site of visual integration, the parietal lobe, in a number of different scenarios using a newly created tool for visuomotor research, the viewing window paradigm (Project 1). Following a successful demonstration of utility, the viewing window paradigm was employed in a series of experiments aimed at answering questions related to the natural aging process and the visual system (Project 2). Lastly, an examination of the neurological correlates of the viewing window was sought (Project 3), which verified the viewing window paradigm as it is presented here utilizes parietal mediated neuronal systems when a mismatch between participants' body movements and the resultant movement of the window were introduced. A diverse research approach was utilized, capitalizing on a wide range of methodology including functional

magnetic resonance imaging, allowing for an extensive examination of the issues at hand. Knowledge gained from this research is thought to have a direct impact on how we design and evaluate tests aimed at assessing visuomotor functioning and how we currently conceive of the natural aging process. Further, the presented research offers a starting point to create a new tool intended not only to examine, but perhaps also to rehabilitate individuals suffering from a myriad of visuomotor impairments.

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APPENDIX A

PARTICIPANT DEMOGRAPHICS

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This information is used to assist us in conducting our study. Please note that there is no personally identifiable information kept, and you are only referred to by an arbitrary participant number. All information will be kept confidential. Your files will only be accessible by the investigators and will be destroyed 5 years after the completion of the study. You may refrain from answering any questions you choose.

Participant # _____ Test Date: _____

Experimental Condition: _____

Vision: Normal:___ Corrected:___ → Wearing Glasses/Contacts?:___

Gender: _____ Age: _____

Hand Used: RIGHT

Handedness Inventory:

1. Throw a ball	L	R
2. Brush Teeth	L	R
3. Eat Soup	L	R
4. Comb Hair	L	R
5. Swing a Hockey Stick	L	R
6. Swing a Racquet	L	R
7. Hammer a Nail	L	R
8. Point to Something	L	R
9. Write Your Name	L	R

10. Is there anything you do with your LEFT hand? _____

APPENDIX B

DEBRIEFING FORM FOR PERCEPTUAL TASK

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Thank you for participating in this study. We are interested in how different visual representations we construct interact with one another and form our experience of vision. From previous research, we know that there are two primary visual pathways. One of these pathways allows us to identify and attach meaning to our surroundings. The other forms representations that allow us to interact with our environment. What we don't know for sure is how these two representations influence one another. In this study we were trying to determine the effect each of these visual streams has by trying to tease apart the individual visual cues you were using to identify the object presented. By blurring the image and observing how you control the window, we are able to see features of the object that you use to identify it. By varying how you interact with the window, we can see how your body actions can help you. If you have any questions later on, please feel free to contact me – my contact information is on your consent form. Thank you again for participating, and have a great day.

APPENDIX C

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Dr. Jonathan Marotta
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University of Manitoba
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This information is used to assist us in conducting our study. Please note that there is no personally identifiable information kept, and you are only referred to by an arbitrary participant number. All information will be kept confidential. Your files will only be accessible by the investigators and will be destroyed 5 years after the completion of the study. You may refrain from answering any questions you choose.

Participant # _____ Test Date: _____

Experimental Condition: _____

Gender: _____ Age: _____

Vision: Normal:___ Corrected:____→ Wearing Glasses/Contacts?:___

Date of last eye-exam: _____

Computer Experience: 1 2 3 4 5

Are you currently taking any prescription medications?

Describe your present state of health: [Excellent Good Fair Poor]

Have you ever experienced / been diagnosed with any of the following:

[Y N] Blow to the head
[Y N] Loss of consciousness
[Y N] Stroke
[Y N] Parkinson's disease
[Y N] Seizures
[Y N] Severe headaches
[Y N] Arthritis
[Y N] ANY neurological disorder

Handedness Inventory

Hand Used: RIGHT

Handedness Inventory:

1. Throw a ball	L	R
2. Brush Teeth	L	R
3. Eat Soup	L	R
4. Comb Hair	L	R
5. Swing a Hockey Stick	L	R
6. Swing a Racquet	L	R
7. Hammer a Nail	L	R
8. Point to Something	L	R
9. Write Your Name	L	R

10. Is there anything you do with your LEFT hand? _____

APPENDIX D

DEBRIEFING FORM FOR PERCEPTUAL TASK

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Thank you for participating in this study. We are interested in how different visual representations we construct interact with one another and form our experience of vision. From previous research, we know that there are two primary visual pathways. One of these pathways allows us to identify and attach meaning to our surroundings. The other forms representations that allow us to interact with our environment. What we don't know for sure is how these two representations influence one another. In this study we were trying to determine the effect each of these visual streams has by trying to tease apart the individual visual cues you were using to identify the object presented. By blurring the image and observing how you control the window, we are able to see features of the object that you use to identify it. By varying how you interact with the window, we can see how your body actions can help you. By tracking your eye movements throughout the study, we can see how your eye movements are integrated to form your visual experience. If you have any questions later on, please feel free to contact me – my contact information is on your consent form. Thank-you again for participating, and have a great day.

