

Is improving gait post-stroke at the tip of our fingers?

The effects of enhanced sensory input

(haptics and walking aids)

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DEDICATION

This work is dedicated to people with stroke and their family caregivers; including my father, the late **Jack Perez** and my mother, **Irmgard Perez**. My father suffered a massive stroke at the age of 66, when I was 15 years old. Despite significant deficits in mobility, self-care and speech, he returned home - thanks greatly to my mother's love, dedication and care. Our family learned what a stroke is, but more importantly, with dignity and determination, patience and humour, we all discovered how to strike back ... from anything.

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A final word of gratitude goes to my sister, Jacky. Despite ups and downs and highs and lows...I am happy to share this masterful accomplishment with you as you have shared many of your masterful creations with me. Thanks and dig in.

PREFACE

This thesis is organised in a manuscript-based format in accordance with the guidelines of the Faculty of Graduate and Postdoctoral Studies of McGill University and features 2 research manuscripts.

Chapter 1 introduces the topic and the objectives of the study.

Chapter 2 presents a review of the literature relevant to the area of study.

Chapter 3 describes the methodology in greater detail than offered in the manuscripts to follow. Chapter 3 concludes with research manuscript # 1 ***“An innovative cane device developed for treadmill gait training and research”***. This manuscript has been accepted to be published in the Journal of Physical Therapy Education (targeted for the Sept 2010 issue). It describes the development and feasibility of the instrumented cane device which was specifically designed for this study.

Chapter 4 consists of a second research manuscript, ***“The touching effects of somatosensory information (haptics and canes) on post-stroke gait”***. This manuscript details the overall findings and was prepared for submission to the journal Archives of Physical Medical and Rehabilitation.

Chapter 5 summarises the study’s main findings and limitations as well as the significance and clinical implications of the work.

Chapter 6 provides the list of references contained within the thesis.

CONTRIBUTION OF AUTHORS

Two manuscripts are presented in this thesis:

1. **“An innovative cane device developed for treadmill gait training and research”** Claire Perez and Joyce Fung. This paper (in press) was accepted for publication in the Journal of Physical Therapy Education special issue on new technological advances for clinical and research use.

2. **“The touching effects of enhanced sensory input (haptics & canes) on post-stroke gait”** Claire Perez, Alison Oates, Bradford McFadyen and Joyce Fung. This paper was prepared for submission to the journal Archives of Physical Medicine and Rehabilitation.

All work for the 2 manuscripts was done under the guidance and supervision of Dr. Joyce Fung and transpired at the Feil/Oberfeld CRIR Research Centre of the JRH. Dr. Fung, Dr. Oates (in her post-doctoral work examining the effect of light touch on anticipatory postural responses during transitions from level to slope walking), Dr. McFadyen (as a member of my supervisory committee) and I contributed to the haptic project in conceiving the experimental design, protocol and the haptic strip apparatus. The idea of adding a treadmill cane to the experimental paradigm was my original concept and Dr. Fung added essential suggestions for its design and instrumentation. I was involved in all data collection and was wholly responsible for the data processing, analysis and drafting the 2 manuscripts and thesis presented here.

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"An innovative cane device developed for treadmill gait training and research"

Claire Perez and Joyce Fung

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LIST OF ABBREVIATIONS

CVA / AVC	Cerebrovascular accident /Accident vasculaire cérébrale
CV	Coefficient of variation
ICF	International classification of functioning
GS	Gait speed
CoM	Center of mass
CNS	Central nervous system
VE	Virtual environment
NT	No touch
LT	Light touch
C	Cane use
L	Level
U	Up
D	Down
MMSE	Mini mental status exam
SW	Step width
OGS	Overground gait speed
VE	Virtual environment
CAREN	Computer assisted rehabilitation environment
ABC	Activities-based balance confidence scale
VAS	Visual analog scale
VR	Virtual reality
NC1	No cane use (baseline trial 1)
NC2	No cane use (baseline trial 2)
PE	Physical environment

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ABSTRACT

While postural control during quiet stance can be enhanced by haptic input, the role of tactile cues on gait ability in healthy or neurological populations is not well understood. The aim of this study was to examine the effects of enhanced somatosensory input from (1) light fingertip touch and (2) cane use, on gait performance during level and slope walking in people post-stroke. Nine people post-stroke and 9 healthy individuals walked on a self-paced treadmill mounted on a motion platform while viewing a virtual scene. The experimental conditions were to walk level, up or down a 5° sloped surface: 1) without touch, 2) with light fingertip touch on a bar and 3) with an instrumented cane. Gait variability, expressed as the coefficient of variation of stride duration (CV), step width and gait speed were measured. Results reveal that light touch is an effective means of improving gait in people post-stroke. Light touch can be as effective compared to the cane even under the challenge of slope walking and may be more effective in downslope walking. Task specific (level, up and downslope) stabilizing strategies (use of either light touch or a cane) may offer specific gait improvements. These effects were not seen in the healthy controls.

ABREGÉ

Nous savons déjà que le toucher léger peut augmenter le contrôle postural en position debout mais les effets haptiques, lors la marche, chez une population saine ou neurologique, sont peu connus. L'objectif de cette étude est d'examiner l'ajout d'information somatosensorielle provenant 1) du bout d'un doigt et 2) d'une canne instrumentée sur la marche d'individus ayant subi un AVC. Neuf adultes post-AVC et 9 individus sains ont marché sur un tapis roulant, à une vitesse qu'ils contrôlaient eux-mêmes. Le tapis roulant était fixé sur une plateforme mobile faisant face à une scène virtuelle. Les conditions expérimentales consistaient à marcher sur une surface plane, inclinée de 5° vers le haut ou vers le bas: 1) sans aucun toucher, 2) avec un toucher léger du bout d'un doigt sur un capteur spécialisé et 3) en utilisant une canne instrumentée. La variabilité de la marche, exprimée par le coefficient de variation de la durée du cycle de marche (CV), la largeur des pas et la vitesse étaient les paramètres étudiés. Les résultats ont démontré que le toucher léger est une façon efficace pour améliorer la marche sur les plans inclinés chez les personnes post-AVC et peut être plus efficace que la canne lors la marche sur un plan incliné vers le bas. Des stratégies spécifiques (toucher léger ou canne) peuvent donc améliorer la marche de façon différente selon la tâche (surface plane ou inclinée). Ces effets n'ont pas été observés chez les personnes saines.

CHAPTER 1: INTRODUCTION

1.1 Overview

Stroke is the leading cause of disability worldwide. The prevalence of stroke is growing as both stroke mortality decreases and average life span increases.

According to statistics compiled by the Canadian Stroke Network,¹ over 300,000 people in Canada presently live with the effects of stroke, and an additional 50,000 individuals will be struck by this life altering event each year. As one of Canada's most expensive health issues (with an estimated \$2.7 billion¹ spent annually), stroke is expected to put increased strain on the health system in the years to come. Additional to the high economic burden to society, the cost of stroke to an individual and his family is incalculable. The enormous personal and societal impact of stroke challenges researchers and clinicians to explore new and effective strategies to reduce the impact of stroke on body functions, activities and participation.

Stroke affects all levels of functioning as defined by the World Health Organization International Classification of Functioning, Disability and Health (ICF).² Over 70% of survivors live with permanent sequelae, including motor control, sensori-perceptual and language impairments, which lead to significant activity limitations and participation restrictions. The inability to walk as pre-

morbidity is one of the more devastating consequences of stroke. Associated with this outcome, individuals post-stroke develop reduced quality of life and increased long-term care needs.³

Regaining ambulatory ability and independence is the most common and at times the only rehabilitation goal expressed by stroke patients.⁴ Gait training, correspondingly, is the most common therapeutic intervention provided by physical therapists. Although approximately 75% of stroke survivors will regain some degree of walking ability following stroke,⁵ gait recovery for the vast majority remains limited. One significant residual problem for 60% of those people who do achieve independence in walking is related to community ambulation.⁶⁻⁹ Successful community ambulation relies on a strong interplay between internal factors (related to the stroke lesion as well as personal aspects) and external factors (physical and social environment). The type, layout and terrain of the community, all place unique demands on the skill and therefore training requirements for walking in the community.^{10, 11} This makes community ambulatory independence post-stroke an even more challenging rehabilitation goal for both patient and therapist.

Although Teasdale et al¹² and other researchers¹³ found evidence of effectiveness of physical therapy for gait training in people post-stroke, no individual technique was recommended over another for improving walking ability. It is therefore necessary to continue advances on existing therapeutic approaches and develop innovative techniques to be incorporated into current clinical practice. The work presented in this thesis reports on a novel method for enhancing gait ability necessary for community ambulation in people with stroke.

1.2 Objective

The objective of this study is to estimate the extent to which additional sensory information affects gait performance during level and slope walking in people post-stroke. Specifically, the additional sensory information will be provided through 1) contact cues at the fingertip with an external surface or 2) hand contact while holding an instrumented cane. Differences in gait variability, step width and gait speed during the light touch, cane and no touch condition will be compared and contrasted during level, up and down slope walking.

The main hypothesis is that the addition of sensory information (through fingertip light touch or cane use) will improve gait performance in individuals with residual walking difficulties post stroke. It is further hypothesized that the beneficial

effects from the two sources of sensory cues will be greater in down slope versus up slope walking.

1.3 Conceptual model

This study uses the ICF model as the conceptual framework for defining the variables and understanding the relationships between variables in people who have stroke. Figure 1-1 illustrates the constructs and variables applicable to this study and how they interact with functioning according to the ICF model.

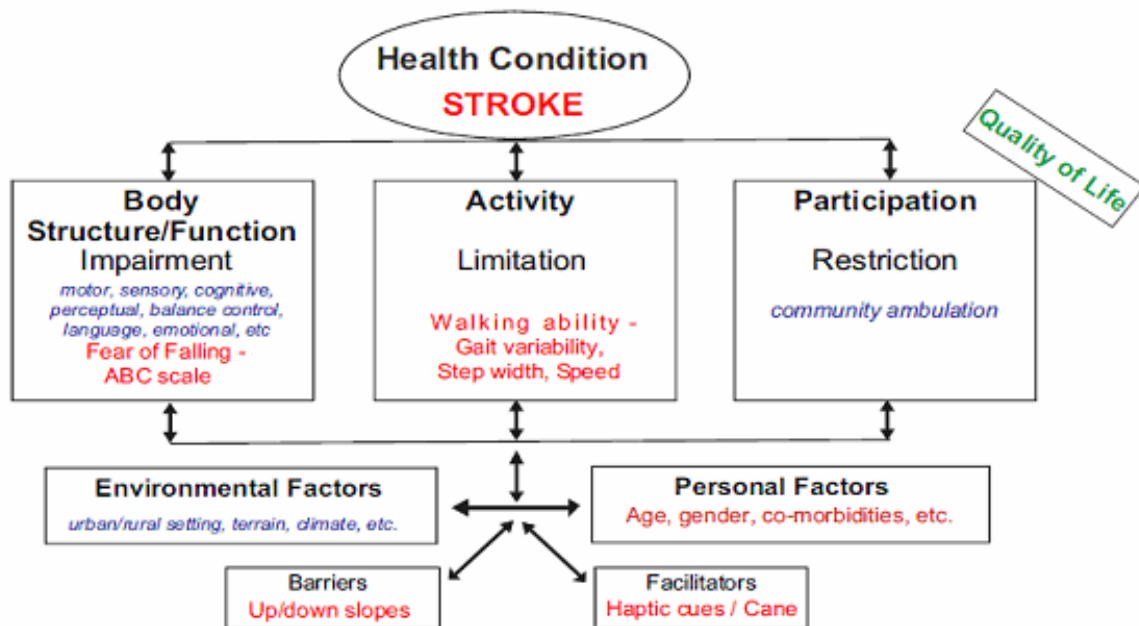


Figure 1-1: The International Classification of Functioning (ICF) framework to understand the relationship between study variables (shown in red).

CHAPTER 2.0 LITERATURE REVIEW

2.1 The effect of stroke on gait

The main characteristics of gait following stroke, clinically referred to as hemiplegic gait, are decreased walking speed, asymmetry (in weight bearing, limb movement, swing/stance phase ratios, etc.) increased effort and abnormal temporal and spatial gait parameters (rate, time and distance measures) compared to healthy normative values. There exist many other qualitative and quantitative methods of characterizing post-stroke gait abnormalities; for example, kinematic (joint angles, excursions and velocities), kinetic (joint moments, powers and forces) and electromyographic (muscle activation and activity) profiles have all be described.¹⁴ This thesis, however, will focus on three spatio-temporal measures of gait which can be commonly used in both research and clinical settings.

All deviations from normal gait patterns seen post-stroke are related to the primary sensori-motor, balance and perceptual impairments as well as to the developed secondary compensatory and adaptive strategies. No single person is likely to encompass all post-stroke gait deviations; however combinations of several of the abnormalities are frequently seen depending on the individual's unique set of impairments. This accounts for the high variability in gait

characteristics and the overall heterogeneous nature of the post-stroke population which significantly complicates both treatment and research.

Average over ground comfortable walking speeds in people post-stroke who were initially non-ambulatory varies from 0.23 m/s (at 6 weeks) to 0.78 m/s (over 3 years post-incident).¹⁵ Although it is generally accepted that independence in community ambulation requires walking speeds of greater than 0.8 m/s,¹⁶ gait speed (GS) alone is not a sufficient indicator of autonomy and safety. One of the major gait difficulties often encountered in older and post-stroke populations is overcoming environmental challenges such as uneven surfaces, sloping ground and obstacles.^{17, 18} Slope walking, either uphill or downhill, is a commonly occurring necessity for both indoor and outdoor mobility. Encounters with slopes, whether natural or man-made (curbs, ramps, etc) are at times, unavoidable and walking on slopes requires different abilities than level walking. Whereas there have been a number of studies examining obstacle negotiation training¹⁹ and avoidance behaviours in both healthy and stroke populations,²⁰⁻²² only more recently has walking up and down slopes garnered more research attention.²³⁻²⁶ It remains, however, that in people with stroke, gait studies primarily focus on level walking conditions.

Stroke-related walking difficulties have been linked to common secondary problems such as depression, inactivity, deconditioning and falls.¹¹ The incidence of falls in stroke survivors is cited to be as high as 73%.²⁷ Both short-term (6-12 months post stroke) and long-term fall rates are much higher than those for the general elderly population. Although the problem of falls is multifactorial in nature, studies reveal that they are associated with gait dysfunctions.^{28, 29} As in the elderly, falls post-stroke are also most likely to occur while walking.^{29, 30} Furthermore, “fear of falling” is recognized independently as an important fall risk factor, causing further restrictions in walking activities in people post stroke.³¹ “Fear of falling” and reduced balance self-efficacy has been shown to impact activities of daily living and overall functioning.^{28, 32} Thus, falls and fear of falling can increase dependency which in turn can lead to devastating and costly physical, psychological and social consequences. Walking up or down slopes further adds to the risk of slipping, tripping or falling³³ and can be particularly hazardous for people with post-stroke gait difficulties.

2.1.1 Balance Control in Gait

Gait is a complex skill which requires the integration of sensory and motor systems in order to produce coordinated movement and dynamic balance control. Following stroke, the multiple impairments in motor, sensory and perceptual functions cause a composite of problems which negatively impact

balance and walking. Tyson³⁴ found the presence of a balance disability in over 80% of first time stroke subjects. Static balance or postural stability can be defined as the ability to maintain one's centre of mass (CoM) over or within the base of support.^{35, 36} Walking, however, involves a very different dynamic balance control in that the CoM projection onto the horizontal plane has to be constantly controlled outside the base of support. Winter³⁷ has described this complex balance during gait as the regulation of dynamic movement of the body about a supporting limb; such the CoM is shifted from side to side and over each successive supporting foot to ensure dynamic equilibrium. Researchers found that CoM instability in standing and walking is significantly higher in people post stroke as compared to age-matched controls.³⁸ The CoM instability, as measured by increased body sway, occurs both medio-laterally (frontal plane) and antero-posteriorly (sagittal plane). In walking tasks that are more challenging such as up- or down slope walking, the sensori-motor demands are increased and, as previously mentioned, necessitate specific modifications.

2.1.2 Walking on inclines

The adaptation to walking on an inclined surface requires changes in gait pattern as well as rapid adjustments in CoM position.^{24,39} Specifically, the individual must be able to raise (upslope) or lower (downslope) the body's CoM, thus resisted or assisted by gravity, respectively, while maintaining and controlling the

forward momentum. Both trunk and lower limb adaptive adjustments must occur, thus altering gait pattern and postures. For example, in healthy people, stride length tends to decrease in downhill walking and somewhat increase in uphill walking.²⁴ The trunk and pelvis, also, typically tilt forward while uphill walking and tilt backward while downhill walking compared to level walking. These are distinct features of slope walking (task-specific) and further differentiate the requirements of up- from down slope walking. People post-stroke generally lack flexibility in walking ability and cannot readily adapt to the increased and task-specific demands of these complex gait activities.

