Control of Steering of Locomotion in Response to Rotational Optic Flows Induced by Active vs. Visually Simulated Head Rotations

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August 2008

A thesis submitted to McGill University in partial fulfilment of the requirements of the degree of

Master's of Science (Rehabilitation Science)

PREFACE

Structure of Thesis

The structure of this thesis is in a chapter format. Chapter 1 includes a background and literature review pertaining to visual motion information and its main effects on locomotion and steering control. This chapter also includes rationale for the study as well as objectives and hypotheses. Chapter 2 of this thesis describes a detailed methodology and instrumentation relating to the study. Chapter 3 consists of a detailed explanation of the results; and finally, Chapter 4 presents a summary and discussion of the main findings, as well as the concluding remarks with future directions.

Contribution of Authors

This study was conducted under the supervision of Dr. Anouk Lamontagne, who contributed to the design of the study, analysis, interpretation of results, and who assisted in editing and revising the thesis. I, Maxim Hanna was the principal investigator who was also responsible for recruiting subjects, collecting and analyzing data, and subsequently writing this thesis.

Acknowledgements

First off, I would like to acknowledge and gratefully thank my supervisor, Dr. Anouk Lamontagne. Her help, knowledge, guidance and scientific expertise were essential to the success and completion of this research study. Dr. Lamontagne's patience and expertise in this field allowed me to develop a critical mind and an understanding for research. I would also like to express my gratitude to Dr. Joyce Fung, who acted as my interim supervisor and co-supervisor during Dr. Lamontagne's maternity leave and, whose brilliance and insightful suggestions were greatly appreciated and valued.

I would like to thank Christian Beaudoin and Lucinda Hughley for their technical assistance and knowledge. Data collection would have been very difficult without the assistance of Jessica Berard and Jennifer Stephenson who were great assets and who were a pleasure to share an office with over the last few years. Thanks also go out to Gevorg Chilingaryan for help in statistical analysis and Vira Rose and Juliana Guy for their administrative assistance. I would also like to express gratitude to all subjects who volunteered their time to partake of this study; their contribution was much appreciated.

This study was funded by the Canadian Institute of Health Research (CIHR), and its financial assistance as well the contribution of Dr. Anouk Lamontagne's research budget, were greatly appreciated.

Last but not least, I would like to thank my parents and the rest of my remarkably supportive family and friends. You have all been with me every step of the way, encouraging me, supporting me, and believing in me. Words cannot express how thankful I am, and may God bless you all. Foremost, I thank God for granting me the strength, knowledge, and courage to complete this chapter or challenge of my life. As it is nearing its end, I look forward to new and future endeavours which life will bring.

"Real knowledge, like every thing else of the highest value, is not to be obtained easily. It must be worked for,--studied for,--thought for,--and, more than all, it must be prayed for."

Thomas Arnold

ABSTRACT

Performing a head turn while walking creates a complex visual pattern that consists of translational and rotational flows, but whether retinal flow is enough to control heading of locomotion or if extra-retinal cues are required is still to be determined. I hypothesize that active head turns will induce smaller heading direction errors and smaller segment reorientation as compared to visually simulated head turns, showing that extra-retinal cues contribute to locomotor steering. Nine subjects were instructed to walk straight in the physical world while being exposed to rotational flows induced by active vs. simulated horizontal head turns. Kinematic variables including the body's center of mass deviations and segment orientations were compared across conditions. Results show that visually simulated head turns during walking resulted in significantly larger heading errors and body segment reorientations, as compared to walking with active head turns. Thus, extra-retinal information does play an important role in the control of heading direction. This is further evidence that the central nervous system has the ability to re-weight relevant sources of sensory information for the control of balance during locomotion in the presence of sensory conflicts.

ABRÉGÉ

Exécuter une rotation de tête en marchant crée un patron visuel complexe qui consiste en des flux de translation et de rotation, mais l'on doit encore déterminer si le flux rétinien peut contrôler à lui seul la direction locomotrice ou si des informations extra-rétiniennes sont requises. J'ai émis l'hypothèse que les mouvements actifs de rotation de la tête induisent de plus petites erreurs de direction et de réorientation des segments corporels que les rotations de tête simulées visuellement, indiquant que les informations extra-rétiniennes contribuent au contrôle directionnel de la marche. Neuf sujets ont eu comme instruction de marcher en ligne droite dans le monde physique pendant qu'ils étaient exposés à un environnement virtuel décrivant des flux optiques rotationnels causés par des rotations de tête actives vs. simulées. Les déviations du centre de masse et les réorientations des segments corporels ont été comparées entre les conditions. Les résultats montrent que les rotations de tête simulées visuellement induisent des erreurs de direction et des réorientations des segments corporels plus grandes que les rotations actives. Les informations extra-rétiniennes jouent donc un rôle important dans le contrôle de la direction locomotrice. Le système nerveux central semble également avoir la capacité de réévaluer les sources pertinentes d'informations sensorielles pour contrôler la marche en présence de conflits sensoriels.

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Chapter 1

BACKGROUND AND OBJECTIVES

1.1 Locomotion

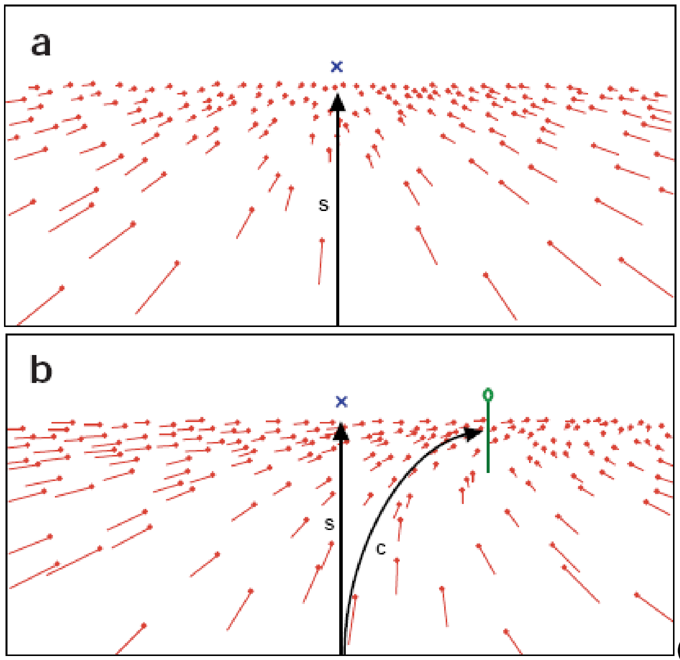
Walking or locomotion is an essential activity in daily living, such as crossing the street to get to work, walking down the hallway to get to the classroom, or even walking the dog down the street. Although the locomotor task is usually done with ease, the control mechanisms can be complex. We must be able to process and integrate all sensory information with the motor command in order to propel the body forward, maintain balance, and simultaneously adapt to environmental constraints. Walking can also be goal-directed, as one walks toward a specified target or goal or in a desired direction. The direction of walking can be referred to as heading direction, and there are different theories as to how one controls or modifies their desired heading, as will be discussed in later sections (sections 1.3-1.5).

There are several sensory systems which assist in the maintenance of heading direction, and they are typically categorized as either retinal or extra-retinal information. Retinal information is typically referred to as the visual information being presented at the retina. This includes, for instance, optic flow or any other visual input or characteristics perceived at the retina. Extra-retinal information includes other types of sensory information such as vestibular information, eye, neck, trunk and leg somatosensory and proprioceptive information and a motor command typically called an efference copy (Crowell et al., 1998) . The focus of this thesis is on the use of optic flow as a source of retinal information to control heading of locomotion.

1.2 Optic flow and its effect on locomotion

Vision provides us with important information about our surrounding environment and self-motion, which in turn allows us to regulate our heading direction. One aspect of vision which is associated with the regulation of walking is optic flow. Optic flow is explained as a typical pattern of visual motion projected at the moving eye during self-motion (Gibson, 1950; Warren et al., 2001). It allows one to accommodate walking direction (Cutting et al., 1997; Warren et al., 2001; Mulavara et al., 2005; Nomura et al., 2005; Bruggeman et al., 2007; Sarre et al., 2008) and walking speed (Pailhous et al., 1990; Prokop et al., 1997; Jahn et al., 2001). For instance, when an individual travels in a linear path, a radial pattern of optic flow is experienced, with a focus of expansion (FOE) being located in the direction of heading (Warren et al., 2001). Optic flow also varies with self-motion, such that, as an individual walks faster, the rate of optic flow will likewise increase in the opposite direction (Larish and Flach, 1990); however, if this information is missing or misrepresented, it can induce illusions or false information to the individual about their heading direction (Bertin et al., 2000). In previous studies it was shown that optic flow influenced body segment orientation and postural equilibrium during quiet stance and locomotion (Lestienne et al., 1977; Previc and Donnelly, 1993; Previc and Neel, 1995; Keshner and Kenyon, 2000).

If an individual were to simply walk a straight path, the optic flow information being presented at the retina would be a radial pattern (Fig 1a). Heading direction could be easily determined from this linear retinal flow by locating the FOE. This type of visual flow is typically referred to as translational flow (Lappe et al., 1999; Warren, 2004). However, if one were to turn the head or eyes while walking, as if pursuing an object, or walking a curved path, the retinal flow would no longer be uniquely translational, but a rotational component would also be produced (Fig 1b). This head or eye rotation would therefore produce a contra-directional pattern of rotation projected onto the retina, opposite to the actual physical rotation of the head or eye. This combined translational and rotational optic flow is presented as a vector sum of both translational and rotational components (Warren, 2004), and is typically referred to as retinal flow (Li and Warren, 2000). Complex retinal flows can be difficult to interpret, such as when one walks and simultaneously rotates the eyes/head toward a target. In such a situation, the heading direction and FOE location may no longer correspond and may even be uncoupled (Crowell et al., 1998; Rushton et al., 1998; Warren, 1998b). Sarre et al. (2008) conducted a study which compared the effects of rotational vs. parabolic complex fields and observed no difference in steering behaviour.



(Warren, 1998a)

Figure 1: a) translation optic flow where ‘x’ is the FOE b) combined translation (‘s’) and rotational (‘c’) optic flow either produced by traveling a curved path or walking straight and shifting head/eyes towards a target ‘o’ .

1.3 Control of heading direction

At this present time, there are two dominant theories as to how we regulate our heading direction when walking. One theory, the egocentric direction strategy, states that we guide ourselves by the use of perceived target location (Rushton et al., 1998; Harris and Bonas, 2002a; Fajen and Warren, 2004). The second theory, the optic flow strategy, suggests that heading direction is specified by optic flow information (Gibson, 1950; Warren et al., 2001; Bruggeman et al., 2007).

The egocentric direction strategy claims that in order to maintain or alter the desired heading direction, an individual would steer towards a target or a goal, therefore maintaining a constant target-heading or bearing angle. Studies that examine walking toward a target while wearing displacing prism lenses suggest that the egocentric strategy is predominant in the control of locomotion on foot (Rushton et al., 1998; Harris and Bonas, 2002b; Huitema et al., 2005).