APPENDIX E

MAGNETIC RESONANCE SCREENING FORM

This questionnaire is intended to confirm eligibility of potential research subjects and to identify factors which could make participation in an MRI study hazardous. For your safety, please complete the following screening form with your physician:

Research Subject's Name: (please print) _____

Date of birth (D/M/Y): _____

Male ☐ Female ☐ Weight _____ lb. *or* _____ kg.

Please refer to the Exclusion Criteria for MR studies and the examples provided.

SECTION A

If you have any metal in your body as a result of surgery, you will NOT be eligible to participate in our MRI research studies

		YES	NO
A 1	Have you ever had any surgery? If yes, please list surgeries and approximate dates: _____ _____	☐	☐
	To the best of your knowledge and your physician's knowledge, did any surgery require any metal to remain in your body?	☐	☐

(If there is doubt, the Principal Investigator may ask your permission to check your medical records)

SECTION B

If you answer YES to one or more of the questions in Section B, you will NOT be eligible to participate in our MRI research studies.

B1	Do you have any of the following?	YES	NO
	Heart Pacemaker or Defibrillator Implant	☐	☐
	Aneurysm clip	☐	☐
	Intravascular coils, filters and stents	☐	☐
	Artificial heart valve	☐	☐
	Neurostimulator Implant	☐	☐
	Cochlear (inner ear) implants	☐	☐
	Metallic implants or objects of any kind (including orthopedic implants)	☐	☐
	Prosthetic devices	☐	☐
	Artificial limb or joint	☐	☐

	YES	NO
B 2 Have you ever worked as a grinder, metal worker, machinist, welder or other occupations where you may have come in contact with small metal slivers?	☐	☐
B 3 Have you ever been injured in the head, eye or body by a metallic foreign body that was not removed? (eg. bullets, shrapnel, metallic slivers)	☐	☐
B 4 Do you have braces on your teeth or non removable dental retainers?	☐	☐
B 5 Do you have dental work held in place by magnets?	☐	☐
B 6 Do you have body piercing (non-removable metal jewellery)?	☐	☐
B 7 Is there any chance you may be pregnant?	☐	☐
Are you breast feeding?	☐	☐
B 8 Do you have an IUD or contraceptive diaphragm?	☐	☐
B 9 Are you being treated for, or do you have a history of:		
Claustrophobia (fear of closed spaces)	☐	☐
Seizures	☐	☐

SECTION C

Some medical conditions can be made worse by stress. If you suffer from any of the following AND you think you may experience stress during the course of the study, please consult with your doctor before participating.

C 1 Do you have:	YES	NO
Uncontrolled high blood pressure	☐	☐
Ischemic heart disease	☐	☐
Congestive heart disease	☐	☐
Angina	☐	☐
Heart palpitations	☐	☐
Other heart disorders:	☐	☐
Specify:_____		
Panic attacks	☐	☐
Any other anxiety disorders:	☐	☐
Specify:_____		
_____		
C 2 Do you have any other illnesses?	☐	☐
Specify:_____		
_____		

SECTION D

The pigment used in some tattoos is iron based and may cause skin irritation during the MRI scan, especially if the tattoo is large and has been done recently. If you have a tattoo, please discuss with the Principal Investigator.

	YES	NO
D 1 Do you have a tattoo?	☐	☐

SECTION E - EXCLUSIONS FOR BRAIN / HEAD IMAGING

If you answer yes to questions E 1 or E 2, you will NOT be eligible to participate in brain/head imaging studies.

Do you have:	YES	NO
E 1 Cataract Lenses	☐	☐
E 2 Tattooed eyeliner	☐	☐

If you have any metal dental work you will be able to participate in brain studies if it is composed predominantly of precious or semi-precious alloys or amalgam.

Most dental work e.g., in crowns, bridges, caps, fillings, is composed of gold, semi-precious alloys or am and is allowed (Please discuss your dental work with the Principal Investigator if it contains metal)

	YES	NO
E 3 Do you have crowns or non-removable dental bridgework	☐	☐

All information provided on this form is accurate to the best of my knowledge.

Physician's Name: (please print) _____

Physician's Address (please print) _____

_____

_____

Physician's Signature _____ Date _____

Research Subject's Signature _____ Date _____