2.1.3 Sensory Input during Gait

The sensory information for balance control in gait is derived from 3 sources: visual, vestibular and somatosensory systems. Current views suggest that the sensory systems provide redundant information such that when feedback from one sense is absent, inadequate or incorrect, compensation by the remaining two is sufficient to maintain equilibrium.⁴⁰ It is still unknown as to how the central nervous system (CNS) integrates sensory information and how multiple sources of sensory signals interact to produce the necessary rapid postural adjustments during gait. A dynamic regulation of sensorimotor interaction has been theorized whereby sensory input is continuously reweighted according to environmental context and personal factors.⁴¹ In conditions when the environmental demands

are high and the individual has sensory impairments, re-weighting would allow the more reliable sensory functions to contribute more to the maintenance of postural control.

In stroke, sensory impairments are extremely common with the nature and severity of the deficits dependant on lesion site and extent. Sensory input from all systems involved in balance control can be adversely affected as a result of potential visual dysfunction and unilateral auditory as well as vestibular deficits. Impaired somatosensation and proprioception along parts of or the entire affected side of the body is also not an unusual consequence of stroke¹.

Additionally, perceptual difficulties (i.e. abnormal sense of verticality, sensory or spatial neglect, etc.) which are the result of problems in higher level processing of sensory information can also further complicate and impact the recovery of balance post-stroke. Therefore, despite the redundancy of sensory inputs and the re-weighting strategy, individuals post-stroke may have such a multitude of sensory impairments that these healthy safeguards are not sufficient for successful postural control.

2.2 Gait rehabilitation post-stroke

The restoration of gait following stroke is a demanding process and its outcome is dependent on several factors. Rehabilitation usually focuses on improving the multiple underlying impairments in body function⁴² (motor control, weakness, dyscoordination, etc.) as well as specific training of the skilled activity. It has been shown that task-oriented interventions^{43, 44} and intense task practice⁴⁵ promote the re-acquisition of locomotor skills. Additionally, the incorporation of learning and motor learning strategies⁴⁶ into the training is effective in combination with task-specific gait activities. Evidence of neural plasticity and activity-dependent cortical reorganization⁴⁷⁻⁵⁰ has put greater (needed) emphasis on the crucial role of rehabilitation specialists for improving gait and functional recovery/remediation in people post-stroke.

Most neurological physical therapists, relying on available evidence and clinical experience, will attempt to incorporate several approaches and interventions simultaneously to optimize patient performance and outcome. For example, clinicians can change the environmental contexts and alter the physical and cognitive demands of the task, as well as provide opportunities for motor problem solving and empowerment. When basic walking ability is present and the rehabilitation goal is advanced toward the complexities of community ambulation,

a myriad of functional walking skills should be added to the therapy program.

The growing time and space constraints faced by clinicians today make the set-up of these complex yet essential gait tasks (surface changes, ramps, obstacles, etc.) extremely problematical and potentially less feasible.

Rehabilitation techniques which target the sensory systems are also of benefit for improving balance and gait capacity. Augmenting sensory information is one useful method for inducing changes in locomotor skills. Therapists may initially facilitate movement and postural control by providing a high degree of sensory input and feedback (manual techniques, use of mirrors, biofeedback, auditory cues, etc.) and gradually reduce these as improvement in gait occurs. Providing additional visual, auditory or tactile input to stroke patients enhances gait rehabilitation and has been shown to be successful.^{51, 52} Although the concept of augmented sensory feedback in stroke rehabilitation is not new, researchers now are discovering more about the bio-physiological mechanism and role of feedback control for motor learning and skill acquisition. Verbal feedback, for example, is commonly used during or after training as a means of promoting learning. The provision of this type of explicit information during rehabilitation, however, may be detrimental to relearning motor skills^{53, 54} in some stroke patients. Interventions that encourage implicit learning by incorporating

feedback and sensory information in the task itself may facilitate learning and improve treatment outcomes.

Over the past two decades researchers and clinicians have begun to explore the effect of using technology for stroke gait rehabilitation. A randomized clinical trial by Visintin et al⁵⁵ examined the use of a treadmill and overhead body weight support system and demonstrated beneficial results for training people with stroke. More recently, an advanced system⁵⁶ which combines the use of virtual environments (VE) with a self-paced treadmill mounted on a motion platform has been developed and used for gait research and training in people post-stroke.

Unlike a conventional treadmill, the self-paced treadmill, offers the walker independent speed control. This is advantageous as it better reflects the reality of overground walking. A more natural pace can develop and vary according to the subject's will as opposed to an imposed constant speed. The additional benefit of using a motion platform in this system is that some of the critical and complex tasks for functional gait (varied slopes, terrain changes, etc) can be easily and rapidly created and manipulated.

VE typically presents the user with opportunities to engage in environments that appear and feel similar to real world situations and events. The rationale for using VE technology in rehabilitation is based on a number of unique characteristics.⁵⁷ These include the ability to objectively measure behavior in a

challenging but safe and ecologically-valid environment. Furthermore, it maintains strict experimental control over stimulus delivery thus permitting the precise manipulation and augmentation of sensory feedback and environmental conditions. The use of virtual reality or virtual environments to study and train both upper & lower extremity motor skills in people with stroke has been well documented.⁵⁷⁻⁶² Researchers have also shown that cortical reorganization can occur while training in virtual environments.^{59, 62} Salient task aspects and difficulty level along with specific degrees of augmented sensory feedback can all be finely controlled in a virtual environment in ways that are not possible in real world settings. VE and technology has enabled researchers to reproduce real-life and functional settings within which they can explore very specific components for enhancing postural control and locomotion. As these systems become commercially available, it also becomes more feasible to clinically use these interesting, new rehabilitation tools.⁶³

2.3 Walking aids and hemiplegic gait

Canes (regular or quadripod) are frequently used during both the rehabilitation process for gait training and as a long term mobility aid for people with hemiplegia. In the past, some physiotherapists have argued against the early introduction of canes or general gait-training with canes in the stroke population as they assumed that it would lead to decreased weight-bearing on the paretic

limb and to greater trunk asymmetry, thereby encouraging a more abnormal gait pattern. Despite some continued controversy, research reveals that these detrimental effects on gait do not actually occur.

Kuan et al⁶⁴ studied the effect of using a cane on hemiplegic gait and found that spatial characteristics (stride length and step length) were significantly increased along with a reduction of kinematic deviations on the paretic side as compared to walking without the use of a cane. Overall walking speed was also positively changed with cane use. Additionally, the study found that canes assist in shifting the body's CoM toward the paretic limb during paretic side single limb support facilitating the swing phase of the non-paretic limb. Tyson¹⁵ demonstrated that trunk movements were not adversely influenced by cane use in a group of chronic stroke survivors. Beauchamp et al⁶⁵ recently showed that cane use can also immediately improve gait symmetry in people in the subacute phase of stroke. Following a study on the effects of walking aids on balance and gait patterns in hemiplegics, Laufer⁶⁶ concluded that the evidence does not support the assumption that cane use in hemiplegic subjects causes greater weight loading asymmetry even when balance is challenged.

The manner in which canes are used by people with hemiplegia (and possibly by other populations with balance problems) may not be the same as that used by individuals who primarily use canes for mechanical support. An early but comprehensive study on the amount of mechanical support provided by standard canes by Murray et al⁶⁷ demonstrated that forces applied to a cane by hemiplegic patients were significantly lower (up to 16% of body weight) than in patients with orthopaedic-type disabilities (closer to 25% body weight). It was also discovered that people with stroke maintain cane contact with the ground for longer periods of time, as compared to other populations with gait disabilities (secondary to joint or bone problems). More recently, Chen et al⁶⁸ reported even lower average peak vertical cane forces applied by subjects with stroke during gait in the range of 12.7% of body weight. Comparing different types of walking canes, both Milczarek et al⁶⁹ and Tyson⁷⁰ independently concluded no statistical difference in the amount of support provided by a quad or tripod cane versus a standard cane. Tyson further noted no difference in the support taken through canes of different heights. In both studies, the walking ability of the hemiplegic subjects was not changed by the use of different aids. Laufer⁷¹ similarly demonstrated that peak and mean vertical forces loaded on 4-point and 1-point canes by hemiparetic patients did not differ. These findings indicate that cane characteristics such as the size of the base of support or the height of the cane⁷² are not relevant

features affecting the amount of physical support people with hemiplegia apply to canes.

In the 2005 review article on assistive devices for balance and mobility, Bateni and Maki⁷³ discussed both biomechanical advantages and neuro-muscular benefits of cane use. The positive attributes of cane use were reported as: 1) providing biomechanical stabilization; 2) reducing lower-limb loads; 3) assisting in propulsion and braking during gait; and 4) augmenting somatosensory cues.

There is growing evidence to indicate that this latter function of canes of providing tactile feedback may play a particularly vital role in stabilizing gait in populations with general balance problems including older individuals and people with stroke. It has been demonstrated that the additional sensory and proprioceptive input to the hand and arm when using a cane provides information on body orientation and sway and thus improves postural stability in both standing and walking.⁷⁴⁻⁷⁶ The additional sensory feedback regarding body position may serve to compensate for impairments affecting balance and help cane users reduce fall risk and achieve independent ambulation.

2.4 The role of haptics (touch feedback) in locomotion

The term haptics refers to the sense of touch and is usually applied to the hand/fingers ability to explore, detect and perceive specific environmental features. Haptic touch has emerged as a novel and efficient technique to improve postural control and dynamic stability in humans. It has been theorized that haptic cues serve as a reference source for postural orientation and that they act similarly to visual and vestibular inputs.⁷⁷ Haptic information is used to “anchor” the body position with respect to the environment through enhanced perception of earth vertical position. The light touch provides information about body sway and position through several somatosensory inputs. Fast and slowly adapting cutaneous receptors can detect movement and direction between the skin and an external surface, while proprioceptive receptors inform about the orientation of the body in relation to the external surface or object.^{77, 79} It is thought that this combined information of position and velocity of body sway is then used in a feed forward mechanism to trigger the activation of postural muscles to attenuate body sway (CoM movement). Leg muscle activity, for example, is increased and proceeds body sway attenuation by 150ms when a light touch cue is used as compared to force or grasp contact.⁸⁰ Studies have revealed that a very light contact of less than 4 Newton’s (N) with an external rigid object can reduce postural sway in stance (with and without eyes open) in

healthy, young subjects.⁷⁶ Similar results using even lighter contact forces (less than 1 N)⁷⁹ clearly demonstrate that no mechanical support is provided with these type of touch cues.

Improved postural stability with haptic touch has also been shown during unexpected surface perturbations and during vibration-induced perturbations in healthy subjects.⁸⁰ Baccini et al⁸¹ and Tremblay et al⁸² investigated the differences in efficacy of light touch in healthy young and older people. They revealed haptic cues to be more useful for balance control in older people (mean age of 75 years) than in younger adults. Nagano et al⁸³ demonstrated that a light finger touch on one's own body (upper legs) can also aid in the control of posture and balance by reducing sway. Secondary to the high density and precise spatial resolution of somatosensory receptors located in the fingertip, this type of cue is used in the majority of haptic studies. However, Rogers et al⁸⁴ have shown that even passive tactile cues applied to either the neck or leg can help control of posture and balance. To summarize, research on haptic cueing in healthy populations has revealed that both passive and active light touch can reduce postural sway in stance even during challenging and perturbed conditions. Additionally, the effects may be more striking in older individuals.

Further evidence for the effect of haptics has been shown in studies of populations with known sensory problems. People with sensory losses secondary to blindness,⁷⁴ diabetic neuropathies^{81, 82} or vestibular deficits^{76, 85} demonstrated significant improvements in stability with a haptic cue that were significantly higher than those in healthy controls. These studies suggest that light touch is of greatest use when there is a notable need for additional postural information such as when one or more of the other sensory systems is impaired. Therefore, in those people who have sensory deficits as many post-stroke people an additional tactile stimulus probably does not act as redundant information for postural control but instead may serve as a needed source of information.

Characteristics of the haptic input have also been investigated. The texture of the surface, whether smooth or rough, appears to have no impact on the amplitude of sway reduction.^{82, 86} Another study⁸⁷, which examined the effect of various arm orientations and location of the external surface, has established that attenuation of body sway is greater when finger tip touch is orthogonal to the more unstable plane. This corresponds to a lateral position of the cueing surface if the expected movement is in the antero-posterior direction. Rabin et al⁸⁸ investigated the time course of haptic input to the changes in postural adjustment revealing a 300ms delay between touch and overall postural adjustment. These

rapid adjustments may suggest that cognitive factors do not play substantial roles in this type of stabilizing strategy. It has been reported however, that there are increased attentional demands when using fingertip touch for postural control,⁸⁹ and therefore this is an area of ongoing research and unresolved debate.

Appendix I summarizes some of the many studies on haptics related to postural control.

Most of the research into the use of haptics for stabilizing postural control has been done in varied standing positions with or without laboratory induced perturbations. To date, there are very few studies which investigate the role of haptics in locomotion. Dickstein and Laufer⁹⁰ demonstrated that fingertip input from a lateral rail while walking on a treadmill did improve CoM stability in healthy young adults. Only 3 studies were found which examined the role of light touch in CNS conditions such as stroke where postural instability and balance problems are often major impairments. One study⁹¹ has demonstrated the positive effect of using haptic input in a stroke population for stabilizing stance and walking during unexpected surface perturbations. Another study⁹² explored the use of light touch for balance control while walking sideways over ground. Even more recently, improved pelvic stability in people post-stroke was established when walking with a light touch cue received from a cane.⁹³ These

findings highlight the benefit of haptic information for improving postural control in people with stroke and its potential impact for enhancing gait capacity. However, the outcomes in these studies were related to the body's CoM (movement and stability) and not to walking ability. In order to generalize the benefits of haptic cueing for gait rehabilitation in stroke survivors, it is essential that improvements in walking are demonstrated. Furthermore, in order to be more clinically relevant, it is imperative that the effect of light touch in improving gait can occur during functional walking activities.

In conclusion, several issues have been identified leading to the work presented in this thesis. First, there exists a growing need for effective treatment techniques in order to improve gait outcomes in people post stroke. Second, a more comprehensive understanding of how canes are used in the stroke population is necessary. Third, although augmented sensory input is recognized as beneficial for improving the performance of gait, the specific role of touch has not been discerned. Additionally, the positive effect of haptic cues on walking ability has not been clearly demonstrated, in particular, in the stroke population. Finally, the use of haptic information to enhance a functional gait activity related to community mobility (up and down slope walking) has never been explored.

CHAPTER 3 METHODS

3.1 Design

A mixed design (Group x Touch x Walk surface), with 2 within- and 1 between-subject factors, was employed. The between-subject factor is that of group (post-stroke vs. healthy). The within-subject factors of touch and walking surface have three levels each: No Touch (NT), Touch (LT) and Cane (C) and Level walking (Level), Level to up-slope walking (Up) and Level to down-slope walking (Down). The order of presentation of the 9 conditions was randomized. Any potential practice effect from order was thereby minimized. The main benefits of using this design were: 1) control against type I error by reducing potential bias from learning, practice or fatigue (potential confounders) and 2) reduction of the chance of type II error as each subject acts as his/her own control. Both aspects added to the statistical power and to the precision of the experimental results.

3.2 Study population

Nine persons diagnosed with stroke and 9 healthy controls were recruited for this study. Table 3-1 summarizes the stroke subject inclusion and exclusion criteria for participation. The target population included independently ambulating persons (between the ages of 45-79 years old), greater than three months post-stroke with walking speeds greater than 0.5 m/s. An age of 80 years old was set

as the upper limit, as peripheral sensory impairments have been reported to increase with healthy aging⁹⁴ secondary to preferential loss of distal large myelinated sensory fibers and receptors. Therefore, sensory information from the fingertip may be less useful in this population. Gait speeds of greater than was chosen, as individuals walking lower than this speed would probably be household only walkers. Walkers at 0.5 m/s or greater may be limited or full community ambulators (thereby more likely to encounter slope walking) and as well suffer a higher risk of falling.⁹⁵ Exclusion criteria included: 1) severe cognitive, perceptual and language impairments which would render their ability to comprehend the study or follow 2-step verbal instructions difficult (MMSE⁹⁶ $\geq$ 26); 2) pre-morbid musculoskeletal or neurological condition which may affect ambulatory ability; and 3) sensory problems of the non-paretic hand/index finger. The first 2 exclusions were determined by chart review and the last criterion was ruled out via a short screening sensory evaluation for light touch and tactile directionality⁹⁷ at the first visit.