The optic flow strategy hypothesizes that we control our heading direction by aligning the FOE of the optic flow with a target or goal (Warren and Hannon, 1988; Warren et al., 1991; Warren et al., 2001). Several studies utilizing virtual reality that creates immersive environments have likewise pointed to the use of optic flow in locomotor steering adaptations (Van den Berg, 1992; Warren et al., 2001; Nomura et al., 2005). Despite the conflicting results and the ongoing debate, it appears that both these strategies may be employed in steering, and the degree of their influence may also be directly related to salient visual characteristics and conditional to the environment (Harris and Carre, 2001; Wilkie and Wann, 2002). In visually sparse environments, it seems that the egocentric direction strategy is dominant (Rushton et al., 1998; Warren et al., 2001; Harris and Bonas, 2002b), whereas in visually rich and structured environments the optic flow strategy is prevalent (Wood et al., 2000; Turano et al., 2005). In the context of this thesis, it is assumed that optic flow is one of the sources of visual information used to control heading direction while walking.

1.4 Optic flow alone and the 'perceptual' hypothesis

If heading is determined by optic flow information, then how is it that we process this, sometimes complex, visual information in order to discriminate proper heading? As shown in Figure 1a, optic flow information can be simple, in that it is pure expanding translational flow being presented at the retina, as when one walks straight ahead. If a more complex flow combining a rotation to an expanding translation is experienced (Fig. 1b), such as when turning the head while walking or walking along a curved path, then a more challenging processing of heading perception involving the decomposition of the translational vs. rotational components has to occur. There are conflicting evidences as to how such decomposition takes place. One theory, the 'perceptual' hypothesis, states that optic flow alone contains enough information to discriminate the rotational flow from the translational flow, and hence to recover heading direction (Warren et al., 1991; Van den Berg, 1992, 1996; Stone and Perrone, 1997) (Van den Berg, 1996; Cutting et al., 1997; Li and Warren, 2000). Doubts have however been raised as to the use of optic flow alone or the validity of the 'perceptual' theory on heading discrimination, in the absence of extra-retinal information (Royden et al., 1992; Royden et al., 1994; Grasso et al., 1996; Grasso et al., 1998; Loomis et al., 2001). There are conflicting results and research studies which hypothesize that retinal flow alone may be enough to recover heading direction (Warren et al., 1991; Van den Berg, 1992, 1996; Stone and Perrone, 1997), whereas, other studies suggest that extra-retinal information is required in order to compute heading direction in the presence of a rotation (Royden et al., 1992; Banks et al., 1996; Crowell et al., 1998; Ehrlich et al., 1998). The other theory, discussed in section 1.5, suggests that extra-retinal information is required in order to compute heading direction in the presence of a rotational flow (Royden et al., 1992; Banks et al., 1996; Crowell et al., 1998; Ehrlich et al., 1998)

The 'perceptual' hypothesis has been studied but the evidence is limited to certain conditions, as in slow rotation rates and dense motion parallax (Van Den Berg and Brenner, 1994; Li and Warren, 2000; Wilkie and Wann, 2003). Several studies have shown that at low rotation rates (<1 deg/sec), visual information can be used purely for heading discrimination, but at a higher rotation rate (>1 deg/sec), extra-retinal information would be required to properly discriminate heading direction (Royden et al., 1992, Banks et al., 1996; Royden et al., 1994)}.

Motion parallax is a depth cue that results from self-motion, and as an individual moves, objects that are closer have a tendency to appear to move farther across the field of view than objects that are in the distance. When viewing a virtual scene, it has been shown that if there is sufficient motion parallax available, then the visual system would be better able to extract the translational component from the rotational component, without extra-retinal information (Li and Warren, 2000; Li and Warren, 2004; Royden et al., 2006).

The following section discusses extra-retinal information and how it may aid in decomposing the retinal flow in order to recover heading direction.

1.5 Extra-retinal information and its function during locomotion

In addition to the use of visual or retinal information, such as optic flow, there are other sources of sensory information that may exert an influential effect on the control of heading and posture during locomotion. These sensory inputs are typically categorized as extra-retinal information, and consist of the vestibular and otoliths inputs, as well as head and neck proprioceptive information. (Crowell et al., 1998).

The vestibular system is comprised of 3 orthogonal semicircular canals within the inner ear which aid in balance control and give information about head orientation. When the head accelerates or is rotated (yaw, pitch, or roll), the endolymph within the vestibular semicircular canals stimulate the cilia along the canal, and provide information which is proportional to the angular velocity of the head (Crowell et al., 1998).

Proprioception is the ability to feel body position based on the sensory information from internal sensors within the joints or muscles (Warner et al., 1996). Subsequently, when the head is rotated, the neck muscles contract, and stimulate the proprioceptive sensors, and the information from these sensors denote the position and orientation of the head with respect to the body.

Another important concept relating to extra-retinal information is the motor efference copy. When our head or eyes are actively turned, a copy of the central motor command to move the eye and neck muscles would be retained to compare with the actual eye/head rotations that occur (Crowell et al., 1998). Therefore, if an individual were to walk and simultaneously turn the head, then one would be required to process the retinal information being presented at the eye, as well as all the extra-retinal information which came about due to the active head turn performed. This processing of retinal and extra-retinal information in order to properly discriminate heading direction and control posture is an important aspect of sensorimotor integration (Maurer et al., 2000; Schubert et al., 2003) (Fig. 2).

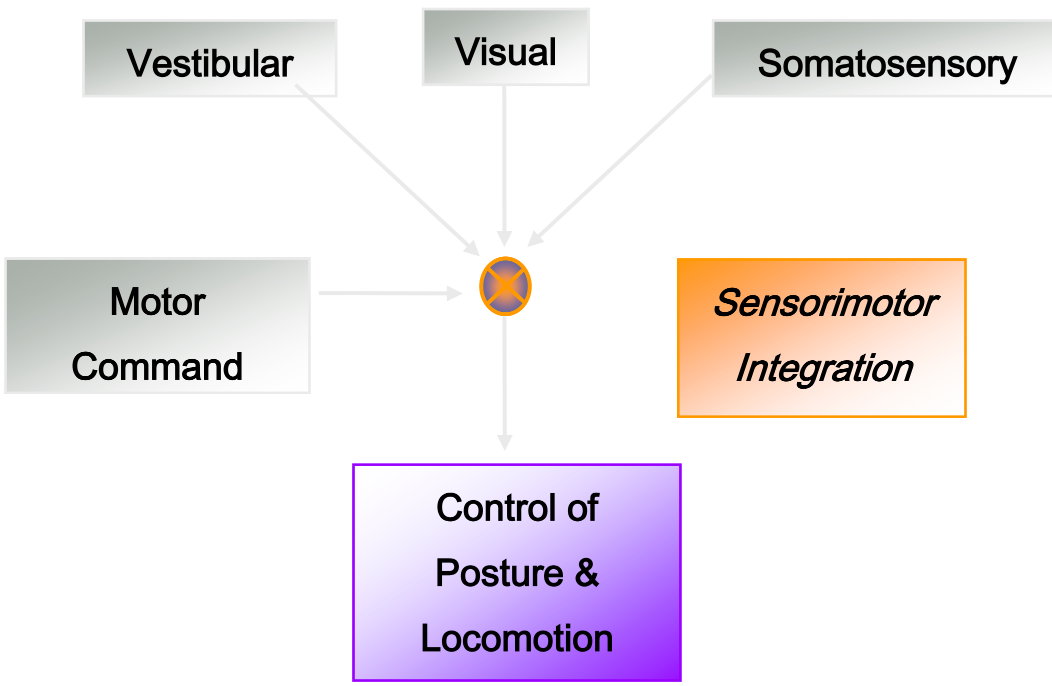


Figure 2: Illustration of sensorimotor integration and its effect on the control of posture and locomotion

Royden and collaborators (1992) conducted a study in which they displayed a flow consisting of a combination of a translational and a rotational flow. Subjects reported that it seemed like they were traveling along a curved path when a 'simulated' rotation occurred, but when an eye pursuit was conducted, small heading errors were yielded. This study concluded that the visual system utilized the extra-retinal information from the eyes in order to properly discriminate heading direction. In addition to the eye rotations, active head turns were likewise found to yield accurate perception of heading, due to the additional extra-retinal information present (Crowell et al., 1998; Vallis and Patla, 2004). It has been suggested that rotations of the eyes and head allow one to discriminate the rotational component from the retinal flow to get the translation component, which would essentially correspond with heading (Van Den Berg and Brenner, 1994; Stone and Perrone, 1997). This is consistent with the findings of other researchers who likewise suggested that extra-retinal information allows one to subtract the rotational component of the visual information from the overall retinal flow in order to recover proper heading direction (Banks et al., 1996; Crowell et al., 1998). Humans also combine static depth cues with optic flow information in order to obtain a precise heading perception (Van Den Berg and Brenner, 1994).

Many of these studies were conducted by presenting the visual information on a screen, while asking subjects to track a moving target with eye rotations, or to fixate on a target while a simulated visual rotation was presented. Hence, in both the ‘real’ and ’simulated’ conditions, the information being presented at the retina was identical, with the exception that in the ‘real’ eye rotation condition, the subject had extra-retinal information concerning their eye position. However, for many of these studies the subjects were in a seated or in a static position which may not be predictive of what may occur during locomotion. During locomotion the body experiences a forward translation and multiple sources of sensory information must be simultaneously integrated.

1.6 Head and Body orientation during steering

During heading adjustments or steering, the body and head is reoriented with the desired travel direction in order to maintain a straight walking direction (Imai et al., 2001). When changing direction during locomotion, a rotation of the body towards the new travel direction and a lateral translation of the center of mass are required, and are superimposed to the normal forward progression of the individual's center of mass (Grasso et al., 1998). It has been suggested that the head is typically used as a natural reference frame, due to the fact that it contains two important systems attributed to self-motion detection; the visual and vestibular system (Pozzo et al., 1990; Hollands et al., 2001).

It has been suggested that during static or dynamic activities, a top-down or head-first scheme of postural organization is utilized (Vallis and Patla, 2004). Thus, the head would orient itself first, and then horizontal rotation of the thorax pelvis, and lower body segments would follow. In straight-path locomotion, the yaw displacement of the head and thorax are typically nominal, however, when a change in heading direction is required, the head starts to turn in the direction of travel before the rest of the body (Patla et al., 1999; Vallis et al., 2001; Vallis and Patla, 2004). While traveling along a circular trajectory it seems that a ‘go where you look’ strategy may be prevalent (Grasso et al., 1996).

In a previous study (Hollands et al., 2001), participants’ heads were immobilized onto their trunk and they were then asked to complete a steering task. It was found that trunk yaw occurred at a much earlier time, signifying that the subjects were attempting to compensate for the lack of head movement, by realigning the trunk and head to towards the new travel direction. It was hypothesized that head re-orientation during steering tasks was not simply used to align to future heading direction, but that head stabilization in space provides a platform for body coordination or a solid reference frame during locomotion.

Head rotations during walking were also studied among patients who have suffered a stroke (Lamontagne et al., 2005a; Lamontagne et al., 2007). It has been documented that stroke is characterized by sensory and motor impairments and by defective sensorimotor integration (Lamontagne et al., 2005a). In these studies it was found, that due to an altered sensorimotor integration and coordination among subjects who have suffered a stroke, poor control of heading was present. However, among healthy subjects it was suggested that head rotations during walking modified the axial segment coordination in a directionally specific manner. Thus, when individuals turn their head while walking, segment re-orientation would be expected.