The research was conducted at the Feil/Oberfeld CRIR Research Centre of the Jewish Rehabilitation Hospital (JRH) in Laval. The JRH, a teaching hospital affiliated with McGill University and a research site of the Interdisciplinary Centre for Research in Rehabilitation of Greater Montreal or Centre de recherche

interdisciplinaire en réadaptation (CRIR), specializes in neurological rehabilitation and provided direct access to the target stroke population.

Table 3-1: Criteria for participation in the haptic study

Inclusion	Exclusion
• single uni-hemispheric (left or right) > 3 months	• bilateral, cerebellar, brainstem or multiple strokes
• 45-79 years old • intact sensation of less-involved hand	• ≥ 80 years of age • sensory deficits of the less-involved hand
• MMSE ≥ 26 • comprehension of either English or French • independent ambulation with or without a cane and able to walk ≥ 30 m without walking aid • gait speed ≥ 0.5 m/s	• severe cognitive deficit • language or communication problems affecting ability to follow verbal 2-step instructions • visual-perceptual deficits i.e. neglect, visual homonymous hemianopsia • gait speed < 0.5 m/s

3.3 Measures

The dependant variables used in this study were 3 gait measures. The main outcome variable was gait variability related to the stride cycle duration. The secondary variables were step width and gait speed.

3.3.1 Gait variability

Gait variability is the intra-individual fluctuation from one step to the next and can be associated with any gait parameter. Measures of variability in gait are recognized as precise indices of walking performance and sensitive markers of pathological mechanisms of gait control.⁹⁸ The variability of a measure may also impart greater qualitative characteristics of the gait pattern than offered by the parameter mean alone.⁹⁹ This can be extremely important clinically where few measures exist to document this important aspect of rehabilitation. Two methods of reporting and describing gait variability are used in the literature; the standard deviation (SD) and the coefficient of variation (CV) of the measured variable. It is not always clear why some authors choose one method over another and no clear consensus exists regarding the best measure suited to quantify gait variability. SD reflects the absolute variation of a parameter while CV, is the variability computed relative to the mean of the distribution.

Advantages of using the CV are that they are a unit less measure, provide a simple and easily interpreted indication of gait variability and can allow for quick comparisons between subjects and groups.

Stride time variability is a gait parameter reflective of the automatic stepping mechanism and thus is thought to require little attention. Typically, stride time variability remains stable and is a very constant feature even as a person ages.¹⁰⁰ The larger the stride time CV, the higher the gait variability which indicates a less rhythmic and less stable gait. Increases in stride time variability have been found to be closely associated with an increased risk for falls in elderly and in some neurological populations.¹⁰¹ Therefore, this work defines gait variability as the percentage CV (% CV) associated with stride time. The % CV of stride time is calculated as a percentage of the ratio of SD to the average gait stride (cycle) time in each walking trial.

$$\% \text{ CV} = (\text{SD}/\text{mean}) \times 100$$

Digital data for calculating the stride duration was provided by a Vicon © MX (Oxford Metrics, UK) 3-dimensional motion analysis system with 6 cameras. The reliability and accuracy of this system has been established and reported elsewhere.¹⁰² In addition, a system calibration was performed prior to each experiment. A sampling frequency of 120 Hz was set. To calculate stride-to-

stride variability, the Vicon data was first processed off line. Customized Matlab programs were used to determine the gait cycle events of initial foot contact and foot-off for each limb during level and incline walking based on foot marker locations. Stride duration was defined as the time taken between 2 consecutive initial foot contacts of the same limb (one gait cycle). A fixed distance of 20m within which all gait cycles were averaged insured consistency of approach. In the level trial, 20m represented the middle section of the 40m path whereas in the incline trials the distance corresponded to the complete incline surface but excluded transitions from level to incline or incline to level (see Figure 3.4). Platform movement was recorded by 4 reflective markers placed at each of the treadmill's 4 corners thereby capturing surface motions during walking trials. The treadmill marker trajectories created during data processing permitted the accurate identification of the inclines. In each trial, the 10m distance walked prior to analysis was considered sufficient to build toward a steady state walking condition. After Matlab processing, data were used to calculate mean stride duration, SD and the %CV for the paretic and non-paretic limb separately for all walking conditions.

3.3.2 Step width

A secondary variable examining gait performance in this thesis is that of step width (SW). This variable is known to be associated with balance adjustments in gait.¹⁰³ Medio-lateral (M-L) stability is a particularly important consideration for anyone with issues affecting postural control including people post-stroke. Falls in older or post-stroke individuals are often associated with decreased M-L (more than antero-posterior) CoM stability. The spatial parameter of step width directly links CoM stability in the frontal plane with attributes of the gait pattern. An increase in step width (either compared to healthy gait or compared to a standard condition) means a wider base of support is required. Typically, this reflects either a rapid gait adjustment (which lasts only one or several steps) or a general adaptation for maintaining CoM stability. On the other hand, decreases in step width can be interpreted as a sign of improved M-L stability. M-L or frontal plane stability during gait is also an important indicator of lower trunk and hip control which is often impaired in people post-stroke. As mentioned for the % CV, the digital 3-D gait data were processed and analysed off line with the use of Matlab programs. Step width was calculated as the perpendicular distance (cm) created from a line along the toe to heel marker of one foot to the imagined line of progression formed by the toe and heel marker of the opposite foot. The 20 m distance in each walking trial as described above were used for analysis.

3.3.3 Gait speed

Gait speed (GS) is probably the most common general descriptor of gait in both clinical and research fields. It can track an individual's progress and change during rehabilitation, indicate overall functional status as well as be used for purposes of classification. In this study, a self-paced motorized treadmill was used, therefore the instantaneous treadmill GS, as recorded by specialized VE software (described in the next section), represented the subject's GS. For use as a dependant variable, the GS was then averaged over the same distance as described for the other 2 variables.

3.3.4 Independent variable

The independent variable was the additional somatosensory information.

Somatosensory information was defined as either the touch input received from a fingertip contact with an external surface (Figure 3-1) or as provided by cane use.

Haptic cues are further specified as a light touch in the order of 4 N of vertical force. This amount of force has been shown to be insufficient to provide mechanical support for humans. Forces exerted by the lesser involved index finger touching the side of a lightweight firm bar (1cm x 1cm x 45cm) located on the subject's right or left side at fingertip height (adjustable for each participant) were measured by an Interlink Electronics pressure sensor strip¹⁰⁴ which was

embedded onto the lateral aspect of the bar. The strip was calibrated prior to use against known weights to verify output validity and to check for hysteresis.

The secondary source of additional somatosensory information was defined as those received from a cane used in the less affected hand of the person with stroke or the preferred hand in the healthy control. The cane (Figure 3-2) was specifically designed for this study and for use with the self-paced treadmill in order to simulate over ground cane use. A standard aluminium cane with a J handle had its base replaced by a universal ball bearing joint (minimal friction) permitting freedom of movement in all directions. The joint bottom was affixed to an aluminium pin which sits in an AMTI tri-axial force transducer¹⁰⁵ providing data on the vertical and shear forces applied through the cane. The force transducer with the cane bottom was securely attached to the left or right sides of the treadmill permitting a safe and similar action to natural cane use while walking. The cane was adjustable to height according to individual participant's need. Analog data was recorded at a frequency of 1200 Hz and information on forces from both the haptic strip and cane was studied off-line. Appendix II provides a schematic illustration of the experimental set-up.



Figure 3-1: Haptic strip with embedded load sensor, placed at fingertip height.



Figure 3-2: View of the instrumented cane with ball-joint base, affixed to left side of the self-paced treadmill.

The VE created for this study used a Computer Assisted Rehabilitation Environment (CAREN) Integrated Reality System¹⁰⁶ to control and synchronize the visual scene with the self-paced treadmill. The motorized treadmill is servo-controlled by the output of an electropotentiometer which is tethered to the

walking person, such that the walking speed can be adjusted instantaneously and voluntarily without any external means. A virtual scene of a 40m long outdoor path with level and inclined surfaces was rear-projected onto a large screen placed in front of the treadmill (Figure 3-3). The scene progression is synchronized simultaneously with the combined motion platform and self-paced treadmill speed through CAREN software such that the subject had full control of his/her movement within the VE. The 5° slope angles (up and down) were chosen based upon national building code¹⁰⁷ and universal design norms for accessibility ramps which recommend a slope rise of 1 in 12 inches in most instances. This represents approximately a 5° angle.

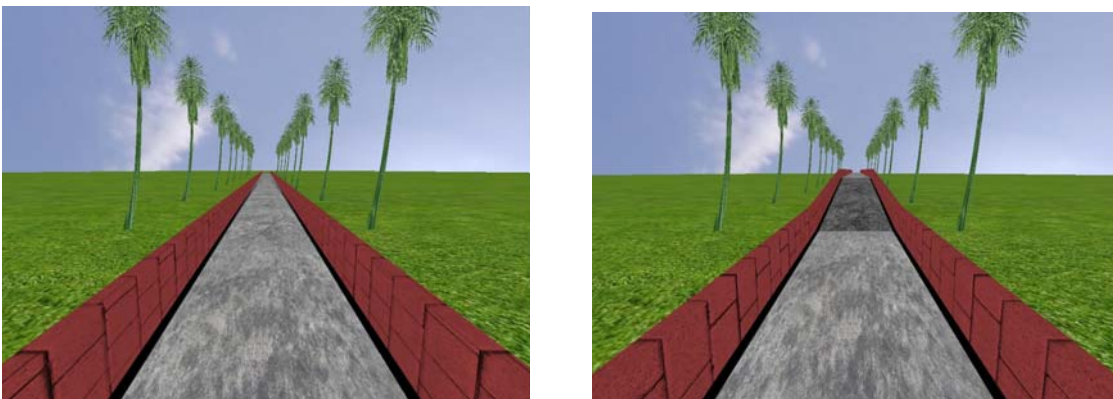


Figure 3-3: Example of the outdoor walking path scene, showing a level, and a level to up slope surface. The scene is projected on large screen placed in front of subject walking on treadmill.

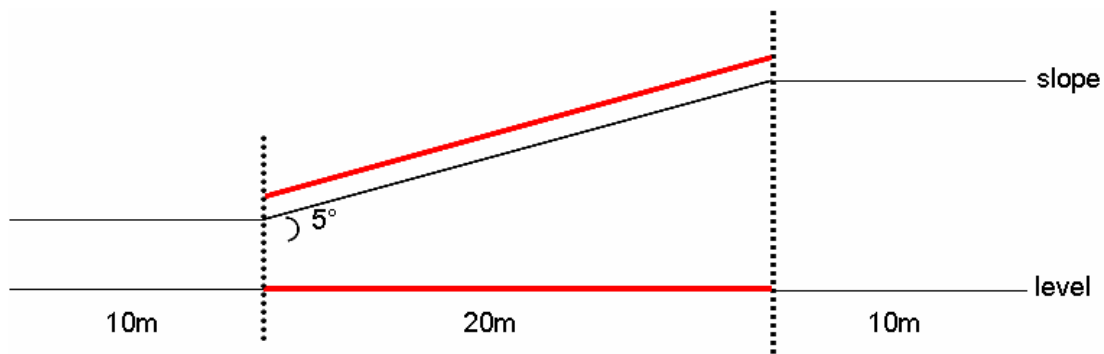


Figure 3-4: Side view perspective of a scene showing a level path (below) and level to up-slope path (above). Red lines indicate distances used for analysis.

3.3.5 Confounding variables

By using each subject as their own control, confounders such as age, gender, chronicity or side of stroke etc. was minimized. By randomizing the order of presentation of the combined conditions of touch (NT, LT or C) & walking (L, U or D) any potential bias from order was reduced. The issue of learning and fatigue as confounders was minimized by using a single experimental block. Finally, as the response time of somatosensory input to postural sway is almost immediate - 300ms⁸⁸ and occurs only when touch is present, carry-over from one condition to another was not expected (no wash-out period between conditions is required).

Individual factors such as balance self-confidence and over ground walking speed may be potential confounders as they can be attributed to walking ability. Balance self-efficacy or self-confidence was measured using the Activities-specific Balance Confidence (ABC) scale (Appendix III). The ABC Scale is a

numerical scale ranging from 0% (no confidence) to 100% (fully confident) which provides self-reported rating of balance self-efficacy while performing 16 activities within the home and in the community.¹⁰⁸ The final score is a combined percentage with higher scores associated with higher levels of confidence. The ABC scale has been found to be internally consistent (Cronbach alpha = 0.96) and demonstrates good test-retest reliability ($r = 0.92$), convergent and criterion validity in both the original and Canadian French version.¹⁰⁹ It is also used extensively in research in stroke, elderly and other populations where fear of falling may be an issue.

Each subject's comfortable walking speed may be related to the overall walking ability and gait variability, thus over ground GS was measured using the 10 meter walk test. The 10-m gait speed is a common clinical measurement and is known to be a reliable and important measure used extensively in stroke and other populations.¹¹⁰ The overground gait speed (OGS) was defined as the average of 2 times taken to walk 10 meters at a comfortable pace and was measured in m/s. As mentioned, the mean OGS was used to characterize the stroke and healthy subjects.

Another potential confounder was the subject's ability and level of compliance in maintaining a light touch (defined as $\leq 4\text{N}$) as instructed during the walking conditions despite a period of habituation. In order to address this issue, real time feedback of the loading pressure on the haptic strip was used to train the subject to apply a fingertip contact force of less than 4N while walking. Also, all data from the loading forces on the haptic strip were examined visually for each LT condition for all subjects. A criterion was set such that a mean vertical loading of less than 4N (used to define haptic touch) for a period of greater than 80% of the walking trial was necessary in order to be accepted for analysis.

Other impressions the participants may have had of the experimental conditions may have influenced performance. Visual analog scales (VAS) were developed in order to evaluate these individual perceptions. The degree of ease or difficulty associated with each touch and walking condition was rated. Additionally, the amount of attention directed to using the light touch and cane device while walking was assessed. The scales are shown in Appendix IV. VAS ratings were collected with the help of a researcher and immediately followed the completion of the experiment.

Finally, although subjects were not blinded to the experimental conditions, they may not have been aware of the potential benefit of various forms of somato-sensory information for improving gait performance.

3.4 Procedure

Ethics approval for this study was attained from the CRIR Research Ethics Committee (#CRIR-314-0807) and all participants signed an informed consent (Appendix V) prior to data collection. The experimental session began with the screening of sensory evaluation followed by the administration of the ABC questionnaire. As previously mentioned, the sensory screening verified intact light touch and touch directionality of the hand and index finger tip involved in touch. The participants then completed the 10m over ground self-paced gait speed evaluation with and without the use of a cane.

Anthropometric data (including height (cm), lower limb length (cm), weight (kg) and joint widths (cm)) were collected using a standard tape measure, weighing scale and callipers to input into Vicon software. As is necessary for video-capturing, small reflective markers were placed on the subject by a trained researcher according to the Plug-In-Gait marker set (Appendix VI) with additional markers on the sacrum and foot. Participants wore a light weight harness (attached to a ceiling rail ensuring subject safety) during all walking trials,

however, no body weight support was provided. For increased safety, a spotter was present nearby the subject for all walking trials. All participants walked on the self-paced treadmill. A period of habituation was provided for each subject until comfortable walking with and without support was achieved, including going up and down slopes. Participants also practiced walking using the 2 sources of additional somatosensory input (fingertip contact on the haptic strip and use of the instrumented cane). Rests were provided between habituation & trial collection and as necessary between walking trials.

Subjects were told that the walking surface may be either level (L), inclined up (U) or inclined down (D) and that they should watch the visual scene presented. Subjects were instructed to begin walking upon hearing “go” sounded by the computer and continue until they passed a yellow line on the virtual walking path. They were asked to walk as normally as possible and at a comfortable and safe pace. Instructions regarding the touch conditions were either not to touch, to lightly touch the side of the bar with the index fingertip or to use the cane while walking. No further verbal information regarding the walking task was provided. Arm swing, hand or finger movement was neither specifically encouraged nor discouraged. A randomized condition sequence was computer generated prior to the subject’s arrival. The total distance walked per condition was 40m.

The entire experiment averaged approximately 3.5 hours; 1 hour for subject preparation and 2.5 hours for the combined gait-lab habituation and data collection as well as for the completion of clinical measures. Laboratory data (digital and analog) were collected and stored in Vicon (for off-line processing) and treadmill speed was captured in CAREN and imported into Excel for further analysis.

3.5 Analysis

This study uses the stride time coefficient of variation as the main outcome variable to describe gait performance (variability). The coefficient of variation is operationally defined as the percentage of the standard deviation of stride duration divided by the mean stride duration. The mean stride duration and standard deviations were calculated by averaging the number of gait cycle stride durations occurring during 20 m of the incline and level walking conditions. The exposure was defined as the presence of somatosensory information received by either the non-paretic index fingertip through lightly touching a rigid bar or the non-paretic hand while using an instrumented cane. Haptic input was defined as tactile forces of 4 N or less. Incline walking (up or down slope) was defined as walking on a self-paced treadmill mounted on a motion base that tilts the surface ± 5 degrees from level with a synchronized visual display of a virtual environment.