In a previous study (Vallis and Patla, 2004), active and passive head turns were studied while walking. During the experiment, subjects were asked to maintain a straight walking trajectory while a head turn was performed either actively or passively, through the use of a head mounted air-jet apparatus. Both conditions were similar with the exception that, during a passive head turn, an efference copy of the motor command was theoretically not present. Results from this study found that when an active head turn was performed, heading was more accurately maintained, suggesting that the efference copy is important in controlling heading direction. Also, results from this study found that when a passive or unexpected head turn was performed, then a whole body coordination pattern similar to that of a steering task, and not of straight walking, was observed. It was concluded that the central nervous system (CNS) interprets unexpected changes in sensory information “and subsequently modifies locomotion patterns according to the perceived whole body orientation in space” (Vallis and Patla, 2004). However, whether similar results would occur due to unexpected or altered visual information is still to be determined. It was suggested that when an active head turn is performed during a heading experiment, an efferent copy of the motor command is sent which further allows a better discrimination of heading direction despite the change in optic flow direction (Crowell et al., 1998; Vallis and Patla, 2004). Further investigation is also needed to verify whether heading direction can be accurately perceived and maintained when a conflict occurs between retinal and extra-retinal information.

The steering response to retinal or optic information was studied by Warren et al. (2001) and in their study healthy individuals were asked to use optic flow in a virtual environment in order to walk towards a goal. The FOE was shifted at 10^{o} to the left or right of the subject, such that optic flow appeared shifted by an angle of 10 ^{o} to their left or right in the virtual world. If the subject were to align the FOE with the goal, then their trajectory in the real world would tend to deviate 10^{o} to the right and left so that a virtual heading error of 0^{o} would can be reached (Fig. 3) (Warren et al., 2001) .

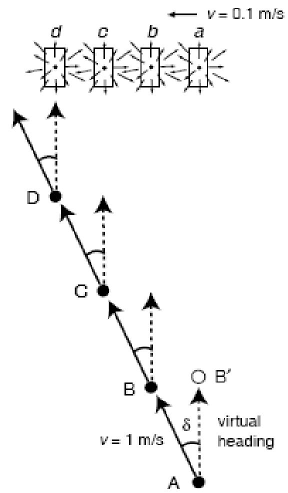


Figure 3: Experimental condition from the Warren et al. 2001 study. *"Optic flow hypothesis: the subject walks 10° to the left of the goal at a (from point A to B), placing the FOE on the goal. The virtual heading is thus toward the goal (from A to B΄). Goal and observer drift leftward together, such that the relative position between the FOE and the goal is constant. Iteratively, this predicts a straight path in both physical and virtual worlds, and a virtual heading error of α = 0." (Warren et al., 2001)*

Optic flow direction can be artificially manipulated , as in the Warren et al. (2001) study, using a virtual reality set-up, or it can ecologically manipulated , as when one walks along a curved path, or when the head is turned to look to one side while walking. When head movements or rotations are performed, the vestibular system is activated and a contra-lateral rotational optic flow is created at their visual field. In the latter case, however, not only the visual system, but also the vestibular and proprioceptive systems are intensively recruited and participate in the control of heading direction while walking (Maurer et al., 2000; Schubert et al., 2003; Vallis and Patla, 2004)..

In studies such as that by Warren et al., the FOE was also shifted laterally to the side, creating an translational optic flow (Warren et al., 2001). In presence of a head rotation, however, a rotational flow is rather induced. It is known that optic flow is processed by specific visual pathways that respond to six degrees of freedom corresponding to translations and rotations about 3 orthogonal axes (Wylie et al., 1998). By incorporating a rotational component into the FOE shift that simulated a head turning action, we should be activating the visual rotational pathways.

In a previous study conducted by Sarre et al. (2008), healthy young subjects were presented with translational vs. rotational optic flows expanding from different FOE locations and were instructed to walk straight in the virtual world. It was found that translational and rotational flows influenced locomotor steering strategies differently. With the translation flow, minimal body segment reorientation in the horizontal plane was produced. A “crab walk” or side stepping strategy was also employed to displace the center of mass (COM) medio-laterally, as reported in Warren et al. (2001). With the rotational flow, however, subjects displayed large horizontal body segment reorientations in the opposite direction of the FOE. It was concluded that the optic flow configuration (translational vs. rotational) has an impact on steering behaviours. Rotational flows induced steering behaviours that resembled more closely those observed under ecological situations, which was attributed to the fact that humans are more exposed to rotational flows in their daily lives. As in previous studies using translational flow, the study by Sarre et al (2008) also set up a conflict between the retinal and extra-retinal information. How heading direction is recovered and how steering strategies are adopted while exposed to congruent rotational flows and extra-retinal information, such as during active head turns, needs to be further investigated.

1.7 Rationale for study

It remains unclear how heading direction and locomotor steering strategies are controlled when subjected to rotational flows. More specifically, whether extra-retinal information is needed, in addition to the optic flow information, to control the heading of locomotion in presence of rotational flows, needs to be examined. Psychophysical studies performed in sitting suggest that optic flow information alone may be sufficient to identify heading direction under some specific conditions. On the other hand, a study of passive head turns during locomotion (Vallis et al. 2004) suggests that elements such as the motor efferent copy may be essential to the recovery of heading direction. Moreover, unlike most virtual reality studies carried out to date, optic flow information in everyday life is normally congruent with other sources of sensory information (e.g. vestibular, proprioceptive), as when one turns the head or change direction while walking. This brings on an additional question as to how the CNS adapts in presence of a conflicting and congruent retinal vs. extra-retinal information. In the present work, by examining the steering strategies in the presence of a rotational flow that is congruent vs. in conflict with extra-retinal information, it will further help to understand the sensorimotor integration mechanisms underlying the control of heading of locomotion. Congruent sensory information will be obtained through active head turns while walking, whereas conflicting optic flow vs. extra-retinal information will be triggered using visually simulated head rotations.

The characteristics of the visually simulated head turns can easily and accurately be manipulated with the virtual reality system. In order to control the amplitude and speed of the active head turns and to make sure they are identical to the visually simulated head turns, however, subjects will be required to visually track a rotating target. Since only one variable at a time can be manipulated and since it is unknown whether the presence of a target element influences the control of the walking trajectory, the visually simulated head turn condition will be carried out with and without the presence of a stationary target.

1.7.1 Research Questions

My research questions are:

(1) To what extent does rotational optic flow direction induced by active versus visually simulated head rotations influence heading direction in healthy individuals?

(2) How do the heading responses differ in simulated head rotations when a target is present or absent.

1.7.2 Objective

The objective of this study was to evaluate the effects optic flow direction on the control of heading direction and body orientation in healthy individuals, when subjected to rotational optic flows, with or without an active head rotation.

1.7.3 Hypothesis

It is hypothesized that:

(1) Active head turns, which provide a congruent change in rotational optic flow and extra-retinal cues, will induce smaller changes in heading direction and body segment orientation while walking, as compared to visually simulated head turns that do not provide extra-retinal cues.

(2) Visually simulated head turns will induce a compensation in the heading direction and in segment reorientation that are opposite to the FOE location (See conceptual scheme in Fig. 4)

(3) The presence or absence of a target in the visually simulated head turn conditions will not induce any significant changes in heading direction or in body segment orientation.

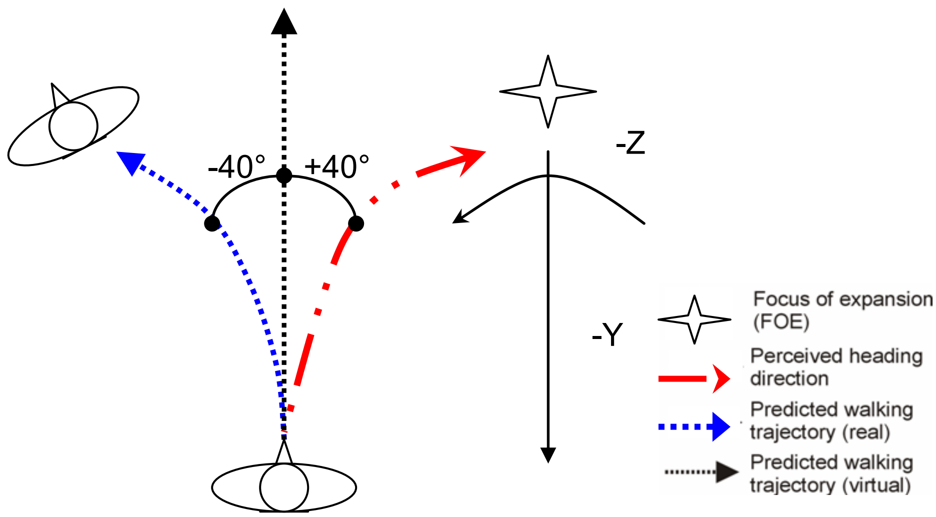


Figure 4: Experimental condition for a visually simulated rotational optic flow when the FOE is located 40° to the right. If the subject were to walk straight in the physical world then a perceived and conflicting heading direction would occur (red line). If the subjects were asked to correct for the conflict, by walking straight in the VE (black line), then a predicted walking trajectory in the physical world (blue line) would occur, causing a heading angle equal in magnitude and opposite in direction to the FOE location.

Chapter 2

METHODS & PROCEDURES

2.1 Subjects

All subjects gave written informed consent (Appendix A) to participate in this non-invasive research study approved by the ethics committee of the Montreal Centre for Interdisciplinary Research in Rehabilitation (CRIR). The healthy young individuals included in the study had to be aged between 18 and 31 years of age and be naïve to the objectives of the study. Exclusion criteria included any health condition that interfered with locomotion or with the ability to follow or comprehend the instructions, as well as the presence of visual deficits not corrected by eyewear.

2.1.1 Sample Size

The primary outcome of this study is the heading orientation, defined as the mean instantaneous angular deviation of the body's center of mass (CoM) in the horizontal plane, as influenced by optic flow and measured by the Vicon motion analysis system. Sample size was calculated using the main outcome measure, CoM heading orientation. The calculation was based on a research design using within-factors, repeated measures ANOVA, with an alpha level set at 0.05 and a power of 80%. CoM heading direction is a very robust measure that shows a small inter-individual variability but also "provides a more accurate description of whole body movement, it can also provide insight into dynamic balance control mechanisms during locomotion" (Vallis and Patla, 2004). In a group of healthy young individual with similar characteristics as those involved in the present study, the within group variance was shown to be 1.9 ° (Turano et al., 2005). Based on previous studies on the effects of optic flow direction and/or type on CoM heading orientation, (Turano et al., 2005; Sarre et al., 2008) a large effect size was also expected. As per Cohen's convention (Cohen, 1988), a large effect size value of 0.4 was therefore chosen. This yielded a sample size of 8 subjects. Sample size calculation was computed using G-Power version 2.0.

The subjects, 4 males and 5 females (Table 1), consisted of a convenience sample recruited from undergraduate and graduate students from McGill University and/or the Jewish Rehabilitation Hospital. All subjects were naïve to the objective of the study and to the type of flow being presented.

TABLE 1: SUBJECT CHARACTERISTICS AND ANTHROPOMETRIC MEASUREMENTS.

SUBJECT	*Gender*	*Age (years)*	*Height (cm)*	*Weight (kg)*	*Gait Speed (m/s)*
1	Male	23	172	68	1.12
2	Male	31	180	77.3	1.02
3	Male	26	170	62.7	0.86
4	Male	20	165	63.6	1.05
5	Female	20	163	54.4	0.74
6	Female	23	168.9	72.6	0.89
7	Female	26	167.6	78	0.97
8	Female	19	160	53.1	0.94
9	Female	22	163.6	56.7	1.04
Mean ± SD		*23 ± 4*	*168 ± 6*	*65 ± 10*	*0.96 ± 0.12*

2.2 Instrumentation

This study examines the ability of healthy young individuals to control their heading direction while walking and being exposed to rotational flows caused by either an active or a visually simulated head rotation. Virtual reality, which allows us to manipulate vision in real time, was used to manipulate optic flow. As shown in several studies, virtual reality can be used as an effective tool for vestibular rehabilitation and motor control research (Keshner, 2004; Sparto et al., 2004). The virtual environment (VE) used in this study was created in *SOFTIMAGE* and consisted of a rich-textured room, with windows, columns, and identifiable markings on the ceiling, floor, and walls (Appendix B). The dimensions of the VE were 40m x 25m and had pillars on both sides of the room which were separated by a distance of 8m.

The VE was displayed in an NVisor helmet mounted display (HMD) allowing the subjects to walk and look freely within the volume of the virtual room. The horizontal and vertical field of view of the HMD was 47° and 37°, respectively (60º diagonal). Three-dimensional body kinematics were recorded using a Vicon-512 motion analysis system with 10 high-resolution (1000 x 1000 pixels) cameras (M60) and which recorded the position of the reflective markers at 120 Hz. This set-up allowed us to record the location of 39 reflective markers located on specific body landmarks and the HMD, as described in the Plug-and-Gait model from Vicon (Sarre et al., 2008). The HMD had 3 markers attached to it (front, left and right) which formed a rigid body of the head, allowing the Vicon system to calculate head position and orientation (pitch, roll, and yaw) in 3 dimensions. If a proper calibration is done, the Vicon 512 system has an accuracy of within 0.04mm when tracking a reflective marker (Vicon, 2005).

The exposure for this study was optic flow direction. This was manipulated through the CAREN-2 (Computer Assisted Rehabilitation ENvironments, by Motek) virtual reality system. CAREN-2 is a closed-loop system which has the ability to adapt the virtual room based on the location and orientation of the head (Lamontagne et al., 2005b). The CAREN-2 software was run using an Intel dual processor PC, with a NVIDIA Quadro FX 4500 video card. The head location and orientation recorded and measured by the Vicon system was fed to the Tarsus real-time engine from Vicon, and then to the CAREN-2 virtual reality system that adapted the virtual visual scene accordingly (Fig. 4). When applicable, the CAREN-2 system allowed adding a visual perturbation to the VE in addition to the visual flow created by the self-motion of the subject and manipulate the visual scene in accordance to the desired location of the FOE.

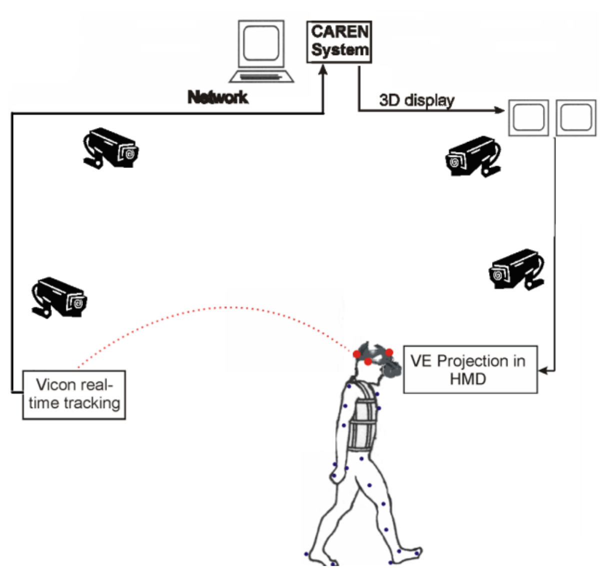


Figure 5: Experimental set-up and method for data collection

2.3 Data Acquisition

The main outcome for this study was the medio-lateral displacement of the subject's CoM, as affected by optic flow direction. Head, trunk, pelvis and feet reorientation strategies were also examined. These kinematic variables were recorded using the Vicon system and 39 reflective markers placed on the subject (Appendix C). A 15-segment model was created based on the upper and lower body Plug-in-Gait marker set developed by Vicon. The upper body marker set was comprised of the head, thorax and the arms. The head was formed by a 3 marker set (front, left and right), which was later mathematically transformed into a 4 head marker set, through the use of the *BodyBuilder v.3.6* software. The thorax was defined as the markers placed on the manubrium, the xiphoid process, C7 and T10 spinous processes, and a right back marker which was placed on the right scapula. The arm segments consisted of bilateral markers on the acromio-clavicular joints, the humeri, the lateral epicondyles, the forearms, medial and lateral wrists, and the head of the second metacarpals. The anterior and posterior superior iliac spines and the sacrum made up the pelvis of the lower body marker set; whereas the mid-thighs, the lateral epicondyle of the femurs, the mid-shanks, the lateral malleoli, heels and head of the second metatarsals defined the leg segments of the lower body marker set (Appendix D). This full-body marker set was then used to calculate joint angles as well as head, pelvis and foot orientation and CoM trajectory. The Vicon system uses published tables based on the distribution of mass within limb segments (Winter, 2005) in order to approximate the segment masses and centers of mass.

2.4 Procedures

Subjects were asked to read and sign the consent form (Appendix A), which explained the nature of the study. Subjects then participated in a 2-hour experiment conducted in the Virtual Reality and Mobility Laboratory of the Jewish Rehabilitation Hospital Research site of CRIR in Laval.

Anthropometric measurements, such as height, weight, leg length, and ankle, knee, elbow, wrist, and hand thickness were measured and inputted in the Vicon Motion analysis system, in order to calculate body kinematics. Reflective markers were placed on specific body landmarks and the HMD was fitted to the subject's head to comfort. Subjects were first habituated and familiarized to walking in the virtual environment for approximately 2 minutes (Appendix B). During this time, no altered visual perturbation was experienced and no data were collected. Throughout the practice session and the experiment, the subject was able to stop or rest as often as they would like.

Subjects were evaluated while walking overground at a comfortable speed and watching the VE in the HMD. They were randomly exposed to FOEs rotating at three different locations: left (-40°), right (+40°) and neutral (0°). The shifts in FOE location were triggered either externally (visually simulated head turn) or by having the subject rotate their head (active head turn). These FOEs were presented to the subject under three conditions: (1) active head turn (AHT), (2) visually simulated head turn with a target (SHT) and (3) visually simulated head turn without a target (SHT_NT). In all conditions there was no rotation or exposure for the first 1.5 meters of forward walking. A rotation of the visual flow occurred over the next 3.5m, inducing a total FOE shift of ±40° (or 0°) at 5m of forward walking. The initial 1.5m of walking with no exposure was included to allow the subjects to initiate gait, and it has been shown that at least one step is required for steady gait to be reached (Breniere, 1986).

The rotational flow was caused either by an active head rotation or a visually simulated rotation of the VE. In the active head turn condition the subjects were asked to track a virtual red spherical target by rotating their head in the horizontal plane (yaw), and keeping the red target in the center of their field of view. The red target appeared 2 meters in front of the subject's field of view and at a height of 1.6m. The red target rotated around the vertical axis (yaw) of the subject's head with a rotational amount that was a function of the subject's forward displacement in the VE (Fig. 5). When the subject reached the end of the

5m walkway, the red target would have rotated 40° to the left, right, or remained at neutral (0°). The rate of flow, whether active or visually simulated, was 11.429° per meter of anterior displacement.

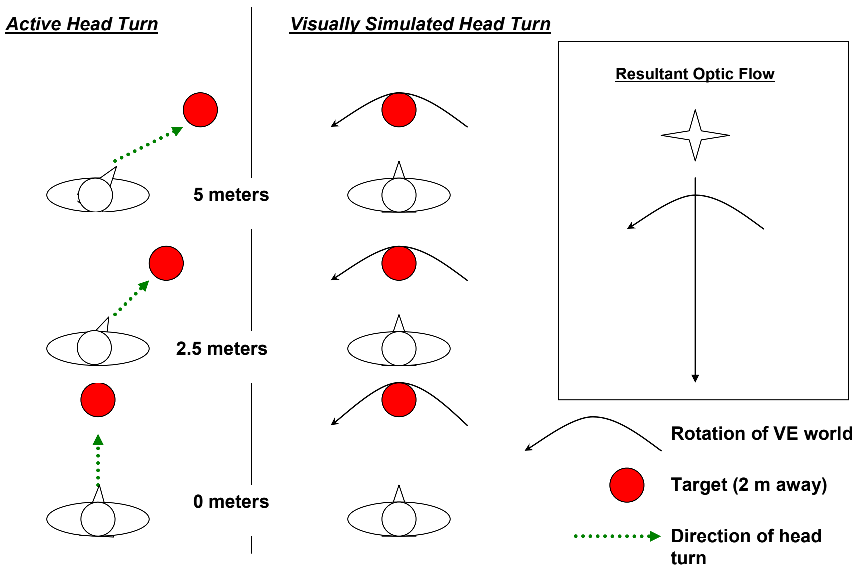


Figure 6: Bird's eye view of the experimental conditions for an active head turn (AHT) and a visually simulated head turn (SHT) toward the right. The AHT and SHT to the right cause the optic flow to rotate toward the left. The result is a complex optic flow pattern which is the sum of an expanding or backward flow, caused by the forward translation of the body, and a rotating flow, caused by the active or simulated head rotation. The third testing condition, similar to the SHT condition but with no target (SHT_NT), is not illustrated.

In the SHT conditions, the VE was rotated so that the rotational OF was similar to the active head turn and the visual information being presented in the

HMD seemed as if the subject was rotating their head. In contrast to the AHT condition, the location of the red target in the SHT condition remained unchanged throughout the trial, such that it was consistently in the center view of the HMD and 2 meters in front of the subject, regardless of head movements or forward displacement. In the SHT_NT condition, the VE rotated exactly as in the SHT condition (with target), except the subject did not have a fixed red target in the center of their field of view.

Three FOE locations (-40°, 0°, +40°) were tested for each head turn condition (AHT, SHT, SHT_NT). Each FOE location was repeated 4 times, ie. 12 trials for each of the 3 head turn conditions and a total of 36 trials for each subject (Fig. 6). Conditions were block-randomized so that the testing order of head turn conditions differed across subjects and that of FOE locations was randomized within each condition.

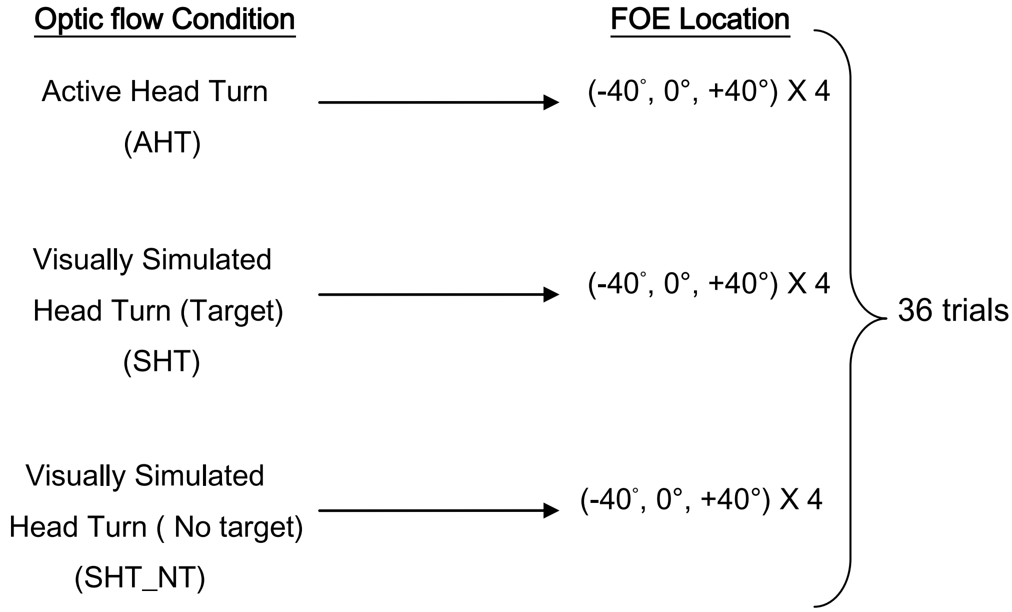


Figure 7: Exposure variables and number of trials for experiment.