The analysis required a few steps in order to answer the main question. Firstly, the study population was characterized using descriptive statistics. This included basic demographic details (age, gender, lesion side, stroke chronicity, etc) as well as providing scores on the ABC questionnaire and OGS with and without cane use for each subject in each group. Forces from both the haptic strip and the cane were also described in terms of means after close examination.

The main outcome variables were analysed using three-way repeated measures analysis of variance (ANOVA). This analysed the 2 within-subject factors of Touch (NT vs. LT vs. Cane) and Walking Surface conditions (Level vs. Upslope vs. Downslope) and the 1 between-subject factor of Group (Post-stroke vs. Healthy). Statistical significance was set at an alpha level of 0.05. Where significant main effects were discovered, post-hoc analyses using paired Tukey tests further examined the conditions of interest. Separate ANOVA analyses were performed for each dependant variable (%CV, GS and step width). Statistical analyses were all performed using Excel and Statistica (v9) software.

3.6 Research manuscript #1:

“An innovative cane device developed for treadmill gait training and research”

Claire Perez and Joyce Fung

Journal of Physiotherapy Education (in press) September 2010

3.6.1 Abstract

Background and purpose. We have developed a novel cane device to be used in conjunction with a treadmill-based virtual reality (VR) locomotor system. This proof-of-principle paper reports the rationale, instrumentation, feasibility and clinical implications of the cane device, as well as preliminary results from persons with stroke and healthy older individuals using the device.

Subjects. Five persons with stroke and 5 healthy older adults participated.

Methods. Average walking speeds with and without use of the cane are compared between the overground physical environment (PE) and a self-paced treadmill-based virtual environment (VE). Additional gait parameters examined while walking with and without the cane in the VE are: (1) gait variability quantified as the % coefficient of variation (% CV) for stride duration and (2) step width. We also reported and discussed the vertical loading forces transmitted through the cane during self-paced treadmill walking in the VE.

Results. Results reveal that walking with the instrumented cane on a treadmill is feasible for use in both healthy and stroke populations. It is evident that people

who normally rely on a walking cane benefit more from the instrumented cane than those people who normally walk unaided.

Discussion and Conclusion. This work represents the first instrumented cane for use with a treadmill-based locomotor system. The use of such an assistive device would add to the ecological validity of such gait rehabilitation systems. It is expected that gait training with the instrumented cane can be carried over to overground walking, although further studies are warranted.

Key words: Walking aid, Virtual Environment, Stroke, Locomotor Rehabilitation

3.6.2 Background and Purpose

Walking aids, specifically canes, are frequently used in gait rehabilitation and often prescribed as a long-term mobility aid for people with a wide range of musculoskeletal, neurological and balance conditions. In both stroke and elderly populations, the frequency of cane use in everyday life is very high, either for all walking activities or solely for community (out-of-home) mobility. In a frail elderly population, canes were rated as the second most important overall assistive device, after eye glasses.¹¹¹ There are two main substantiated reasons why many people depend on this simple aid for mobility. First, using a cane is known to improve confidence and reduce the anxiety associated with “fear of falling”, which is a very important consideration for both the elderly and stroke

populations.¹¹² Often, many elderly people and even high-functioning ambulators post stroke do not venture outdoors without a cane secondary to the increased security and safety they feel the cane provides them. This dependency may be more pronounced in areas where weather conditions (i.e. high winds, snow, ice, etc.) can promote even greater fear when ambulating outdoors. The second reason is that ample evidence now exists to clearly establish the role that cane use can play in improving balance control and postural stability during stance and gait.^{34,64-66,68,69,71,73,76,93,112,113} As rehabilitation specialists, physical therapists, more so than any other professional, are in the position to offer patients appropriate recommendations and training with walking aids. Furthermore, it is the responsibility of physical therapists to assure that the theoretical knowledge upon which they base their clinical decisions is based on current information and up-to-date evidence.

3.6.3 Literature Review

One of the main goals of rehabilitation in stroke and other populations is the restoration of independent gait with or without the use of an assistive device. Evidence has shown that task-oriented interventions and intense task practice⁴⁵ promote the re-acquisition of motor skills including gait. Although evidence-based stroke practice recommendations strongly support the use of treadmills for

gait training^{12, 13} due to the intense repetition of gait cycles that can be performed, many clinicians believe that gait practice overground is nevertheless necessary to assure the transition from treadmill walking to 'real world' walking (with or without a cane).

The ability to generalize learning and transfer gait adaptations gained from treadmill training to overground walking has improved with the emergence of virtual reality technology. The increased visual (optic flow) and other sensory inputs now available can better simulate natural, true to life walking conditions. However, even with these advances there remains an important dissimilarity between treadmill and overground gait training. In our clinical experience, the fixed bars on treadmills (either in front or to the side of the treadmill walking surface) provide stabilizing support very similar to the 'parallel bars' presented in many physical therapy departments. Parallel bars are often used for preparation of gait training and a variety of balance/gait exercises. However, many physical therapists will restrict gait training conducted in parallel bars and promote early overground training (with a walking aid and assistance as needed) with the rationale that the rigid bars provide too much balance support that does not challenge the postural control required to eventually walk with a walking device. The same rationale can be used to explain the potential problem of limited carry-

over effects from treadmill to overground walking with an aid. In order to master the dynamic skill of cane walking, the skill itself (or a simulation equally challenging) must be practiced.

An often reported clinical opinion held by some physical therapists working in stroke rehabilitation is that gait abnormalities and asymmetry might increase with cane use. Laufer,¹¹⁵ however, investigated the effects of walking aids on balance and gait patterns in hemiparetic (chronic) stroke survivors, and concluded that cane use does not cause greater weight loading asymmetry even when balance is challenged. Moreover, the spatial gait characteristics (stride length and step length) were found to significantly increase while kinematic deviations were reduced on the paretic side, as compared to walking without the use of a cane. A recent study, examining the immediate effect of cane use in a subacute stroke population with existing gait asymmetry further established that temporal gait symmetry is significantly improved with a standard, single point cane but not with a four-point (quad) cane.⁶⁵ Additionally, cane use did not adversely affect trunk movements in people post stroke as demonstrated by Tyson.³⁴ Another recent study involving patients post stroke in the early phases of rehabilitation¹¹³ compared 3 different walking aids on walking capacity, temporal distance gait parameters, and patient satisfaction. The simple cane with an ergonomic

handgrip was found to be the most efficient compared to 2 other commonly used walking aids during gait training (quad cane & Nordic stick). It was also most preferred by patients, which is an important consideration especially when prescribing aids. The reality is that as many as 76% of people post-stroke have been reported to use at least one gait aid¹¹⁴ and for most that includes a simple cane. Regardless of treatment approach, all clinicians recognize that cane use is necessary at times and can improve an individual's level of independence, safety and confidence particularly in community ambulation. In the stroke population, as noted above, evidence is mounting in favor of using standard, single point canes over multi-legged versions (such as quad canes or walkers) in both acute and chronic phases and that beneficial gains for the patient far outweigh any potential disadvantages. Therefore, evidence has shifted the clinical question away from whether or not to use a cane at all for stroke rehabilitation to when in the rehabilitation process the introduction of a regular cane is most appropriate.

Although primarily known for providing mechanical support and in reducing weight bearing through a weaker limb, a cane also assists in the propulsion and braking portions of gait as well as augmenting somatosensory information.⁷³

There is growing evidence to support that this latter function of canes, providing additional sensory and proprioceptive feedback, may play a particularly vital role

in stabilizing gait in populations with general balance problems, including older individuals and people with stroke. The sensory feedback related to body position may serve to compensate for sensorimotor impairments affecting balance control and help cane users reduce fall risk and achieve independent ambulation.

Studies examining the forces exerted on canes in people with post-stroke gait dysfunctions have demonstrated generally lower peak vertical forces as compared to people with musculoskeletal or orthopaedic conditions where the reduction in limb loading is of primary concern.⁶⁴ It is possible that people with balance problems (including elderly and stroke populations) use canes more for this attribute of facilitating postural control through increased somatosensory information, rather than as a means of physical support. Preliminary results from a current study on the effects of enhanced somatosensory input (from both haptic cues and cane use) on level and incline walking in people post-stroke are pointing toward beneficial effects including increased gait rhythmicity (decreased stride time variability) and gait speed, decreased step width as well as improved center of mass (CoM) control.¹¹⁵⁻¹¹⁷

Over the past two decades, researchers and clinicians have explored the effect of using technology for stroke gait rehabilitation. An advanced system which combines the use of virtual environments (VEs) with a self-paced treadmill

mounted on a 6-degree-of-movement motion platform has been developed and used for gait evaluation and retraining in people post-stroke.⁵⁶ The use of VE typically presents the user with opportunities to engage in environments which appear and feel similar to real world situations and events. The use of virtual reality (VR) technology to study and train both upper and lower extremity motor skills in people with stroke has been well documented and established.¹¹⁸ VR systems also are now more accessible in hospital and rehabilitation settings therefore more available for everyday clinical use. Despite the important and widespread use of canes, canes have not yet been incorporated into these new methods of gait training. The concept of creating a cane for use with a self-paced treadmill, although simple, adds to the ecological validity of a VR system and thus enhances the simulation of 'real world' walking activities. It is suggested that transfer of learning to overground walking with a cane may also be facilitated. The purpose of this paper is to present the development of this novel cane device and provide results from a pilot study investigating the cane's feasibility.

3.6.4 Methods

Population

Five people with stroke (age 65.2 ± 5 years) and 5 healthy controls (67.6 ± 6 years) participated in this study (Table 3-1). The participants were part of the larger study examining the extent to which additional sources of sensory information affect gait performance during incline walking in people post stroke mentioned earlier.¹¹⁵⁻¹¹⁷ The additional sensory input was provided through contact cues at the fingertip (haptic cues) or through the palm of the hand with use of a specifically designed instrumented cane presented in this paper.

Instrumentation and Measures

An advanced locomotor system which combines the use of VR with a self-based treadmill and a motion platform, as previously documented,⁵⁶ was used. This system is coupled with a 3D scene rear-projected onto a large screen as a VE in front of the treadmill. The Computer Assisted Rehabilitation ENvironment (CAREN)¹⁰⁶ software (Motek BV, NL) controlled and synchronized the instantaneous treadmill speed with the VE scene progression and the platform movement.

The VE scenario designed for this project was that of a long (40 meters) and clearly delineated outdoor walking path set amidst grass and trees. Kinematic data, sampled at 120 Hz, was gathered using a 6-camera Vicon MX motion analysis system (Oxfordmetrics, UK).¹⁰² Subjects wore reflective markers positioned on body landmarks according to Vicon's Plug-in-Gait model. Prior to walking, the Activities-specific Balance Confidence (ABC) questionnaire was completed with subjects in an interview format. The ABC rates balance self-efficacy, reflecting the subject's own perspective on his/her walking abilities and is valid in a stroke population.¹²⁰

Three walking trials within the VE were analyzed; the first or baseline trial without cane use (NC1), the cane trial (which was randomly inserted within other walking conditions for another study¹¹⁵⁻¹¹⁷ and the last trial without cane use (NC2). For two subjects, only the baseline trial was used (due to a technical problem in S3 and fatigue in S5). The gait parameters under study were speed, variability (% coefficient of variation for stride duration (% CV) and step width. The overground gait speed was measured with the 10-meter walk test, whereas gait speed within the VE was calculated using the instantaneous speed output from the treadmill motor through the middle 20 meters of "steady-state" walking. Values were averaged over the two 10-meter lengths for comparison with the

overground measures. To calculate stride-to-stride variability and step width, the kinematic data was processed with a customized computer script in Matlab (Mathworks Inc., USA) to determine the gait events of initial foot contact and foot-off for each limb, based on the sagittal plane foot trajectory. Measures of gait variability have been found to be more sensitive than direct gait measures such as gait speed and therefore provide more precise indices of walking performance.¹²¹ Less variability in a gait parameter such as stride duration would indicate a more rhythmic and stable gait pattern. It is suggested that measures of variability may also reflect qualitative aspects of gait otherwise overlooked by measuring gait speed alone. Stride duration was defined as the time taken between 2 consecutive initial foot contacts of the same limb (one gait cycle). The % CV for stride duration, measured as the percent standard deviation over the mean, was compared between conditions (cane versus no cane) and between groups (stroke versus controls). Step width was defined as the distance (cm) between the left and right limb heel as measured by heel marker distance when in the double support phase of gait. Step width is often related to dynamic gait stability such that decreases in width represent better balance and improved postural control. The gait cycles occurring in the middle 20 meters of walking were retained for analysis.

Visual analog scales (VAS) were used to evaluate individual differences and were completed immediately following the experiment. Two parameters of interest were quantified: 1. the degree of ease (0/10) or difficulty (10/10) in using the cane; 2. the attention directed towards walking (0/10) or cane use (10/10).

Treadmill Cane Device

A typical single point, adjustable aluminium cane with an offset foam handle was refurbished for use with the treadmill. The lower section of the cane was affixed with a ball-joint with its centre mounted onto the centre of an AMTI tri-axial force transducer (MC2.5-500).¹⁰⁵ The ball joint permits the cane to be moved in three degrees-of-freedom, but constrained to $\pm 30^\circ$ in both the sagittal and frontal planes. The combined cane tip-ball joint force transducer unit was then mounted onto a metal plate which was screwed on to either the left or right side of the treadmill as needed (Figure 3-5). The upper cane part with the handle could then be slipped over the lower unit and adjusted for cane height. Three additional holes were drilled into the upper cane tube to accommodate the extra height of the force transducer (approximately 3 inches). The analog force data were sampled at 120 Hz. The vertical force data were processed using a customized Matlab program. The values were expressed as a proportion of the body mass of the individual and then normalized to the gait cycle.

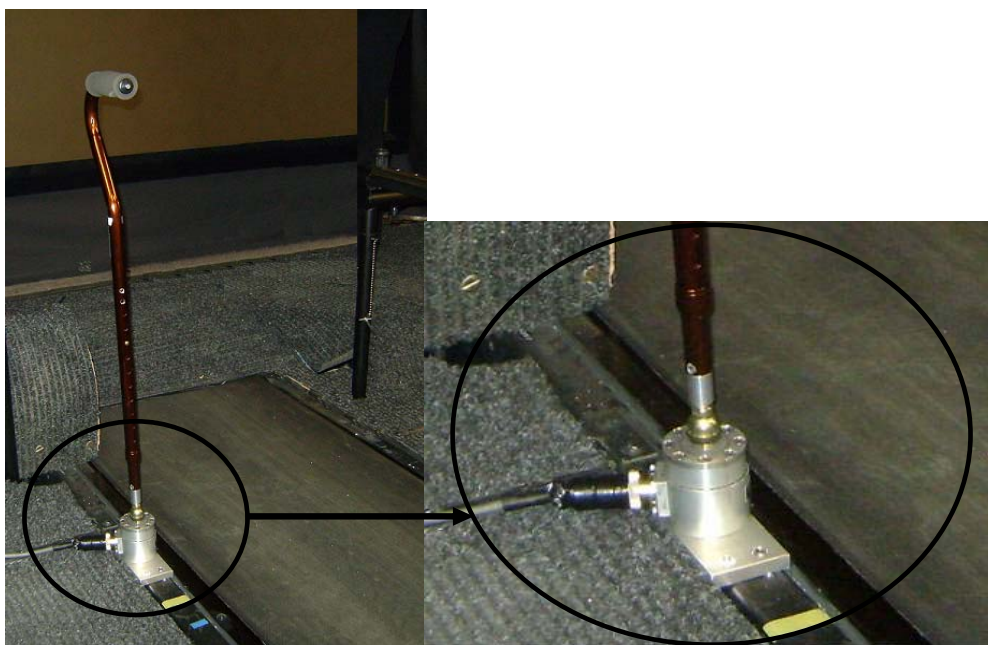


Figure 3-5: View of the instrumented cane attached to left side of self-paced treadmill facing a large screen on which virtual scenes are projected. Inset shows a close-up perspective of the cane tip base, ball joint and force transducer unit.

Protocol

All participants signed an informed consent form approved by the Montreal Centre for Interdisciplinary Research in Rehabilitation (CRIR) institutional ethics review board. The single experimental session began with an interview and clinical measures including the 10-meter walk test which was performed with a cane (for those who used the aid in their everyday lives) and/or without the cane. The reflective markers were attached and a safety harness was positioned on all subjects, which was then secured to a ceiling track during walking trials.

Participants walked on a self-paced treadmill while viewing the VE scene projected in front as they walked a 40-meter, level path. For added safety, a physical therapist stood nearby and supervised the subjects with stroke as needed.