The verbal instructions for the AHT condition were "walk straight in the real or physical world while maintaining the red target in the center of the HMD field of view", such that a head turn would have to be actively performed. Looking at the target by simply performing an eye rotation would not be sufficient since the VE only responded to head position. For the SHT conditions, the verbal instructions were to walk straight in the real world.

During the experiment a research assistant was present and close to the subject in order to prevent the individual from potentially losing balance or falling. No loss of balance or falls occurred during the experiments. The assistant also helped in placing the subject back to the starting position and aligning the subject straight with respect to the walkway.

2.5 Study design

This experiment was a cross-sectional study that examined the differences in heading direction when an active head was performed as compared to a simulated head turn while walking over-ground. Study variables are shown in Table 2.

Table 2: Study exposure and outcome variables.

Variables	**Definition**	**Type**	**Scale**
Location of FOE (optic flow direction)	-Rotational optic flow conditions (-40°,0°,+40°)	Exposure	Discrete
Type of Rotation	Active head turn vs. Simulated head turn	Exposure	Discrete
- CoM deviation (real and VR world) - Head, thorax, thorax and feet orientation	- heading errors (real and VR) -orientation angles (real and VR)	Outcome	Continuous

2.6 Data Analysis

The primary outcome of this study was CoM deviation, and secondary outcomes were head, thorax, pelvis, and foot orientation. All 39 reflective markers were labelled with the use of the Vicon Workstation software (version 5.2.9), which then allowed to create a 15 segment model and calculate 3D joint angles, segment orientations, and body CoM at each given frame of a trial. Body segment orientations were calculated by the Vicon software, which used raw data (individual markers) to calculate Euler angles (yaw, pitch, roll) and 3-dimensional coordinates of the head and body. Data were thereafter imported in MATLAB program (v.6.5.1.1) for data analysis and graphing. Mediolateral deviation of body CoM was calculated both with respect to the physical and virtual world coordinates. The heading angle defined as the angular deviation of the CoM deviation in the horizontal plane, was also calculated with respect to both coordinate systems. No difference between the subject's medio-lateral displacement and their starting position, in degrees, would consequently relate to a heading angle of 0° and would signify a perfectly straight trajectory.

2.7 Statistical Analysis

Repeated measures 2-way analyses of variance (ANOVA) were performed to assess any main or interaction effects due to rotational optic flow conditions (AHT, SHT and SHT_NT) or FOE locations (-40°, 0°, +40°) on heading direction and on body segment orientations. Although outcome measures were described in both physical and virtual environments, statistical tests were performed only for measures in the real world, which represents the coordinate system of interest. The global level of statistical significance was set at $p<0.05$, after adjusting for the number of ANOVA ran with the Bonferonni test. Since a total of 5 ANOVA was performed for the outcome measures, a p-value of <0.01 was accepted as significant for each of the 5 outcome measures in the real world. Posthoc comparisons were made with Tukey's test. Statistics were performed in *Statistica 7.1*.

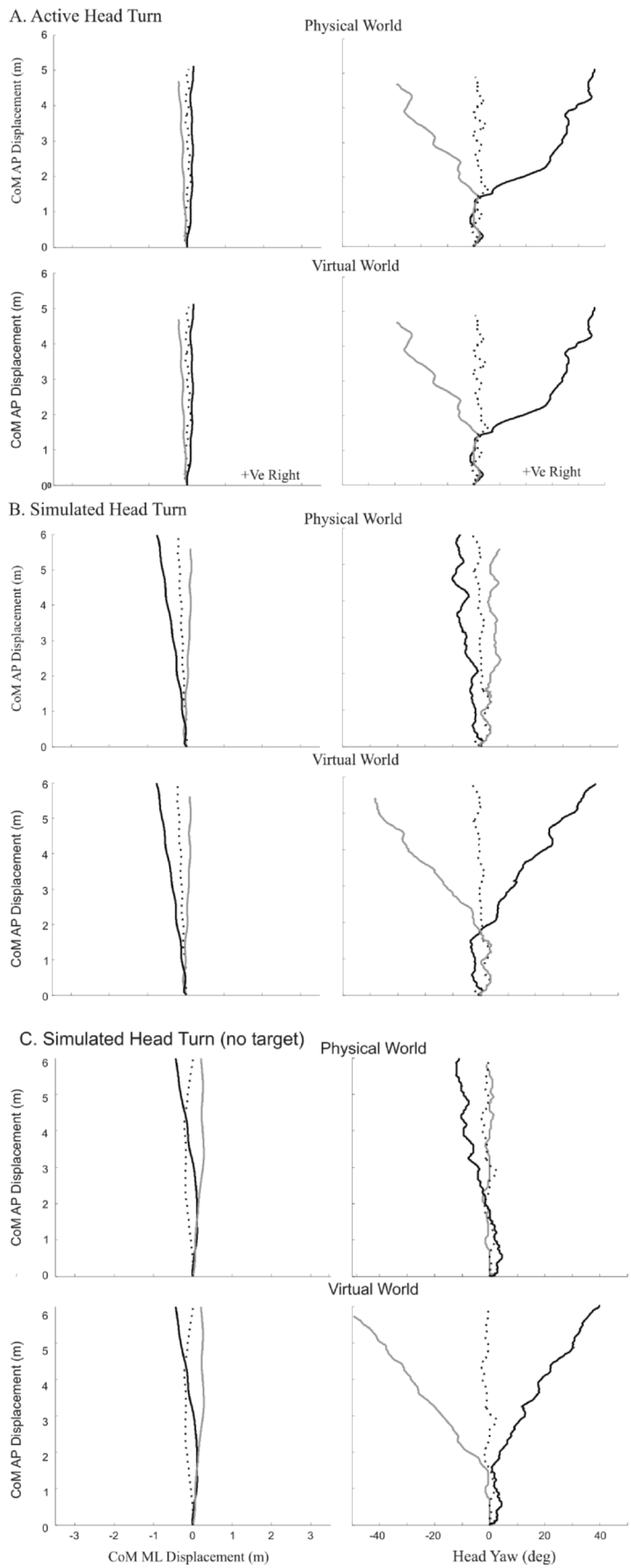
Chapter 3

RESULTS

The main results from this thesis show that there are significant differences in locomotor steering behaviour when subjects experience different optic flows simulating a head turn as opposed to actively performing a head turn. Differences were observed in body segment orientation between the active (AHT) and simulated conditions (SHT,SHT_NT) when the FOE was located in different positions.

In all three optic conditions, the instruction was to walk straight in the physical world while being presented with a rotational flow pattern, whether simulated or actively induced. The mean flow rotation rate, which is dependent on gait speed, was found to be approximately 11°/sec. A perfect maintenance of heading direction should result in no deviation of CoM trajectory, as well as no segment reorientation in the horizontal plane in the physical world (other than when an active head turn is present). Figure 8 illustrates examples of CoM trajectories and head reorientation patterns across optic flow conditions and FOE locations. Subtle changes in CoM trajectory were observed when the FOE was shifted at a position different from the neutral (0°). In the example illustrated, the subject veered in the direction of the FOE shift in the AHT condition, but away from the FOE in SHT and SHT_NT conditions. CoM trajectories were also identical between the physical and virtual worlds, signifying a rotation around the subject's head and not a translation. For head rotation, the difference across conditions in the physical world accounts for the fact that an active head turn was performed in the AHT condition, while it was visually simulated in the SHT and SHT_NT conditions. In the virtual world, head orientation traces were similar across optic flow conditions, indicating that subjects were exposed to similar amounts of perceived head rotation.

In the physical world, main effects of FOE location and interaction effects between optic flow condition and FOE location were found for CoM heading direction as well as most body segment horizontal orientation (Figure 9, left panel). On average, CoM heading direction deviated away from the FOE location for the SHT and SHT_NT conditions, but not the AHT condition. While no significant differences in CoM heading direction emerged for any FOE location between the different optic flow conditions, a differential effect of FOE location was observed in the simulated head turn conditions only, as CoM heading direction was found to differ between the left (-40°) vs. right (+40°) FOE locations ($p<0.01$ to $p<0.05$). The head was reoriented in the direction of the active head turn in the AHT condition while a small reorientation (typically < 8°) in the same direction of CoM heading reorientation was systematically observed for the SHT and SHT_NT conditions.



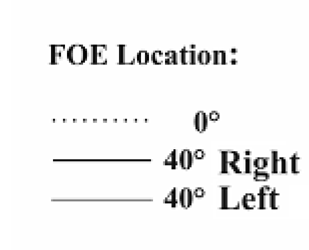


Fig. 8: - Traces of individual trials for all three locations (40° left, 0°,40° right) of focus expansion (FOE) for the active head turn (A) the visually simulated head turn (B) and the visually simulated head turn with no target (C) conditions. For each condition, mediolateral (M\L) displacement of body centre of mass (CoM) (left panels) and head yaw (right panels) are illustrated as a function of CoM anteroposterior (A\P) displacement, both in the physical (upper graphs) and virtual (lower graphs) worlds.

The head reorientation pattern differed across optic flow conditions when a FOE shift other than 0° was present ($p<0.001$). Furthermore, head reorientation differed across all FOE locations for the AHT condition ($p<0.0001$), and between the right vs. left FOE locations for the visually simulated head turns (SHT, SHT_NT). Thorax and pelvis displayed a behaviour similar to that of the head, with differences in their reorientation across optic flow conditions when a FOE shift other than 0° was present ($p<0.001$ to $p<0.05$), but no such difference was observed for foot reorientation. In contrast to head orientation, however, thorax, pelvis and foot segment orientations remained similar across FOE locations for the AHT condition and were only found to differ between left (-40°) vs. right (+40°) FOE location for the SHT condition.

Although the task was to walk straight in the physical world, which represents the coordinate system of interest, the variables in the virtual world were also illustrated for explanatory purposes (Figure 9, right panel). The CoM heading direction was identical in both virtual and. physical worlds, as no changes in planar coordinates took place. In the virtual world, condition and FOE location also affected all body segment orientations, with the exception of head rotation that was, as expected, identical across optic flow conditions but different across head turn directions. In contrast to physical coordinates, however, a large reorientation of thorax, pelvis and foot segment toward the FOE location or head turn direction was observed in the virtual world's coordinates for the SHT and SHT_NT, but not the AHT. Such reorientation is consistent with the fact that small 'physical' corrections of those segment orientations took place in the horizontal plane in the simulated head turn conditions, despite the rotation of the VE. Segment reorientation in the virtual world was qualitatively observed across FOE locations.

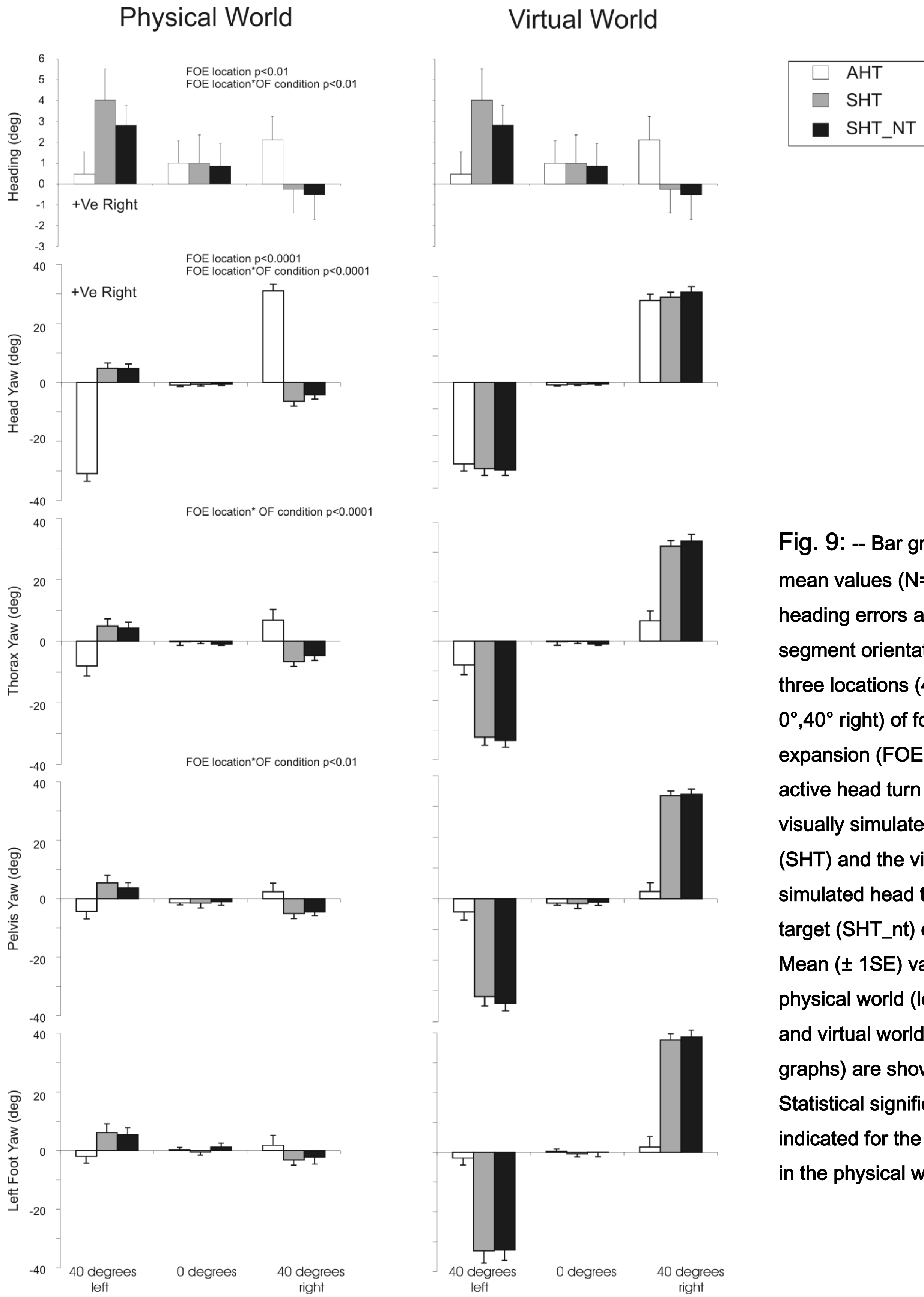


Fig. 9: -- Bar graphs of mean values (N=9) of heading errors and body segment orientations for all three locations (40° left, 0°,40° right) of focus expansion (FOE) for the active head turn (AHT), the visually simulated head turn (SHT) and the visually simulated head turn with no target (SHT_nt) conditions. Mean (± 1SE) values in the physical world (left graphs) and virtual world (right graphs) are shown. Statistical significances are indicated for the variables in the physical world.

Chapter 4

DISCUSSION

&

CONCLUSION

4.1 Discussion

The purpose of this study was to investigate whether optic flow information alone is sufficient in determining ones heading direction and controlling steering of locomotion in the presence of a rotational flow, or if extra-retinal information is needed. Our initial hypothesis, which was that an active head turn would induce a smaller deviation in heading and body re-orientation as compared to visually induced head rotations, was shown to be true. Likewise, it was observed that during a simulated head turn condition, a deviation of CoM occurred in the opposite direction of the FOE, which is consistent with our secondary hypothesis. Finally, it was hypothesized that the presence of a target during a simulated head turn would not induce significant changes in heading direction and segment orientation; this hypothesis was similarly shown to be true in this study.

The ‘perceptual’ hypothesis states that optic flow information is enough to dissociate rotational flow information from translational flow information and hence recover heading direction (Van den Berg, 1996; Li and Warren, 2000). It has been argued that this is only true under certain conditions, such as slow rotation rate and dense motion parallax (Stone and Perrone, 1997; Li and Warren, 2002; Wilkie and Wann, 2003). Studies have claimed that at higher rotation rates (>1^{o}/sec), extra-retinal information is required in order to properly discriminate heading direction(Banks et al., 1996). Our optic flow rotation rate was averaged out to be approximately 11^{o}/sec, which should theoretically allow for better discrimination with available extra-retinal information.

During an active head turn, both retinal and extra-retinal information are available, whereas in a visually simulated head turn, one cannot rely on extra-retinal information such as oculomotor or cervico-collic proprioceptive or vestibular information. A previous study (Vallis and Patla, 2004) has shown that no veering in walking trajectory occurred when an active head turn was performed, as opposed to a passive head turn, suggesting an involvement of extra-retinal information in heading control. In contrast to what was expected, our study shows that CoM mediolateral deviation and heading did not significantly differ between the active vs. simulated head turn conditions.

However, results from this thesis showed that when subjects were presented with visually simulated head turns (SHT and SHT_NT), veering in the opposite direction occurred. Likewise, head, thorax and pelvis displayed small but significant and systematic reorientations in the direction opposite to the FOE when exposed to visually simulated head rotations. Similar findings were observed in previous studies when subjects were presented with simulated (Sarre et al., 2008) and passively induced (Vallis and Patla, 2004) rotational flows. It appears that in all these studies, that instead of perceiving a head rotation, subjects perceived themselves as walking along a curved path. Thus, as the retinal flow direction changed and induced the illusion that the subjects were veering toward the FOE shift, subjects had the tendency to veer in the opposite direction in an attempt to correct their heading direction and walk straight ahead. Such changes in direction was accompanied by similar body reorientation as those observed during steering of locomotion (Vallis et al., 2001; Vallis and Patla, 2004)

While our results may be limited by our small sample size, it seems that subjects do, to some extent, deviate their CoM trajectory and heading direction and do reorient their upper body segments when exposed to visually simulated head turns, which is not the case during the active head turn condition. This suggests that the extra-retinal information present during the active head turn did help to interpret rotational flow to control steering of locomotion. The small changes observed in the visually simulated head turn conditions, however, may indicate that the central nervous system (CNS) does have some ability to discriminate heading direction from optic flow information alone. It was also suggested that the CNS has the ability to re-weight and up-regulate accurate sources of sensory information when subjected to sensory conflicts (Mergner et al., 2000). It thus appears even more likely that the small steering changes observed in the simulated head turn condition reflects the ability of the CNS to re-weight the sensory information in favor of eye, neck and leg proprioceptive information, as well as vestibular information, which all signaled that no change in heading direction occurred.

In addition to results already discussed, the effects of the presence vs. absence of a target were also assessed by comparing the SHT and SHT_NT conditions. The flow rate between both conditions was similar and the only difference during the conditions was the fact that in the SHT_NT condition, the subject did not have a red target in their field of view. In previous studies it was shown that an interaction in steering strategies (optic flow vs. ego-centric and centering strategies) were present when both optic flow and target elements were utilized during locomotion (Cinelli and Warren, 2007). Results from our study, however, show that the presence or absence of a target does not affect CoM heading direction and body segment orientation in the simulated head turn conditions. This finding is not surprising as the target element in the present study was not used to guide heading, i.e. subjects were not instructed to walk 'toward' a target.

4.2 Study limitations

A first factor which may have affected our results is the speed at which the subjects walked. The rate of optic flow being presented to the subject was dependent on the subject's forward displacement; therefore a person walking at a greater gait speed would be exposed to a faster or stronger rate of rotation, and vice versa. As gait speed increases, the influence of optic flow is reduced (Jahn et al., 2001), and path integration is improved (Dickstein et al., 2005). Inter-subject and inter-condition variability in gait speed could therefore have contributed to increase the variability of the optic flow rates and of the heading responses, or account for differences between the optic flow conditions. Such variability was minimized, however, by asking subjects to walk at a comfortable pace during the experiment, while their gait speed was recorded through the CAREN-2 and Vicon motion analysis systems. Post-hoc calculations revealed similar optic flow rates between the AHT (mean ± 1SD: 10.5 ± 1.6 deg/sec), SHT_NT (11.3 ± 1.6 deg/sec) and SHT condition (11.1 ± 1.3 deg/sec). In addition, a small variability across subjects was observed (all conditions confounded), with means and standard deviations of 0.96 ± 0.12 m/s for gait speed and 10.96 ± 1.34 deg/sec for optic flow rate.

Another study limitation is the fact that eye movements were not recorded during the experiments. A fine eye-head coordination is present during steering of locomotion, whether in forward or backward walking (Grasso et al., 1998). To record eye movements, an eye-tracking system would have needed to be fitted to the HMD. This would have allowed the eye movements to have a real-time effect on the control of the virtual environment, as well as to monitor whether subjects were actually looking at the target by rotating the eyes and/or head. Despite the fact that our laboratory does have access to an eye-tracker that can be mounted in a HMD, it proved extremely difficult and we were not successful at stabilizing the combined HMD/eye-tracking system with respect to the pupil in a dynamic task such as locomotion, and therefore a valid recording of eye data could not be pursued. However, we made sure our subjects were achieving a 40° rotation of the head during the active head turn condition by instructing them to keep the red target in the center of their visual field. This could have only been completed by performing an active head turn because the visual scene did respond only to head rotations, not to eye rotations. Recorded data also confirmed, *a posteriori*, that similar virtual head turn amplitudes were reached between the active vs. simulated head turn conditions, as discussed above. However, one point worth mentioning, is that the motor efference copy is important extra-retinal information and as a result, it is very possible that subjects were not tricked into believing that they were rotating their head in the SHT conditions even though they visually perceived a head turn.

Another possible study limitation is the inertia of the head caused by the additional weight of the HMD, during the AHT condition. Due to the extra weight (approx. 1kg) of the HMD, the orientation of the head or the vestibular information may be misjudged. In our attempt to correct for this factor, we allowed the subjects to fit the HMD to comfort and were given time to be habituated to the additional weight while walking and turning their head.

4.3 Conclusion

In conclusion, this current study provides further insight on the use of extra-retinal information and optic flow information in the control of heading direction. Results suggest that extra-retinal information does play a role in the control of heading direction, in addition to optic flow, and that a healthy CNS has the ability to re-weight relevant sources of sensory information, for the maintenance of balance during walking, even in the presence of sensory conflict.