As noted, the participants were in control of their own walking speeds on the treadmill since they were tethered onto an electropotentiometer with the digital output and its first-derivative servo-controlling the treadmill motor. They were instructed to walk at a comfortable pace. Each subject underwent a period of habituation which included walking on the self-paced treadmill on level, up and down slope surfaces (5° slope change), with and without cane use as well as adapting to the VE. The experimental protocol involved three walking surface conditions including level, up slope and down slope along with three touch conditions including no cane (NC), cane (C) and use of light touch (LT). The presentation order of the walking conditions was randomized between 2 baseline trials (NC level walking). The baselines were used in order to examine the effect of learning and adaptation to the system as well as to evaluate fatigue. Rests were provided as necessary during both the habituation and the experimental phases. For the purpose of this paper, only the experimental trials of level walking with and without the cane were analyzed.

3.6.5 Results

Participant characteristics and their overground gait speeds are described in Table 3-2. The average chronicity of stroke was 5.1 ± 2.1 years. ABC scores are also provided. For all subjects with stroke, the instrumented cane was held in the non-affected hand during treadmill walking whereas the controls were asked to choose their preferred hand for cane use (likely corresponding to their dominant hand). As expected, gait speeds were generally lower in people with stroke, as compared to healthy older adults, regardless of environment (VE or physical environment (PE)). All subjects walked with a lower gait speed on the self-paced treadmill within the VE, as compared to overground walking within in the PE. The mean reduction in gait speeds in the VE was greater for the subjects with stroke, as compared to controls. For both groups, the speed in the VE cane conditions was closer to the overground speed. The mean speed changes from overground walking in the PE to treadmill walking in the VE walking without the cane was a reduction of only 2% with the cane, as compared to 27% without. For controls, the reduction in speed ranged between 6% (with cane) and 10% (without cane). The second baseline condition without cane use (NC2), when available, tended to be higher than the first (NC1). The mean gait speeds with and without cane use for both groups are provided in Figure 3-6.

A mean increase of 20% in speed occurred when the subjects with stroke used the cane; while healthy controls demonstrated a mean change of 3%.

Table 3-2: Subject Characteristics.

Stroke Subjects	Age (years)	Gender	Lesion side	Cane Use	OG Gaitspeed (m/s)	Treadmill Cane side	ABC Score (%)
1	61	M	L	Yes	0.62	L	67.8
2	72	M	L	No	1.01	L	97.8
3	63	M	R	Outside	0.80	R	83.3
4	69	M	R	Yes	0.83	R	65.6
5	61	F	L	Yes	0.30	L	60.0
	65.2 (± 5.0)	3M 2F	3L 2R	3 Yes 1 No 1 Outside	0.71 (± 0.27)	3L 2R	71.3 (± 17.8)
Healthy Controls							
1	68	M	n/a	No	1.30	L	96.8
2	77	F	n/a	No	1.27	R	89.1
3	61	F	n/a	No	1.22	R	99.4
4	64	M	n/a	No	1.25	L	92.4
5	68	M	n/a	No	1.25	R	98.5
	67.6 (± 6.0)	3M 2F			1.26 (± 0.03)	3R 2L	95.2 (± 3.6)

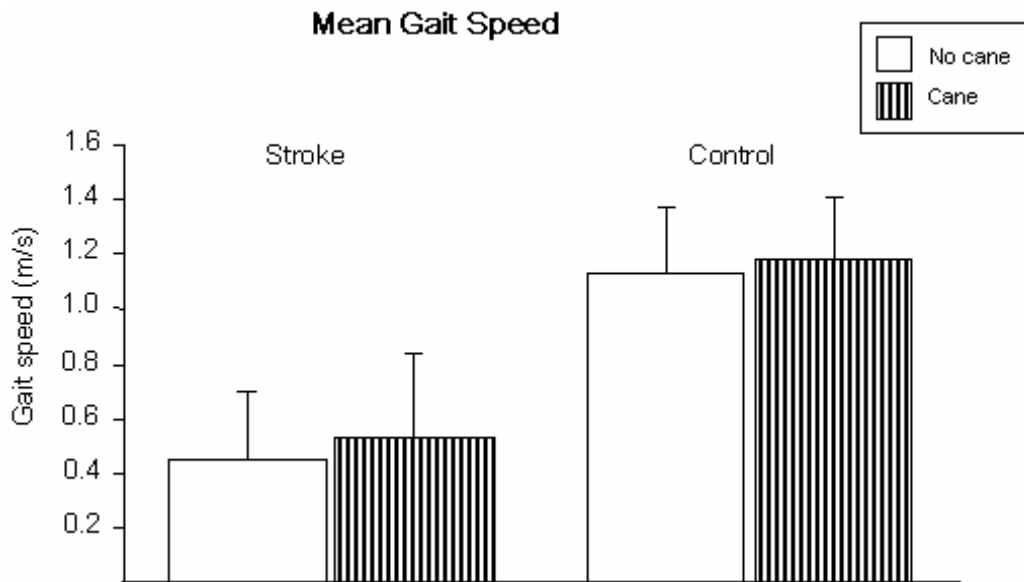


Figure 3-6: Mean gait speeds and standard deviations for stroke and control groups in the virtual environment (VE) with and without the use of the instrumented cane.

Figure 3-7 shows the gait speeds from three representative individuals; two subjects with stroke and one healthy control subject. The two individuals with stroke contrast between higher and lower functioning, based on their overground walking speeds. The stroke subjects, when using the instrumented cane, were able to closely match their PE walking speed when using the cane in the VE. The control subject appears to show greater difficulty in using the cane as reflected by the corresponding lower gait speed in the VE cane condition.

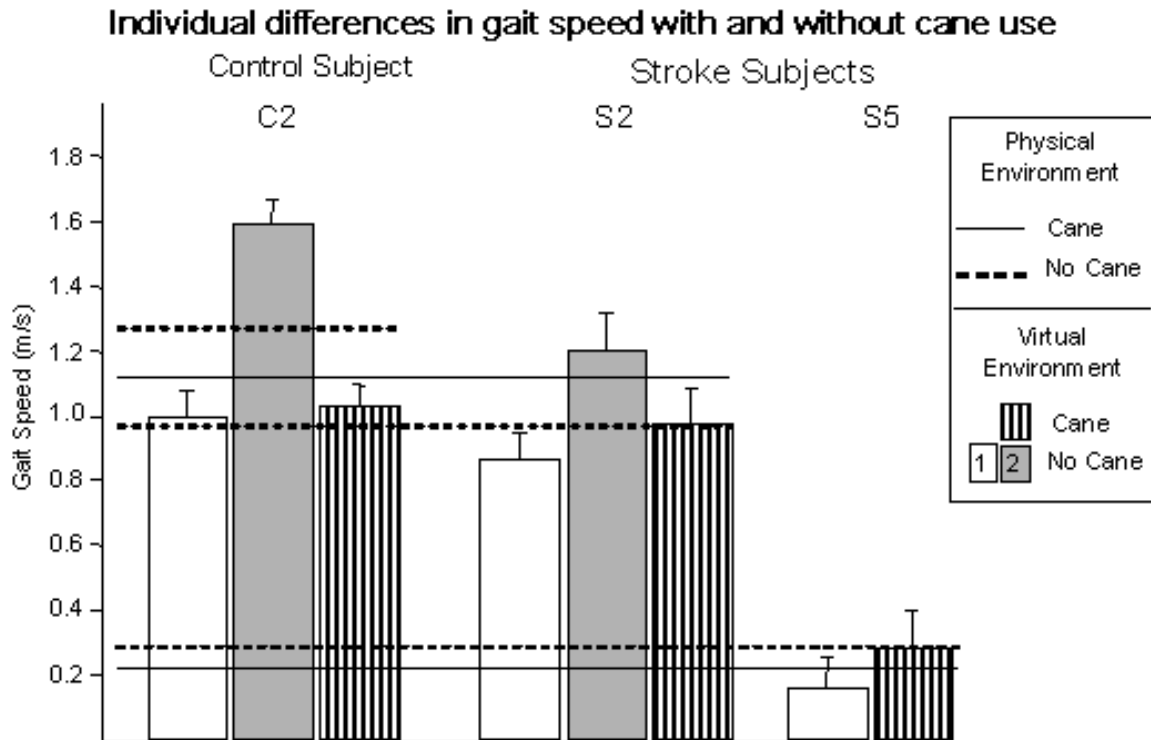


Figure 3-7: Gait speeds (m/s) with and without cane use for 1 control and 2 stroke subjects are shown. The bar graphs represent speeds in the virtual environment (VE) and horizontal lines represent the overground gait speeds in the physical environment (PE). S2, who no longer uses a cane, responds more like a healthy non-cane user, C2 than to S5 who continues to require a cane.

Mean gait variability for the stroke and control group is shown in Figure 3-8. As expected, gait variability quantified as % CVs of stride duration was higher in the stroke group regardless of walking condition. All subjects in the stroke or control groups show a significant decrease in stride duration variability in both limbs when using the instrumented cane. The reduction in variability ranged between 16 to 18% for the subjects with stroke; and 5 to 15% for the healthy controls.

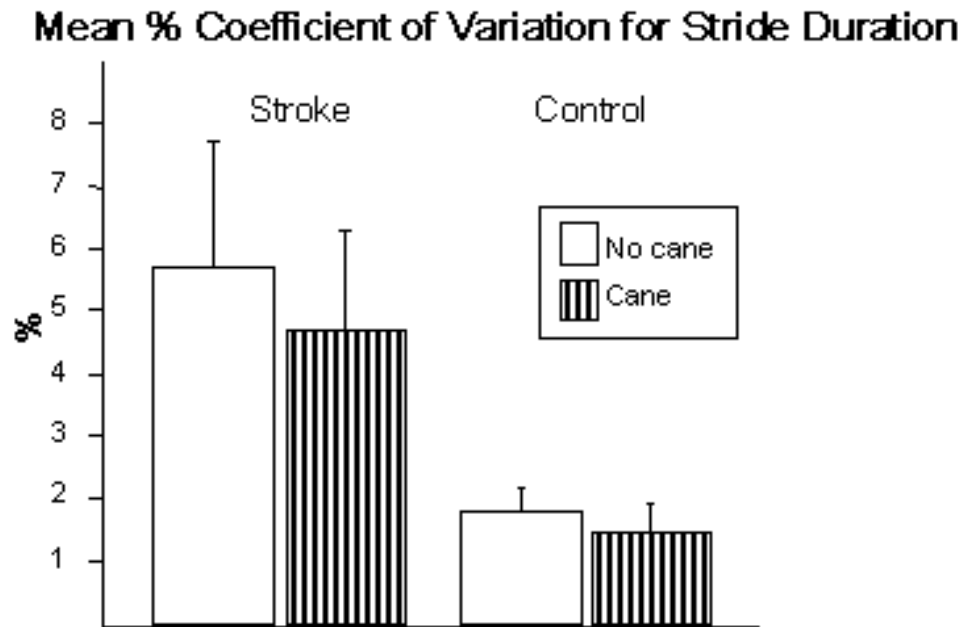


Figure 3-8: Gait variability, as shown by the mean % coefficient of variation (CV) for stride duration with its standard deviation, for stroke (hemi leg) and healthy subjects (left leg). The use of the treadmill cane reduced mean gait variability for both groups.

Step width for the stroke group was reduced by a mean of 9.9% when using the instrumented treadmill cane, as compared to the no cane condition (Figure 3-8) with all subjects demonstrating decreased step width. In controls, although an overall mean reduction of 9.6% also occurred with cane use, the responses were more varied and 2 subjects increased step width when using the cane.

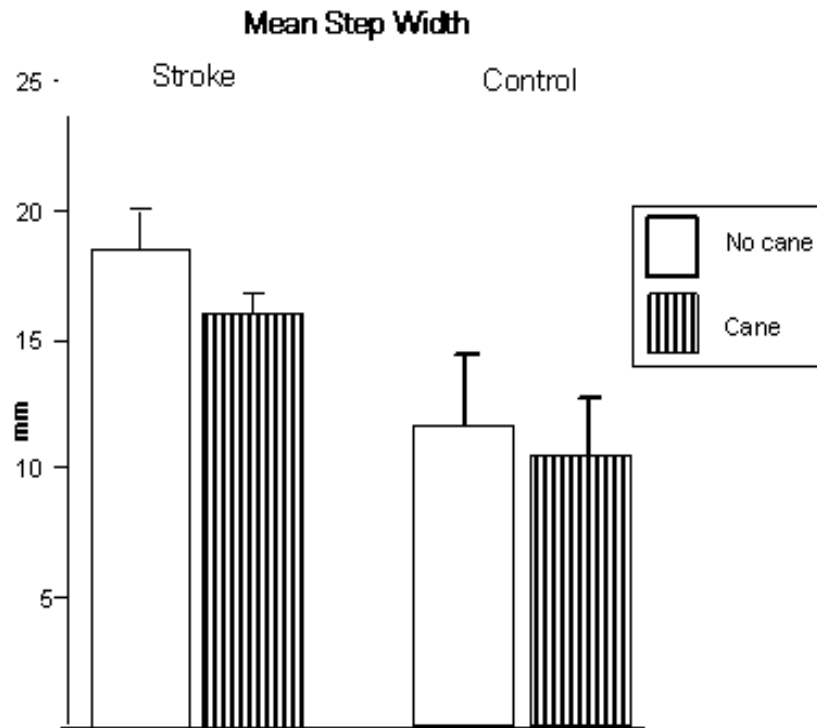


Figure 3-9: Mean step width and standard deviation measured in mm for stroke and control groups.

As expected, the peak and mean loading forces applied to the cane were higher in the stroke group compared to controls (stroke: mean F_z $64.75 \pm 32.32 = 7.82\% BW \pm 3.39$; controls: mean F_z $23.54 \pm 14.01 = 3.1\% BW \pm 1.70$).

Moreover, distinct differences were seen among the study subjects who normally used canes and those who did not. Figure 3-10 shows the cane forces calculated for the same three subjects as shown for gait speed (one lower vs. one higher functioning subject with stroke and one control). The peak force exerted on the cane coincided with the stance phase of the more involved limb for the lower functioning stroke individual who normally required a cane to walk,

due to greater gait and balance dysfunction. The peak force and force pattern in the higher functioning stroke individual, who did not use a cane, was more similar to that found in the control subject.

Subjectively, all participants found walking with the treadmill cane to be “easy” according to the VAS questions (with a rating (mean $\pm$ SD) of 1.5/10.0 $\pm$ 1.1 for stroke; 0.8/10.0 $\pm$ 0.4 for controls). With regards to the focus of attention, all subjects perceived that more attention was directed towards walking than cane use, but interestingly, the perceived attention to cane use was higher in healthy controls (2.5/10.0 $\pm$ 2.1) than stroke participants (2.0/10.0 $\pm$ 1.6).

3.6.6 Discussion

The purpose of this paper was to introduce a novel cane device specifically developed and designed for use with an existing treadmill-based immersive VE locomotor system. The overall concept was to add to the realism of the VE by making the walking activity more natural and similar to overground walking with a cane. The cane device, together with the motion platform, self-paced treadmill and VE, created a more ecologically valid locomotion system which can be used as a tool for both clinical and research purposes.

Individual Differences in Forces Exerted on Cane

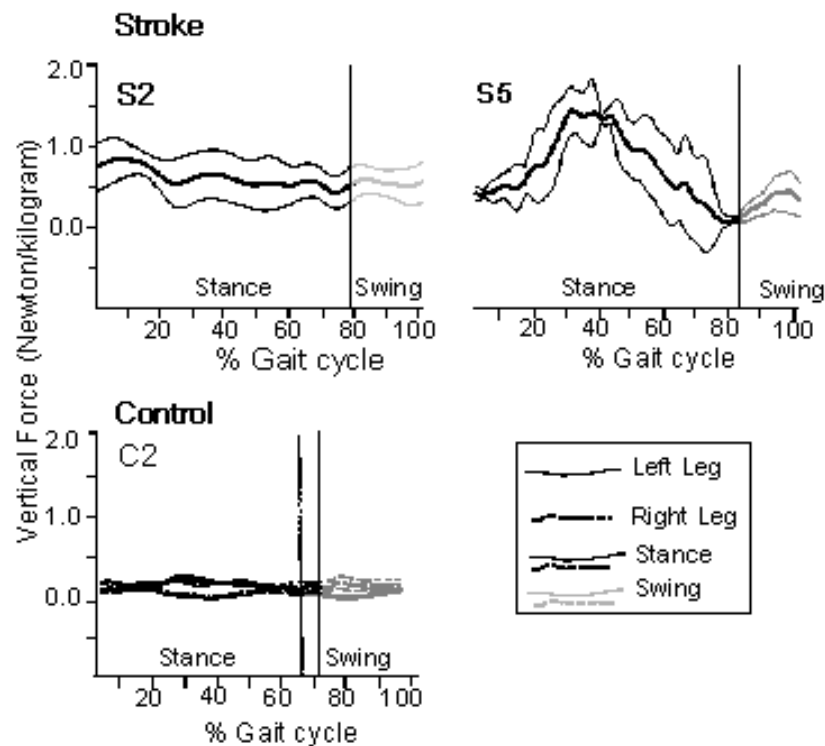


Figure 3-10: Mean vertical loading forces (mean $\pm$ sd, thick and dashed traces, respectively) exerted on the instrumented cane (Newton) across the normalized gait cycle. The upper graphs represent data from a higher functioning (S2) and a lower functioning subject (S5) (affected limb only). The lower graph shows cane forces from a healthy control (C2) left limb. Vertical lines depict stance-swing transition.