4.4 Significance and Future Direction

This current study provides further insight on the use of optic flow and extra-retinal information in the control of heading direction. The most prominent findings of this research project were that extra-retinal information does play a role in the control of locomotor steering and that the CNS was able to re-weight the information being presented in order to properly adapt steering trajectory. Whether an active head turn was performed or whether a retinal and extra-retinal conflict was created, it was found that the subjects were able to properly dissociate the information and adapt to an appropriate steering strategy in order to maintain heading.

However, a better understanding of eye movements and rotational compensations during locomotor steering would be necessary to appreciate the full extent of sensorimotor integration and the effect of extra-retinal information in the maintenance of heading direction. Through a better understanding of the role of retinal and extra-retinal information, we can better understand the deficits in locomotor steering in populations with altered sensorimotor function, such as the aging population and people who have suffered a stroke (Lamontagne et al., 2005a; Lamontagne et al., 2007), and possibly design virtual environments or rehabilitation programs that will allow them to retrain and regain this ability.

Centre de recherche interdisciplinaire en réadaptation du Montréal métropolitain

Appendix A

Hôpital juif de réadaptation
Jewish Rehabilitation Hospital

INFORMED CONSENT DOCUMENT

Principal Investigator:
Anouk Lamontagne, Ph.D., PT
Jewish Rehabilitation Hospital (JRH) and School of P & OT, McGill University

Co-Investigators:
Joyce Fung, Ph.D., PT
JRH and School of P & OT, McGill University
Jocelyn Faubert, Ph.D.
School of Optometry, University of Montreal
Bradford McFadyen
IRDPQ and Département de réadaptation, Université Laval

Vision plays an important role in the control of walking. It allows us to walk and steer toward the desired goal and helps control our gait speed. With ageing or with the occurrence of a cerebrovascular accident (CVA), problems in balance and mobility may occur. Such problems may be related to an altered visual perception of self-motion, also called 'optic flow'. In this project, we manipulate visual information using *virtual reality.* We then examine how elderly persons or persons with a CVA perceive this information and use it to control their walking speed and trajectory.

Objectives:

1. To examine the ability of persons with a CVA to discriminate the speed and the direction of visual information
2. To examine how persons with a CVA uses visual information of self-motion in the control of walking speed and walking trajectory

Nature of my participation: The evaluation consists in two separate sessions that will ideally take place the same week. My visual perception will evaluated during the first session, and my walking pattern in the second one. These two sessions will take place at the Jewish Rehabilitation Hospital. A resource person and one of the researchers will be present during the evaluation to greet me and give me assistance.

Evaluation 1 (visual perception): *The evaluation of my visual perception will last approximately one hour.*

Preparation : None

Evaluation : The evaluation takes place while seated. I will watch images consisting of moving white dots on a black screen placed in front of me. I will first be asked to identify in which direction the dots are moving, which could be right, left, forward or backward. Later during the experiment, I will be invited to watch examples of dot moving at different speeds. I will be asked to determine, between two displays, which of the two was moving faster. My responses will be given verbally to the experimenter.

Evaluation 2 (walking assessment)

For the assessment of walking, I shall be attending one experimental session that will take approximately two and a half (2.5) hours of my time. This includes preparation time (0.5 hour) and the evaluation time (2 hours). A resource person and one of the researchers on the team will be present during the evaluation to assist me as needed.

Preparation. In order to record the movements of my body and limbs as I walk, small reflective markers will be taped onto my head, upper and lower body, arms, forearms, wrists, thighs, legs, and feet.

Evaluation:
Overground walking. I shall walk several times along a ten-metre walkway. I shall view a visual scene displayed within the eyepieces of a helmet that I wear while walking. This helmet is light and comfortable, and developed for virtual reality display. The visual scene will be modified during the experiment, as if objects were coming towards me from straight ahead, from the left, or from the right while I walk. I will also be asked to perform head rotation to look to the right or to the left during walking. I shall walk for 36 trials, for a total time of approximately 10 minutes. I shall rest as often as needed in between the walking trials. A therapist will walk next to me for additional safety.

Treadmill walking. In the second part of the experiment, I will be asked to walk on a treadmill while wearing the same helmet and viewing different scenes. As I walk, the flow of objects that I shall be seeing will change in speed, such that it moves sometimes slow and sometimes fast. I shall walk on the treadmill for about 6 minutes. I shall rest *as often as needed and a therapist will stay beside me for additional safety.*

Risks and disadvantages:
Risks associated to my participation in this study are minimal. During my walking evaluation, a therapist will always be present to provide any assistance and to prevent me from falling. I may, however, feel tired following the evaluation. I may also experience nausea following exposure to the virtual scenarios. The feeling of fatigue or nausea will wear off with rest.

Benefits:
This study does not provide me any direct benefit. However, the results from this study will provide information that will help in developing better techniques for rehabilitation of persons with a vestibular dysfunction.

Financial compensation:
Transportation and parking costs incurred through my participation in this project will be reimbursed, up to a maximum of $30.00.

Access to my medical chart:
I understand that some relevant information concerning my medical history may need to be collected, and for that purpose, a member of the researcher team may need to consult my medical file.

Confidentiality:
Any personal information making it possible to identify me is kept confidential and will be filed in a locked cabinet. The data relating to my evaluations will be transferred onto a computer file server where access is protected by passwords. Only members of the research team have access to the information collected during the project. If I withdrew my participation from this project, all the research data collected would be destroyed. Otherwise, the information will be preserved for a minimal duration of 5 years, after which they will be destroyed. The data of this research will only be revealed in the form of scientific presentations or publications, without my name or identity exposed.

CONSENT: I can be assured that the information that I have received about this project is accurate and complete. My participation in this project is entirely voluntary. My refusal to participate would in no way affect the treatment I receive in this hospital. In addition, I may withdraw from the study at any time.

Should I have any questions or require further information regarding the study, I can contact Dr. Anouk Lamontagne at phone number 450-688-9550 ext. 531 or by e-mail at anouk.lamontagne@mcgill.ca. If I have any questions regarding my rights and recourse concerning my participation in this study, I can contact Ms. Anik Nolet, Research Ethics Co-ordinator of the CRIR establishments: 514-527-4527 ext 2643 or by e-mail at: anolet.crir@ssss.gouv.qc.ca

In accepting to participate in this study, I shall not relinquish any of my rights and I shall not liberate the researchers or their sponsors or the institutions involved from any of their legal or professional obligations.

My signature indicates that I have read this document, that I understand the purpose of the research, that this project will not be of direct benefit to me, and that I agree to participate. A copy of this form will be provided to me for my record.

Subject: ________________________ Date: ________________________
(Signature)

________________________ Tel: ________________________
(Name)

Witness: ________________________ Date: ________________________
(Signature)

________________________ Tel: ________________________
(Name)

Responsibility of the principal investigator:

I, the undersigned, ________________________________ certify that (a) I have explained to the participant the terms of the present agreement, (b) I have responded to all questions posed to me, and (c) I have clearly indicated that the participant is free to leave the study described above at any time, and (d) I have provided a signed and dated copy of this consent document to the participant.

FORMULAIRE DE CONSENTEMENT

Centre de recherche interdisciplinaire en réadaptation du Montréal métropolitain

Hôpital juif de réadaptation
Jewish Rehabilitation Hospital

Chercheur principal:
Anouk Lamontagne, Ph.D., pht
Hôpital juif de réadaptation (HJR) et École de physiothérapie et d'ergothérapie, Université McGill

Co-chercheurs:
Joyce Fung, Ph.D., PT
HJR et École de physiothérapie et d'ergothérapie, Université McGill
Jocelyn Faubert, Ph.D.
École d'optométrie, Université de Montréal
Bradford McFadyen, Ph.D.
IRDPQ et Département de réadaptation, Université Laval

La vision joue un rôle important dans le contrôle de la marche. Celle-ci nous permet, en outre, de contrôler la direction et la vitesse de marche. Avec le vieillissement ou suite à un accident vasculaire cérébral (AVC), des problèmes de la marche et de l'équilibre peuvent survenir. Ces problèmes pourraient être dus à une perception déformée des informations visuelles de déplacement, aussi appelées flux optique. Dans le cadre de ce projet, nous manipulons les informations visuelles à l'aide la *réalité virtuelle*. Grâce à celle-ci, nous examinons comment les personnes âgées ou celles avec un ACV perçoivent et utilise ces informations pour contrôler la direction et la vitesse de leur marche.

Objectifs:

1. Examiner l'habileté à différentier des informations visuelles bougeant à différentes vitesses ou dans différentes directions
2. Étudier l'influence des informations visuelles de déplacement sur la vitesse et la trajectoire de la marche

Nature de ma participation:
L'évaluation se déroulera en deux sessions séparées mais qui auront lieu préférablement la même semaine. La première session servira à évaluer ma perception visuelle. La seconde servira à évaluer ma démarche. Ces deux sessions d'évaluation se dérouleront à l'Hôpital juif de réadaptation. Une personne-ressource et un des chercheurs de l'équipe seront présents lors des évaluations afin de m'accueillir et m'aider à me déplacer.

<u>Session 1 (évaluation visuelle)</u> : L'évaluation de ma perception visuelle durera approximativement 1heure.

Préparation : aucune

Évaluation : *L'évaluation prendra place en position assise. Je regarderai des images composées de points blancs sur un écran noir placé devant moi. On me demandera*

d'abord d'identifier dans quelle direction bougent les points, soit vers la gauche, la droite, vers l'avant ou vers l'arrière. Par la suite, on me présentera des exemples d'image avec des points bougeant à différentes vitesses. Je devrai déterminer, entre deux exemples, lequel avait les points bougeant le plus rapidement.
Session 2 (évaluation de la démarche) :L'évaluation de ma démarche nécessitera une session d'une durée approximative de 2 heures 30 minutes. Cette durée inclut le temps de préparation (30 minutes) ainsi que le temps d'évaluation (2 heures).

Préparation. Pour enregistrer mes mouvements pendant que je marcherai, de petits marqueurs ronds et réfléchissants vont être placés sur ma tête, mon dos, mes bras, mes jambes et mes pieds.

Évaluation:

Marche au sol: Je marcherai plusieurs fois le long d'une allée de 8 mètres. Pendant que je marcherai, je regarderai une scène d'animation à l'aide d'un casque portatif de réalité virtuelle. Ce casque, très léger, est utilisé pour visionner des scènes animées, comme dans les jeux vidéo. Ces scènes d'animation seront modifiées pendant l'expérimentation. Par exemple, la scène pourra sembler bouger de l'avant vers l'arrière, ou encore de la droite vers la gauche. On me demandera aussi d'effectuer des rotations de la tête pendant que je marcherai. Au total, j'effectuerai 36 essais de marche, pour une durée totale de marche d'environs 10 minutes. Je pourrai prendre autant de repos que j'en ai besoin entre les essais de marche. Un thérapeute marchera derrière moi pour plus de sécurité.

Marche sur tapis roulant: *Pendant cette partie de l'évaluation, on me demandera de marcher sur un tapis roulant tout en regardant une scène d'animation à travers le casque portatif de réalité virtuelle. Cette fois-ci, la vitesse de la scène d'animation sera modifiée pendant l'expérimentation, de telle sorte qu'elle bougera parfois lentement, et parfois rapidement. Cette partie de l'expérimentation requerra que je marche sur le tapis roulant pendant environs 6 minutes. Je pourrai prendre autant de repos que j'en ai besoin et un thérapeute restera à côté de moi pour plus de sécurité.*

Risques et inconvénients:
Les risques reliés à ma participation sont minimes. Pendant l'évaluation de ma démarche, un(e) thérapeute sera toujours présent(e) pour m'aider et m'empêcher de chuter. Je pourrais, par contre, ressentir une fatigue suite à cette évaluation. Il est également possible que j'aie des nausées, dû au visionnement des images. Si tel est le cas, cette fatigue et ces nausées se résorberont pendant les périodes de repos.