Training gait with the cane device on a self-paced treadmill and immersed in a VE would allow patients to practice a variety of real-life walking skills safely (i.e. crossing streets, manoeuvring inclined surfaces, negotiating around or avoiding obstacles, walking and shopping, etc.) while offering therapists precise control over condition complexity and difficulty such as would be impossible overground

with conventional therapy. The patients can walk with an aid similar to that which they would eventually use overground (a cane) and therefore training would be more skill-specific. The balance control required for cane use as well as the motor control necessary to stabilize the cane would be promoted and practiced with greater repetition. Additionally, the sensorimotor integration involved in coordinating cane use with the gait cycle (i.e. timing and loading patterns) could be developed more intrinsically during the intense training possible with treadmill walking. The instrumentation of the cane provides valuable information to the therapist concerning the amount of support a patient uses while walking. Based on this knowledge, clinicians could better evaluate and train cane use. Precise recommendations with respect to the amount of force to apply on the cane could be made through real-time (immediate) feedback as the patient walks on the self-paced treadmill. This augmented feedback may facilitate more effective overground cane use. Patients may learn that only light support through the cane is required in order to improve gait performance and safety as well as enhance self-efficacy.

The improvements in gait (higher gait speeds, lower gait variability, and reduced step width) observed when the individuals with stroke walked with the instrumented cane on a treadmill as compared to walking without a cane, are

consistent with gait changes seen during overground walking with a cane.⁶⁴⁻⁶⁸

Moreover, as expected, it appears that lower-functioning ambulators with stroke (or anyone who normally uses a cane) may benefit more from the instrumented cane than higher functioning individuals who do not need a cane. The timing of the peak vertical forces, coinciding with the stance phase for the affected limb, is consistent with other studies examining cane forces used in people with stroke.⁶⁸ This further demonstrates the similarity in function between the instrumented cane on a self-paced treadmill and a regular cane for walking overground.

Using the instrumented cane was perceived to be easy for both stroke and control subjects. It is important to note that no explicit instructions for using the cane were provided to the subjects and therefore the use was intuitive and the gait changes occurred naturally. An interesting observation is that the control subjects rated a relatively higher level of attention shifted to the cane as compared to the subjects with stroke. This might be due to the fact that cane walking was a novel task for the healthy controls, and as such, increased attention was necessary for skill acquisition, especially in what could be considered a dual task activity.

3.6.7 Conclusion

This study demonstrates the successful development and feasibility of an instrumented cane to be used on a self-paced treadmill. To our knowledge, this is the first instrumented cane to be used in conjunction with a VR and treadmill-based locomotor system. It is suggested that treadmill gait training with the instrumented cane could transfer to overground walking with a cane. Further studies are required to explore this possibility and address clinical intervention issues related to using the instrumented treadmill cane.

3.6.8 Acknowledgments

The authors would like to thank all study participants. We acknowledge the technical assistance of C. Beaudoin and Y. Bayat in the creation and programming of the virtual scenes, as well as G. Lepkyj for cane instrumentation. We also gratefully acknowledge the expert assistance of V. Goussev, L. Hughey, R. Kizony and A. Oates for their contributions to the study. This study was funded in part by a (CIHR) team grant in Multi-disciplinary Locomotor Rehabilitation. C. Perez is a recipient of a studentship award from the Fonds de la recherche en santé de Québec (FRSQ).

CHAPTER 4: RESULTS

“The touching effects of enhanced sensory input (haptics and canes) on post-stroke gait”

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Prepared for submission to Archives of Physical Medicine and Rehabilitation

4.1 Abstract

Objectives: To examine the effects of enhanced somatosensory input in the form of light fingertip touch and cane use on gait performance during level and slope walking.

Design: Quasi-experimental, mixed design: Subjects (Group) x Touch x Slope Conditions

Setting: Rehabilitation center research laboratory

Participants: Nine post-stroke and 9 healthy individuals

Interventions: Level and slope walking (5° up and 5° down) on a self-paced treadmill immersed in a virtual environment while 1. not touching anything (No touch), 2. lightly touching a horizontal sensor bar with a fingertip (Light touch) and 3. using an instrumented cane (Cane).

Main Outcome Measures: Gait variability as measured by the percentage coefficient of variation of stride duration (% CV), step width and gait speed.

Results: A significant decrease in gait variability (% CV in stride duration $p < 0.01$) and reduction in step width ($p < 0.005$) were seen in people post-stroke walking

with either light touch or cane use as compared to no touch. These same gait improvements were not evident in the healthy group.

Conclusions: Beneficial effects on gait post-stroke are observed with the use of additional somatosensory information. Light touch can be as effective as a cane even under the challenge of slope walking. Under various walking conditions (level, up and downslope), different stabilizing strategies afforded by additional somatosensory input (via light touch or cane use) may induce specific gait improvements. These findings may impact the way clinicians view and train cane use for people with balance difficulties post-stroke who may not require mechanical support but would benefit from the enhanced sensory input provided simply via a cane or light touch.

Key Words: Light Touch, Slope Walking, Walking Aid, Virtual Environment, Cerebrovascular Accident, Rehabilitation

Abbreviations	CVA -	Cerebrovascular accident
	CV -	Coefficient of variation
	SW -	Step width
	GS -	Gait speed
	NT -	No touch
	LT -	Light touch
	C -	Cane use
	VAS -	Visual analogue scale

4.2 Introduction

Over 70% of stroke survivors live with permanent sequelae, including physical, mental, sensori-perceptual and language impairments, which lead to significant lifelong activity limitations and participation restrictions.³ The inability to walk is one of the more devastating consequences of stroke and regaining ambulatory independence is the most common rehabilitation goal expressed by stroke patients.⁶ Correspondingly, gait training is the most common therapeutic intervention provided by physical therapists. A major gait dysfunction encountered in both older and post-stroke populations and targeted during rehabilitation is the difficulty in overcoming environmental barriers such as surface changes, slopes and obstacles.^{17, 19} In walking tasks that are more challenging such as slope walking, the sensorimotor demands are increased and necessitate specific modifications i.e. changes in gait pattern and rapid postural adjustments.^{24, 39} Older individuals and people post-stroke lack this flexibility in walking ability and therefore cannot readily adapt to the increased task demands. To help compensate for this and other gait difficulties, canes are frequently used during training and prescribed as a long term mobility aid. There is growing evidence to suggest that a particular feature of canes, providing tactile feedback, may play a vital role in stabilizing gait in populations with general balance problems^{73, 76, 93} including older individuals and people with stroke. The sensory

feedback related to body position may serve to compensate for sensorimotor impairments affecting balance control and help cane users achieve independent ambulation and reduce fall risk.

The term haptics refers to the sense of touch and is usually applied to the hand/fingers ability to explore, detect and perceive specific environmental features. Haptic touch has emerged as a novel and efficient technique to improve postural control and dynamic stability in humans.^{77-83, 85, 86} It has been theorized that haptic cues serve as a reference source for postural orientation and that they act similarly to visual and vestibular inputs to “anchor” the body position with respect to the environment.⁷⁶ Results from these studies have demonstrated that even a very light finger-tip contact with an external rigid object (whereby mechanical support is not possible) can reduce postural sway in stance.

Most of the research into the use of haptics for stabilizing postural control has been done in standing positions with or without laboratory induced perturbations. There have been, however, 2 studies which explore the use of light touch for postural control (center of mass displacement) in gait^{91,92} and point to the potential benefit of haptics for enhancing gait post-stroke. A recent study,⁹³ has

demonstrated that light touch through a cane while walking overground can improve pelvic stability in people post-stroke. None of these studies, however, have clearly established that gait performance in people post-stroke is improved with the use of light touch. The goal of this study, therefore, was to examine the effects of enhanced somatosensory input in the form of 1) light fingertip touch and 2) cane use on gait performance during level and slope walking in people post-stroke.

4.3 Methods

Subjects

A convenience sample of 9 people with a cerebrovascular accident (CVA) and 9 healthy controls participated in this study. Inclusion criteria for the stroke group included people with a single, uni-hemispheric cerebral lesion, independent ambulation without a walking aid for a minimum of 40m and persisting gait difficulties (describe more). Additionally, subjects were excluded if they (1) were greater than 80 years old secondary to the greater potential of peripheral sensory nerve impairment and (2) had language, cognitive or perceptual impairments affecting their ability to understand and follow instructions. Subjects with impaired light touch sensation of the non-paretic (stroke group) or dominant (healthy group) fingertips and/or hand were excluded from the study.

Protocol

All participants signed an informed consent form approved by the institutional ethics review board of the Montreal Centre for Interdisciplinary Research in Rehabilitation (CRIR). The experimental protocol involved three walking surface conditions including level, up-slope (5°) and down-slope (5°) and three touch conditions including no touch (NT), light touch (LT) and cane use (C). The presentation order of the walking conditions was randomized between 2 baseline trials (NT level walking). Rests were provided as necessary during both the habituation and the experimental phases. Habituation to walking on the treadmill without support, using light fingertip touch and using the cane, as well as walking on inclined surfaces and viewing the VE scene were all performed prior to data collection. During habituation to the LT condition, real-time feedback of the loading pressure on the haptic strip was used to train the subject to apply a fingertip contact force of less than 4N while walking. No other specific training or instructions were provided.

Instrumentation and Measures

An advanced locomotor system which combines the use of virtual reality (VR) with a self-paced treadmill mounted on a motion platform was used.⁵⁶ The motorized treadmill is servo-controlled by the output of an electropotentiometer

which is tethered to the walking person, such that the walking speed can be adjusted instantaneously and voluntarily. The system includes a VR scene which is rear-projected onto a large screen placed in front of the treadmill. A special software, Computer Assisted Rehabilitation ENvironment (CAREN),¹⁰⁶ controlled and synchronized the instantaneous treadmill speed with the VR scene progression and the platform movement. The VR scene designed for this project was that of a 40-meter, clearly delineated outdoor walking path set amidst grass and trees. A virtual environment (VE) was hence created in which subjects would be able to control their own walking speed, have correspondingly appropriate visual (optic flow) and proprioceptive (platform movement) input and thereby interact more naturally in a more “real world” laboratory set-up. Forty-two reflective markers were positioned on body landmarks according to the Plug-in-Gait model of the Vicon motion analysis system. Kinematic data were acquired at 120 Hz using a 6-camera Vicon MX motion analysis system (Oxfordmetrics, UK).¹⁰²

The parameters under study were gait variability as measured by the percentage coefficient of variation in stride duration (% CV), step width and gait speed. To calculate stride-to-stride variability, the kinematic data were batch-processed with a customized computer script in Matlab (Mathworks Inc., USA) to determine the

gait events of initial foot contact and foot-off for each limb, based on the sagittal plane foot trajectory. Measures of gait variability have been found to be more sensitive than direct gait measures such as gait speed and therefore provide more precise indices of walking performance.^{99,100} Less variability in a gait parameter such as stride duration would indicate a more rhythmic and stable gait. It is suggested that measures of variability may also reflect qualitative aspects of gait otherwise overlooked by measuring gait speed alone. Stride duration was defined as the time taken between 2 consecutive initial foot contacts of the same limb (one gait cycle). The % CV was computed as a percentage of the standard deviation of stride or cycle duration over the mean.

Step width was defined as the distance (cm) between the left and right limb heel marker distance when in the double support phase of gait. Step width is often related to dynamic stability in the frontal plane such that decreases in width represent greater balance stability and improved postural control. The overground gait speed was measured with the 10-meter walk test, whereas gait speed within the VE was calculated using the instantaneous treadmill speed output from the motor as recorded by the CAREN software. The gait cycles occurring in the middle 20 meters of level walking and during the 20 meters of slope walking were retained for analysis.

Both the haptic strip and the cane were specifically designed for this study. A load sensor was embedded into the haptic strip while the cane was affixed to a ball joint and instrumented with a tri-axial force transducer (Figure 4-1) The development and feasibility of the cane device has previously been described¹²² and was added to the study paradigm to enhance the realism and ecological validity of the VE. Both haptic strip and cane could be attached to either side of the treadmill and were adjustable to height as required. The analog 3D force data from the instrumented cane were sampled at 1200 Hz. The haptic strip load sensor data were converted to force (N). All force values were then expressed as a proportion of the body mass of the individual (% body weight).

Visual analog scales (VAS) were also developed to measure subjects' individual perception of ease or difficulty associated with the assistive devices (haptic strip and cane) and their rating of attention directed toward using the devices relative to walking. For the first point, perception of the handling of the haptic strip and cane were rated separately on 10 cm lines which ranged from "easy" (0 cm) to "difficult" (10 cm). For the second point assessing divided attention, subjects rated on separate VAS (concerning haptic strip or cane use) their relative attention directed towards "walking" (0 cm) or handling the device (10 cm). Subjects placed a vertical mark on a continuous 10-cm line for each question

with prior responses blocked from view. The distance was then measured and converted to a percentage score. Higher scores indicated greater difficulty or greater amount of attention towards using the device.

(A)



(B)



Figure 4-1: Instrumented devices used in the study. (A) Haptic strip embedded with load sensor placed at fingertip height. (B) Instrumented cane device with ball joint base affixed to left side of the self-paced treadmill.

Data Analysis

Descriptive statistics were used for demographic and baseline characteristics (overground gait speed, ABC scores). Independent sample Student's t-tests evaluated the differences in characteristics and subjective perceptions between groups. The loading force data (haptic strip and cane) were also examined with

descriptive statistics. All dependant variables were compared across the 3 touch (NT, LT and C) and 3 walking surface (level, up-slope and down-slope) conditions and between the 2 groups (stroke vs. healthy) using a 3-way, repeated measures analysis of variance (ANOVA). For the purpose of analysis, data from the paretic limb for the post-stroke group was compared to the left limb of the healthy group. Two-way ANOVA were performed on the VAS percentage scores to determine the main effects of group and somatosensory device (LT vs. C) for the subjective perception of difficulty and attention. Posthoc pairwise comparisons with Tukey tests were conducted to identify the differences if the ANOVAs resulted in significant main or interaction effects ($p < 0.05$).

Excel and Statistica software (version 9) were used to perform statistical analyses.

4.4 Results

Participant characteristics are summarized in Table 4-1. With a mean overground gait speed of $0.89 \pm .2$ m/s, the post-stroke group would be classified as 'full' community ambulators (> 0.8 m/s) according to the criterion set by Perry¹⁶, however, the significantly lower ABC scores ($p = .01$) in the post-stroke (75.7 ± 15) compared to the healthy group (96.6 ± 3) clearly reflects a high level of fear of falling associated with mobility.

ANOVA results for the % CV of stride duration revealed main effects due to group ($p=.0003$), walking surface condition ($p=.007$) as well as an interaction effect between walking surface and touch conditions ($p=.02$). Post-hoc Tukey tests identified a significant difference ($p=.007$) between the NT and LT conditions during down-slope walking in the stroke group.

Table 4-1: Characteristics of the Post-CVA and Healthy Participants.

		Age (Yrs)	Gender (M/F)	Lesion Side (R/L)	Touch Side (R/L)	Cane Use (Y/N)	Overground Gait Speed (m/s)	ABC Score (%)
Post-CVA	S1	61	M	R	L	Y	0.62	67.8
	S2	72	M	L	R	Y	1.05	97.8
	S3	63	M	R	L	Outdoors	0.80	83.3
	S4	70	M	L	R	N	1.02	74.1
	S5	54	M	L	R	N	1.31	95.0
	S6	61	F	L	R	N	1.22	92.2
	S7	69	M	L	R	N	0.83	65.6
	S8	70	F	R	L	Y	0.59	40.0
	S9	68	F	L	R	N	0.59	65.6
Healthy		65 (5)	67% M	67% L	67% R	56% N	0.89 (.2)	75.7 (15)
	C1	68	M	-	L	N	1.30	96.8
	C2	70	M	-	L	N	n/a	98.8
	C3	68	F	-	R	N	n/a	97.1
	C4	63	F	-	R	N	1.27	99.4
	C5	77	F	-	R	N	1.22	89.1
	C6	61	F	-	R	N	1.25	99.4
	C7	64	M	-	L	N	1.25	92.4
	C8	68	M	-	R	N	1.30	98.5
	C9	57	F	-	R	N	1.16	98.1
		66 (4)	55% F	-	67% R	N	1.25 (.03)	96.6 (3)

Figure 4-2 provides details of % CV results for the 2 groups under all touch and walking surface conditions. In level walking, there was a trend toward % CV reduction under touch (LT and C) conditions, as compared to NT ($p=0.65$ and 0.62 , respectively). A higher level of performance variability was evident in the stroke group compared to the healthy group across all conditions.

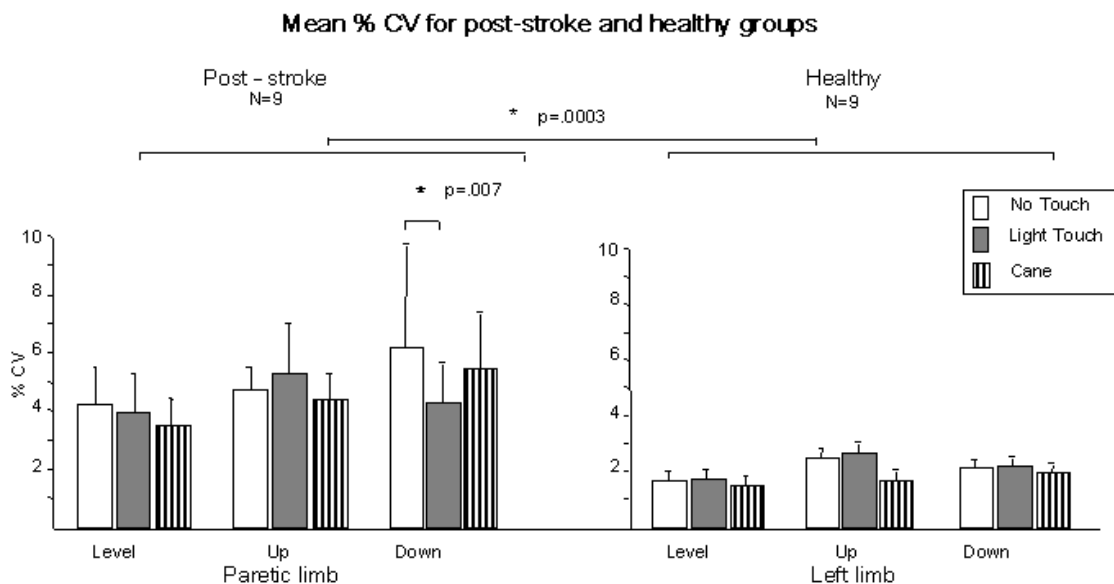


Figure 4-2: Mean % CV for stride duration and standard deviation for all conditions in Post-CVA (paretic limb) and Healthy (left limb) groups. % CV is greater in Post-CVA compared to Healthy group regardless of condition.

The results for step width are shown in Figure 4-3. A main effect due to group ($p=.009$) was found along with a main effect due to touch ($p=.00003$). Further examination with Tukey tests revealed that the step width for people in the post-stroke group in both LT ($p=.002$) and C ($p=.0001$) conditions were significantly reduced compared to the NT condition.

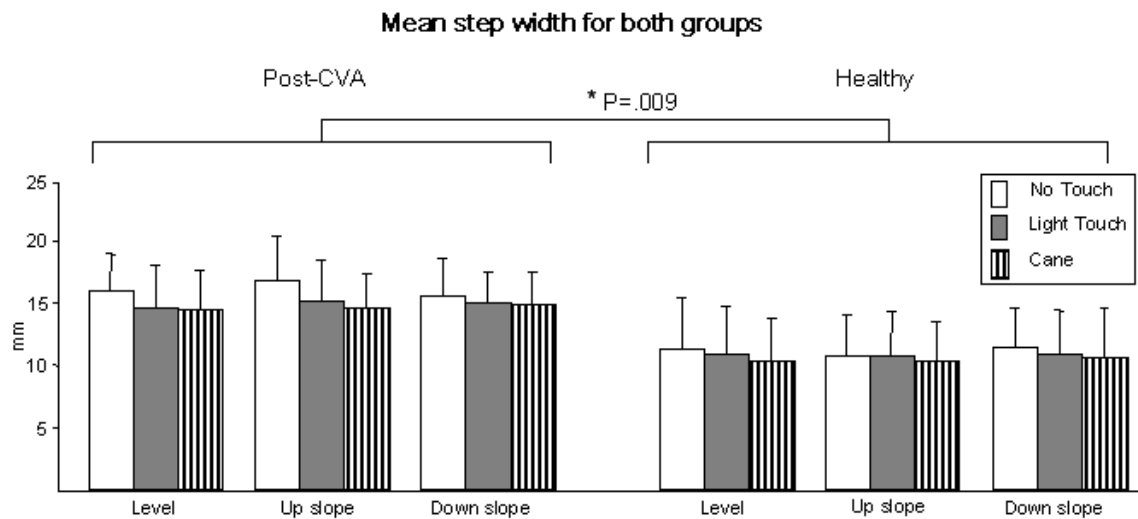


Figure 4-3: Mean Step Width and standard deviations in Post-CVA and Healthy groups. Mean reduction of step width in Post-CVA group was 8% (Level), 9% (Up-slope) and 3% (Down-slope) using LT and 9% (Level), 14% (Up-slope) and 4% (Down-slope) using cane (C) vs. NT conditions.

Figure 4-4 illustrates the results for gait speed. As expected, a main effect of group ($p=.0005$) was also discovered for gait speed.

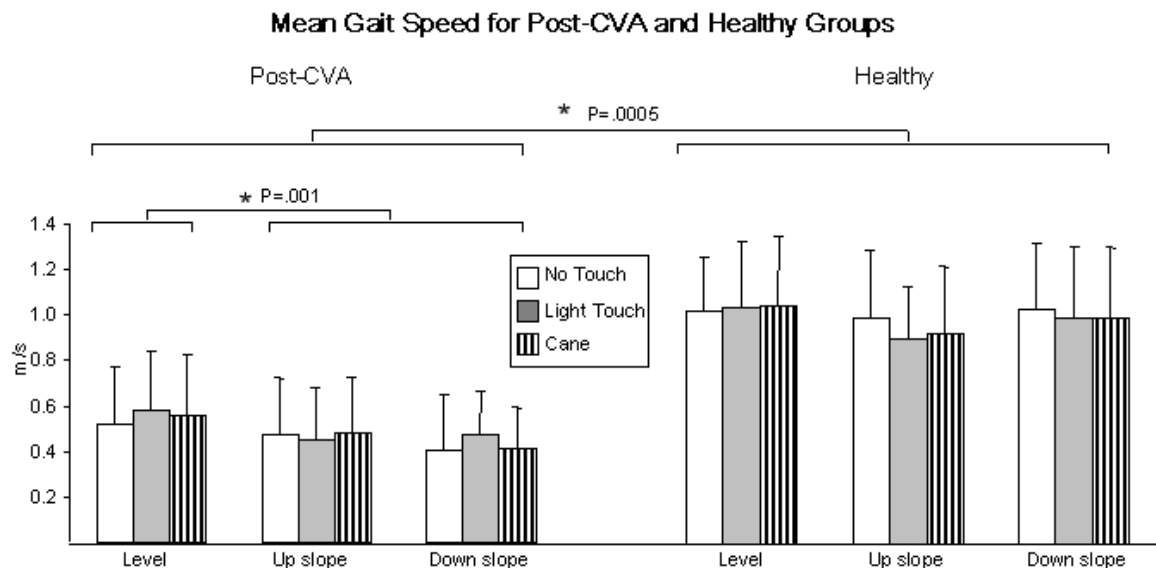


Figure 4-4. Comparison of mean gait speed and standard deviations in both groups for the 3 walking conditions. During the more challenging tasks of either up- or down- slope walking, gait speed was decreased compared to the level surface regardless of touch condition. Interestingly, the lowest gait speeds in each group were obtained under different walking surface conditions (down-slope for the post-stroke and up-slope for the healthy group).

A main effect of walking surface condition ($p=.001$) was also seen, such that the speed of walking on the level surface was significantly greater compared to both up-slope ($p=.002$) and down-slope ($p=.009$) walking for both groups regardless of touch conditions.

The mean loading forces applied on the cane (normalized to % body weight) are shown in Figure 4-6. In the post-stroke group, the loading forces on the cane tended to be highest in up-slope walking and lowest in level walking. The opposite tendencies were seen in the healthy group where the level surface walking condition elicited the highest forces on the cane whereas the lowest forces were seen during up-slope walking. The overall mean loading forces on the cane was 4.9% ($\pm .29$) for the post-stroke group and 2.75% ($\pm .7$) for the healthy group. The mean load exerted on the haptic strip was below 1% body weight in both groups.

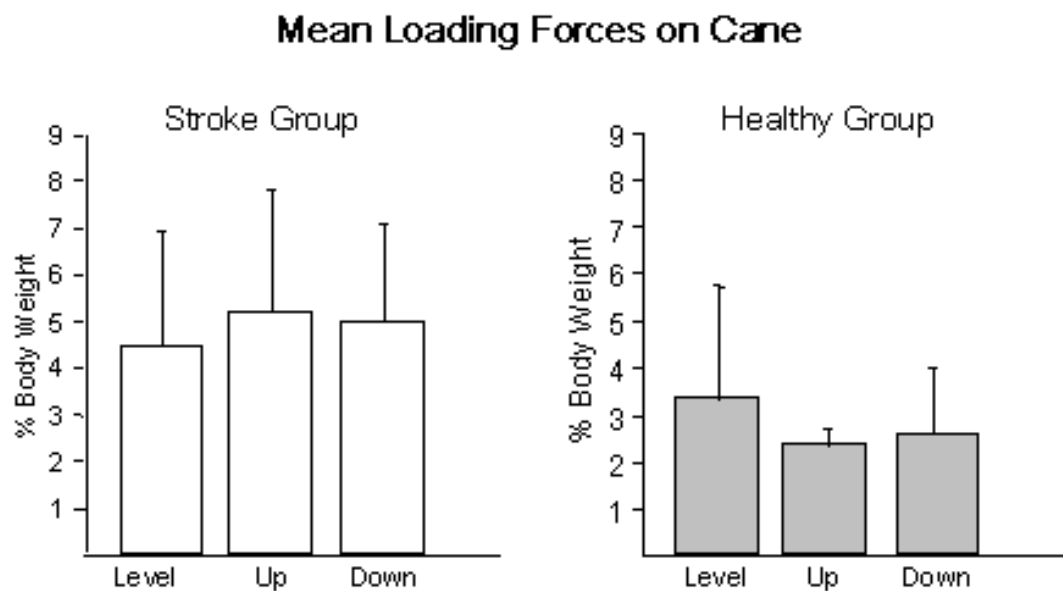


Figure 4-5. Comparison of mean loading forces on the cane (normalized to % body weight) in the 3 walking surface conditions between post-CVA and healthy groups.

Overall results from the VAS measures reveal that both post-stroke and healthy individuals rated the use of the instrumented haptic strip and cane as relatively “easy” (with a mean score across groups = 17.7% ± 6.0). Figure 4-6 compares the percentage scores for both groups as well as the ANOVA results. As can be seen, there were significant differences between groups for the 2 key issues of difficulty and attentional level. Interestingly, the healthy group rated a significantly higher degree of attention required to handle either the somatosensory cue (light touch or cane) compared to the post-stroke group.

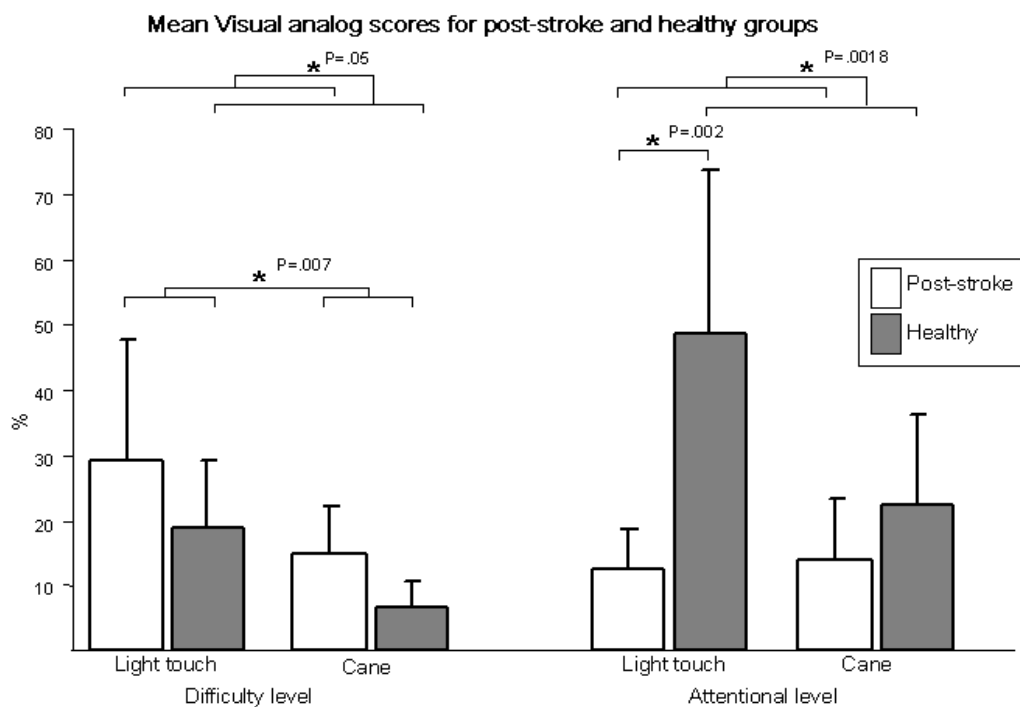


Figure 4-6: Results from visual analog scales (mean percentage scores) for both groups rating the difficulty level associated with using the haptic strip and cane (left side of graph); and the attention directed toward using the haptic strip or cane versus attention directed toward walking.

4.5 Discussion

The aim of this study was to examine the effects of enhanced somatosensory input from (1) light fingertip touch and (2) cane use on gait performance during level and slope walking in people post-stroke. The results indicate that gait improvements occur with the use of somatosensory input. A statistically significant decrease in gait variability (% CV in stride duration) and reduction in step width were seen in people post-stroke when additional touch input is present. Additionally, a tendency toward increased gait speed occurred when using one or both sources of touch input. These same gait changes were not evident in the healthy group.

The maximum mean gait improvement with the use of a light touch cue in the post-stroke group was an 18% reduction for the % CV of stride duration (during down-slope walking) and a 9% decrease for step width (during up-slope walking). When using the instrumented cane, a maximum reduction of 15% in the % CV of stride duration occurred during level walking and a 13% decrease in step width occurred during up-slope walking. These findings suggest that light touch can be more effective than cane use in reducing the variability in stride duration (% CV) under the specific task of down-slope walking. In up-slope walking, cane use was slightly more effective than light touch in reducing step width. This is

consistent with the different sensorimotor and biomechanical constraints required for up- and down-slope walking thereby resulting in different responses to sensory inputs. Under various walking conditions (level, up- and down-slope), different stabilizing strategies (use of either light touch or a cane) may offer specific gait improvements.

The gait speed results are consistent with the idea that both up- and down-slope walking are more challenging tasks compared to level walking and therefore necessitate a reduction in speed to accommodate the increased demands in postural control. This was particularly evident for the post-stroke group. Interestingly, a tendency was seen in the post-stroke group for gait speed to increase when somatosensory input (either light touch or cane use) was used across all the 3 walking conditions. Although this was not a statistically significant finding, it may still represent clinically important changes in gait speed for the post-stroke individuals. This same trend was not seen in the healthy group.

The mean loading forces on the cane (% body weight) found in this study ($< 5\%$) were considerably smaller than those previously reported in people post-stroke by both Tyson⁷⁰ (13-15%) and Chen⁶⁸ (13%). This can be explained by differences

in experimental conditions. This study used treadmill-based walking as opposed to overground walking and therefore a specialized treadmill-cane was required. The degree to which using the instrumented treadmill cane can be compared to using an overground cane is not yet established. Therefore the reported loads on the cane in this study must be viewed as specific to our paradigm and cannot be compared to those from an overground cane at this time. It is also acknowledged that only the loading and not the shear forces on the cane were examined in this study. Although the shear forces (both propulsive and braking) probably play an important role particularly in incline walking, analysing these forces on the cane was beyond the scope of this study. Further work and advanced analysis of all the forces applied on the treadmill cane and their covariance with posture and gait parameters is presently underway.

The mean loading forces on the haptic strip were less than 1% body weight, which would indicate a successful ability by all the participants to apply only a light fingertip touch insufficient for providing mechanical support. This validates the haptic strip set-up and the idea that light touch alone is sufficient to elicit gait improvements. As discussed above, distinct gait changes occurred in the post-stroke group when using a light contact cue (decreased variability in stride

duration and decreased step width) with the amount of improvement dependent on the walking surface condition (level, up- and down-slope).