Avantages:
Ma participation au projet ne comporte aucun avantage personnel. Cependant, les résultats de cette étude vont apporter des informations qui pourraient aider au développement de meilleures techniques pour la réadaptation de la marche et de l'équilibre suite à une dysfonction vestibulaire.

Indemnité compensatoire:
Les frais de transport et de stationnement encourus pour ma participation à ce projet me seront remboursés, jusqu'à un montant maximal de 30$.

Accès au dossier médical:
Je comprends que des informations sur mon état de santé devront être recueillies et que, à cette fin, un membre de l'équipe de recherche pourrait consulter mon dossier médical.

Confidentialité:
Toute information personnelle ou permettant de m'identifier est confidentielle et sera gardée sous clef. Les données relatives à ma démarche, qui sont enregistrées à l'aide d'ordinateurs,
seront transférées et conservées dans un espace serveur dont l'accès est limité. Seuls les membres de l'équipe de recherche auront accès aux informations recueillies pendant le projet. Si je me retirais du projet, les données de recherche se rapportant à ma participation seraient détruites. Dans le cas contraire, ces informations seront conservées pour une période de 5 ans après la fin du projet, après quoi elles seront détruites. Les données du projet ne seront dévoilées que sous la forme de présentations scientifiques ou de publications, sans que mon nom ou toute autre information pouvant révéler mon identité n'y apparaisse.

CONSENTEMENT: Je peux être assuré(e) que l'information que j'ai reçue concernant ce projet est exacte et complète. Ma participation à ce projet est entièrement volontaire. Mon refus de participer n'affecterait en rien le traitement que je reçois dans cet hôpital. De plus, je pourrai me retirer de cette étude à tout moment.

Pour obtenir réponse à toute question supplémentaire en rapport à cette étude, je pourrai contacter Anouk Lamontagne au (450) 688-9550 poste 531 ou par courriel à l'adresse anouk.lamontagne@mcgill.ca. Si j'ai des questions sur mes droits et recours ou sur ma participation à ce projet de recherche, je pourrai communiquer avec Me Anik Nolet, coordonnatrice à l'éthique de la recherche des établissements du CRIR au (514) 527-4527 poste 2643 ou par courriel à l'adresse: anolet.crir@ssss.gouv.qc.ca.

En acceptant de participer à cette étude, je ne renonce à aucun de mes droits ni ne libère les chercheurs, le commanditaire ou les institutions impliquées de leurs obligations légales et professionnelles**.**

Ma signature indique que j'ai lu ce formulaire, que je comprends le but de la recherche et que ce projet ne comporte pas d'avantage personnel, et que j'accepte de participer. Une copie de ce formulaire me sera remise pour mes dossiers.

Sujet: ______________________________ Date:__________________________
(Signature)

______________________________ Tél.: ________________________
(Nom)

Témoin: ______________________________ Date: ________________________
(Signature)

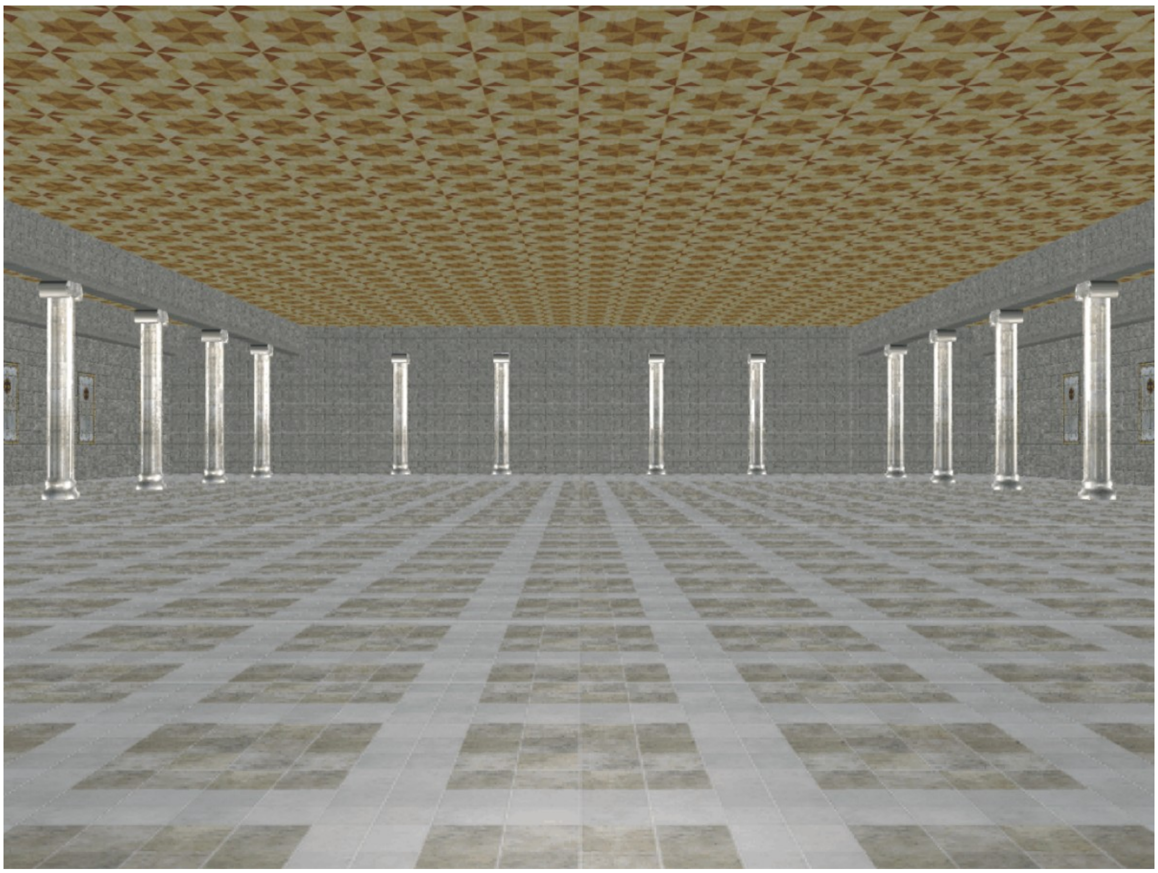
______________________________ Tél.: ________________________
(Nom)

ENGAGEMENT DU CHERCHEUR:

Je, soussigné(e), ____________________________, certifie: (a) avoir expliqué au signataire les termes du présent formulaire; (b) avoir répondu aux questions qu'il m'a posées à cet égard; (c) lui avoir clairement indiqué qu'il reste, à tout moment, libre de mettre un terme à sa participation au projet de recherche décrit ci-dessus; et (d) que je lui remettrai une copie signée et datée du présent formulaire.

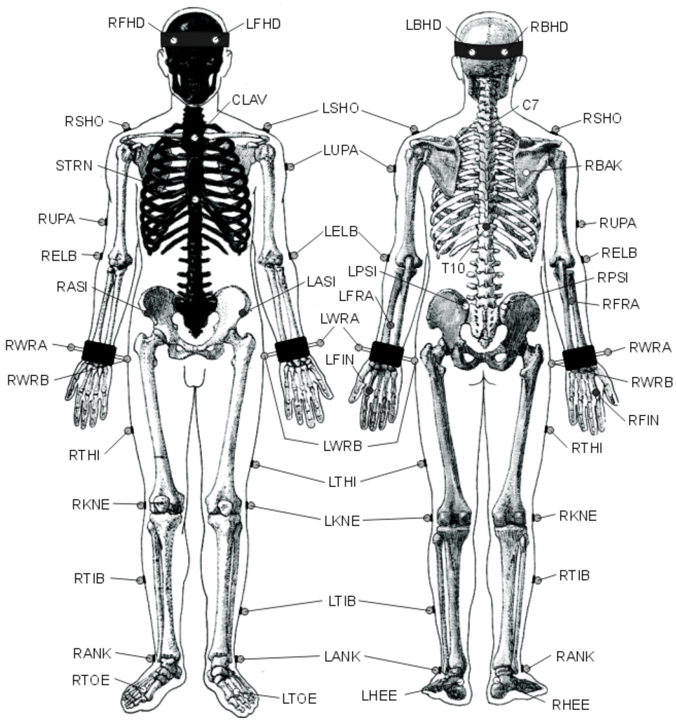
Appendix B

Virtual Reality Scene



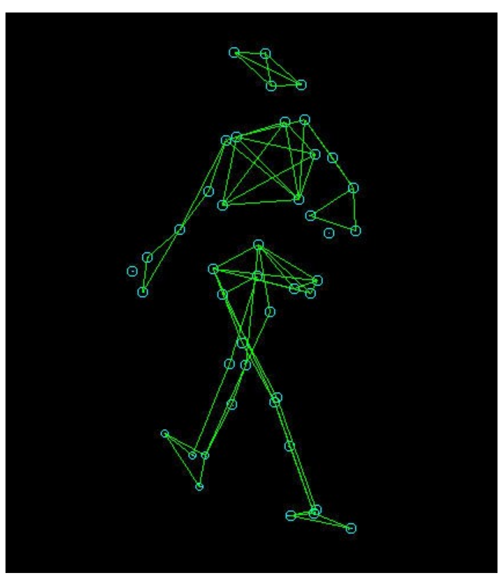
Appendix C

Plug-in-gait Marker set up



Appendix D

Labelled Plug-in-Gait Marker set



Appendix E

Ethics Certificate

Centre de recherche interdisciplinaire
en réadaptation du Montréal métropolitain

CRIR

Certificat d'éthique

(Renouvellement)

Pour fins de renouvellement, le Comité d'éthique de la recherche des établissements du CRIR, selon la procédure d'évaluation accélérée en vigueur, a examiné le projet de recherche **CRIR-168-0805** intitulé :

« Visuomotor Control of Locomotion».

Présenté par: **Anouk Lamontagne**

Le présent projet répond aux exigences éthiques de notre CÉR. Ce projet se déroule dans le site du CRIR suivant : **Hôpital juif de réadaptation.**

Ce certificat est valable pour un an. En acceptant le présent certificat d'éthique, le chercheur s'engage à :

1. Informer le CÉR de tout changement qui pourrait être apporté à la présente recherche ou aux documents qui en découlent (Formulaire M) ;
2. Rapporter aux participants toute information susceptible de modifier leur consentement ;
3. Fournir annuellement au CÉR un rapport d'étape l'informant de l'avancement des travaux de recherche (Formulaire R) ;
4. Demander le renouvellement annuel de son certificat d'éthique ;
5. Aviser le CÉR de l'abandon ou de l'interruption prématurée du projet de recherche ;
6. Tenir et conserver, selon la procédure prévue dans la *Politique portant sur la conservation d'une liste des sujets de recherche*, incluse dans le cadre réglementaire des établissements du CRIR, une liste des personnes qui ont accepté de prendre part à la présente étude ;
7. Envoyer au CÉR une copie de son rapport de fin de projet / publication.

Me Michel T. Giroux
Président du CÉR

Date d'émission
18 octobre 2006

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