Using either somatosensory cue (haptic strip or cane) was perceived to be easy for both the post-stroke and healthy subjects. It is not unexpected that overall the cane was found to be easier to use than the haptic strip, but it is remarkable that using the haptic strip was not perceived to be significantly more difficult than using the cane in the post-stroke group. This is a positive finding as this haptic device will be used in future studies for gait training. Another interesting observation was that the healthy individuals rated a relatively greater level of attention shifted to using either the haptic strip or the cane during walking as compared to stroke individuals. This might be due to the fact that using assistive devices (regardless of haptic strip or cane) is a novel task for the healthy controls, and as such, increased attention was necessary for skill acquisition, especially in what could be considered a dual task activity. On the other hand, this may also be viewed in terms of the attention directed toward walking. The healthy group may have considered walking totally automatic with little or no attentional requirement and therefore pay extra attention toward using a device (a novel task). People post-stroke generally pay attention to their walking (often with a conscious awareness and focus which has been “trained” during

rehabilitation). This may have influenced their perception of the relative amount of attention devoted to walking or using a device.

Care must be taken in generalizing the findings from this study to the post-stroke population. The small sample size and 'higher' level post-stroke walkers (mean GS = 0.89 m/s) present in this study may have produced either an over or under estimation of effects, the specifics of which as reported may not apply to all people post-stroke.

4.6 Conclusions and Clinical Implications

Beneficial effects on gait post-stroke are observed when additional somato-sensory information in the form of a light fingertip touch or a cane is used. Light touch may be more effective in down-slope walking (reducing gait variability in stride duration) whereas both light touch and cane use are effective in up-slope walking (reducing step width).

Based on the findings of this study, greater evidence is established for some common clinical observations and recommendations related to walking with the use of either light touch or a cane. It is clear now that light touch input alone without any mechanical support can produce 'real' gait improvements in people

with stroke. Touch contact from a therapist, handrail, wall, cane or other can induce more than only a 'confidence boost' in walking performance. This finding may also impact the way clinicians view and train cane use for those people with balance difficulties who may not require mechanical support but would benefit from the enhanced sensory input a cane can provide. A different type of sensory or haptic cane may be devised for this population whereby longer ground contact time is facilitated. Further research to explore these and other possible clinical implications for the use of touch input to improve gait post-stroke is required.

4.7 Acknowledgments

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Chapter 5: DISCUSSION AND CONCLUSION

5.1 Summary

The main hypothesis proposed with this study in Chapter 1 was that the use of enhanced somatosensory input in the form of 1) light fingertip touch on a horizontal sensor strip and 2) use of an instrumented treadmill cane would improve gait performance in level and slope walking in people post stroke. It was additionally hypothesized that the beneficial effects from the two sources of sensory cues would be greater in down slope versus up slope walking. The results as presented in Chapter 4 indicate that the main hypothesis is completely accepted and the second hypothesis is partially supported.

A significant decrease in gait variability (measured by the % CV in stride time) and reduction in step width were seen in people post-stroke when additional touch input is present (either light fingertip touch or a cane) during slope walking. This clearly represents an improvement in a challenging gait activity for the post-stroke group thereby supporting the first hypothesis. Similar gait changes were not evident in the healthy group.

Differences in the effect of the additional touch input during up and downslope walking were apparent as well as between level and slope walking in general. In

people post-stroke, light touch was more effective in downslope walking by reducing gait variability in stride duration whereas both light touch and cane use were effective in upslope walking by reducing step width. This suggests that the second hypothesis regarding a greater effect of enhanced sensory cues during down slope walking versus up slope walking is conditionally supported. It appears that different gait parameters can be preferentially improved with the touch cues in the different tasks of up and down slope walking. During the specific task of downslope walking, gait variability as measured by the % CV of stride duration was reduced by 18% with the use of light touch in the post-stroke group. Compared to either of the secondary measures (SW or GS), this represented the greatest overall % improvement change thereby supporting the hypothesis. However, if only one measure is considered, for example, SW, the greater improvement in this variable (13%) occurred with use of the cane during upslope walking. These findings are consistent with the known different sensorimotor and biomechanical constraints required for up- and downslope walking thereby resulting in different responses to sensory inputs. Under various walking conditions (level, up and downslope), different stabilizing strategies (use of either light touch or a cane) may offer specific gait improvements.

5.2 Study limitations

This study used a newly created virtual environment with 2 instrumented devices (haptic strip and cane) in order to examine the effects of somatosensory input on gait in a stroke population. The study also represented the first time an instrumented treadmill cane was used. Therefore, we can not assume that this cane fully simulates natural cane use. Generalizations to overground cane use in natural walking environments should be made only with caution.

The sample size calculated for this work was based on an estimate of % CV variability from pilot data and corresponded to a large effect size. It is quite possible, however that the participants with stroke used for this calculation do not reflect the true variability of stride duration % CV's that exist in other people with stroke. In fact, the variability in % CV was found to be higher than anticipated. The small sample of 9 subjects post-stroke may not have been large enough to detect all significant differences for the main effect of touch regardless of walking condition.

Another potential limitation is the use of % CV as the primary dependent variable. The variable itself is dependent on the parameter mean as well as the standard deviation. This could have impacted our group comparisons as lower parameter

means can drive the CV's to appear higher. Gait speed is also known to have an influence on gait variability. The subjects with stroke in this study, as is typically found, walked slower than the healthy controls. Therefore, a greater number of gait strides in the post-stroke group contributed to the analysis of the dependant measures. Again, this may have exaggerated the between-group differences but not the within-group comparisons. It is also acknowledged that although a deliberate choice was made to focus on gait outcomes, other parameters, for example, CoM measures may have provided additional information.

It is clear that the subjects in this study do not represent the entire stroke population. Our target group were stroke subjects who were capable of walking without the use of a cane for a minimum of 40 m and short distances without cane. The ability to walk without aid was necessary as this was one of our comparison conditions. Inferences from the results of this study to stroke survivors with a full range of walking abilities (particularly lower level walkers) may be made only with caution. Additionally, although we do not believe stroke lesion side or gender influenced the findings, this can not be fully ruled out.

5.3 Significance and Clinical Implications

The work presented in this thesis contributes to 3 important areas: overall body of scientific knowledge, technical development and clinical implications for rehabilitation. Firstly, this study provides new information regarding the ability of additional somatosensory information acquired by a fingertip lightly touching a rigid bar or a hand holding a cane to enhance gait performance in people with post-stroke impairments. Additionally, greater insight is provided into the specific contribution of the sensory modality of touch (haptics) to postural control during gait, thus broadening our comprehension of sensorimotor integration. It clearly demonstrates the ability of people post-stroke to use different stabilizing strategies which induce specific gait improvements which are task-dependent. A new understanding of how canes are used may also be inferred. Finally, it is one of the few studies in people with stroke which examines the complex yet functional activity of walking up and down inclined surfaces.

In terms of technical development, this study involved the novelty of an instrumented cane device specifically designed for this work which has potential for both research and clinical use. We believe that this is the first instrumented cane for use with a treadmill and the research article presented in Chapter 3 serves as a proof-of-principle paper. Additionally, there may be potential for the haptic strip apparatus for use in gait training.

Several clinical implications from this work are apparent. The results as presented in Chapter 4 provide evidence for some common clinical observations and recommendations. For example, it has often been noted that patients with stroke (and other balance problems) demonstrate improvements in gait and postural control with minimal (fingertip) contact from a therapist or other person. Additionally, patients report increased ease and security walking when they slide their finger lightly along stable surfaces, furniture or walls. People post-stroke are also known to sometimes drag or minimally use their canes. Therapists often recommend maintaining at least a light touch on a handrail when going up or down stairs or a ramp. Previously, it may have been believed that only psychological factors were involved or that quicker responses would be elicited because of the close proximity for mechanical support. This study provides a scientific rationale to explain these observations and support making these recommendations by proving that real gait improvements are associated with the use of light touch. Furthermore, findings from the study support the use of other therapeutic approaches for gait training which employ the strategy of enhanced somatosensory input. Finally, clinicians may view canes in a new light particularly for people with balance problems. The clinical practice related to gait training with canes for this population may change as clinicians stress and

encourage the haptic input received from a cane over the more traditional mechanical support.

5.4 Future directions

We believe future work in many areas studied in this thesis is warranted. Firstly, a study to explore a gait training protocol for people post-stroke using haptic input and the VE described herein is already planned. Studies focusing on the development of different methods to clinically incorporate touch feedback into gait rehabilitation and training should also be considered. Research to determine if other neurological conditions can benefit from additional touch input would be a logical extension. Additionally, it is hoped that studies will examine the similarity and use of the treadmill cane compared to an overground cane in order to advance the cane's potential for clinical use. Finally, new technological devices which provide haptic information for gait rehabilitation or remediation (i.e. 'haptic' canes with advanced feedback capacity) may emerge.

Chapter 6 BIBLIOGRAPHY

1. The Canadian Stroke Network.
<<http://www.canadianstrokenetwork.ca/eng/about/aboutstroke.php>>.
Accessed 2008 January.
2. World Health Organization - International Classification of Functioning.
<<http://www.who.int/classifications/icf/site/index.cfm>>. Accessed 2008 February.
3. Mayo NE, Wood-Dauphinee S, Côté R, Durcan L, Calton J. Activity, Participation, and Quality of Life 6 Months Poststroke. *Arch Phys Med Rehabil* 2002;83:1039.
4. Bohannon R, Andrews A, Smith M. Rehabilitation goals of patients with hemiplegia. *Int J Rehabil Res* 1988;11(2):181-183.
5. Sullivan KJ, Mulroy S, Kautz SA. Walking recovery and rehabilitation after stroke. In: Stein J, Zorowitz R, Harvey R, Macko R, Winstein C, editors. *Stroke Recovery & Rehabilitation*. New York, NY: Demos Medical Publishing; 2009. p 323-342.
6. Lord SE, McPherson K, McNaughton HK, Rochester L, Weatherall M. Community ambulation after stroke: how important and obtainable is it and what measures appear predictive? *Arch Phys Med Rehabil* 2004;85(2):234-9.
7. Lord SE, Rochester L. Measurement of community ambulation after stroke: current status and future developments. *Stroke* 2005;36(7):1457-61.
8. Lord S, McPherson KM, McNaughton HK, Rochester L, Weatherall M. How feasible is the attainment of community ambulation after stroke? A pilot randomized controlled trial to evaluate community-based physiotherapy in subacute stroke. *Clin Rehabil* 2008;22(3):215-25.
9. Jorgensen H, Nakayama H, Raaschou H, Olsen T. Recovery of walking function in stroke patients: The Copenhagen stroke study. *Arch Phys Med Rehabil* 1995;76:27-32.

10. Ada L, Dean C, Hall J, Bampton J, Crompton S. A treadmill and overground walking program improves walking in persons residing in the community after stroke: A placebo controlled, randomized trial. *Arch Phys Med Rehabil* 2003;84:1486 – 1491.
11. Rochette A, Desrosiers J, Noreau L. Association between personal and environmental factors and the occurrence of handicap situations following a stroke. *Disabil Rehabil* 2001;23(13):559-69.
12. Teasell R, Bhogal, S., Foley, N., Speechley, M. Gait Retraining Post Stroke. *Top Stroke Rehabil* 2003;10(2):34.
13. Manning CD, Pomeroy VM. Effectiveness of Treadmill Retraining on Gait of Hemiparetic Stroke Patients. *Physiotherapy Canada* 2003;89(6):337-349.
14. Woolley SM. Characteristics of gait in hemiplegia. *Top Stroke Rehabil* 2001;7(4):1-18.
15. Baer G. The recovery of walking ability and subclassification of stroke. *Physiotherapy Research International* 2001;6(3):135-144.
16. Perry J, Garrett M, Gronley JK, Mulroy SJ. Classification of walking handicap in the stroke population. *Stroke* 1995;26(6):982-9.
17. Gerin-Lajoie M, Richards CL, McFadyen BJ. The circumvention of obstacles during walking in different environmental contexts: a comparison between older and younger adults. *Gait Posture* 2006;24(3):364-9.
18. Donovan K, Lord SE, McNaughton HK, Weatherall M. Mobility beyond the clinic: the effect of environment on gait and its measurement in community-ambulant stroke survivors. *Clin Rehabil* 2008;22(6):556-63.
19. Bassile CC, Dean C, Boden-Albala B, Sacco R. Obstacle training programme for individuals post stroke: feasibility study. *Clin Rehabil* 2003;17(2):130-6.
20. Chen HC, Ashton-Miller JA, Alexander NB, Schultz AB. Stepping over obstacles: gait patterns of healthy young and old adults. *J Gerontol* 1991;46(6):M196-203.

21. Galna B, Peters A, Murphy AT, Morris ME. Obstacle crossing deficits in older adults: A systematic review. *Gait & Posture* 2009;30(3):270-275.
22. Said CM, Goldie PA, Patla AE, Sparrow WA, Martin KE. Obstacle crossing in subjects with stroke. *Archives of Physical Medicine and Rehabilitation* 1999;80(9):1054-1059.
23. Leroux A, Fung J, Barbeau H. Adaptation of the walking pattern to uphill walking in normal and spinal-cord injured subjects. *Exp Brain Res* 1999;126(3):359-68.
24. Leroux A, Fung J, Barbeau H. Postural adaptation to walking on inclined surfaces: I. Normal strategies. *Gait Posture* 2002;15(1):64-74.
25. Lay AN, Hass, C.J., Nichols, T.R. and Gregor, R.J. The effects of sloped surfaces on locomotion: a kinematic and kinetic analysis. *Journal of Biomechanics* 2006;39:1621-1628.
26. Lay AN, Hass, C.J., and Gregor, R.J. The effects of sloped surfaces on locomotion: an electromyographic analysis. *Journal of Biomechanics* 2007;40:1276-1285.
27. Forster A, Young J. Stroke rehabilitation: can we do better? *BMJ* 1992;305(6867):1446-7.
28. Hellstrom K, Lindmark B, Wahlberg B, Fugl-Meyer AR. Self-efficacy in relation to impairments and activities of daily living disability in elderly patients with stroke: a prospective investigation. *J Rehabil Med* 2003;35(5):202-7.
29. Harris JE, Eng JJ, Marigold DS, Tokuno CD, Louis CL. Relationship of balance and mobility to fall incidence in people with chronic stroke. *Phys Ther* 2005;85(2):150-8.
30. Menz HB, Lord SR, Fitzpatrick RC. Age-related differences in walking stability. *Age Ageing* 2003;32(2):137-42.
31. Schmid AA, Rittman M. Fear of falling: an emerging issue after stroke. *Top Stroke Rehabil* 2007;14(5):46-55.

32. Salbach NM, Mayo NE, Robichaud-Ekstrand S, Hanley JA, Richards CL, Wood-Dauphinee S. Balance self-efficacy and its relevance to physical function and perceived health status after stroke. *Arch Phys Med Rehabil* 2006;87(3):364-70.
33. Redfern M, DiPasquale J. Biomechanics of descending ramps. *Gait Posture* 1997;6(2):119-25.
34. Tyson SF. Trunk kinematics in hemiplegic gait and the effect of walking aids. *Clin Rehabil* 1999;13(4):295-300.
35. Horak FB. Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? *Age Ageing* 2006;35 Suppl 2:ii7-ii11.
36. Horak F, Macpherson, J. Postural orientation and equilibrium. In: Sheperd R, editor. *Handbook of Physiology: American Physiological Society*; 1996. p 254-292.
37. Winter, DA. Human balance control during standing and walking. *Gait & Posture* 1995; 3:193-214.
38. Marigold DS, Eng JJ, Tokuno CD, Donnelly CA. Contribution of muscle strength and integration of afferent input to postural instability in persons with stroke. *Neurorehabil Neural Repair* 2004;18(4):222-9.
39. McIntosh A, Beatty, KT, Dwan LN and Vickers DR. Gait dynamics on an inclined walkway. *Journal of Biomechanics* 2006;39:2491-2502.
40. Shumway-Cook A, Horak FB. Assessing the influence of sensory interaction of balance. Suggestion from the field. *Phys Ther* 1986;66(10):1548-50.
41. Peterka RJ, Loughlin PJ. Dynamic regulation of sensorimotor integration in human postural control. *J Neurophysiol* 2004;91(1):410-23.
42. Pollock A, Baer G, Langhorne P, Pomeroy V. Physiotherapy treatment approaches for the recovery of postural control and lower limb function following stroke: a systematic review. *Clinical Rehabilitation* 2007;21(5):395-410.

43. Sullivan K, Klassen T, Mulroy S. Combined task-specific training and strengthening effects on locomotor recovery post-stroke: a case study. *J Neurol Phys Ther* 2006;30(3):130-41.
44. Salbach NM, Mayo NE, Robichaud-Ekstrand S, Hanley JA, Richards CL, Wood-Dauphinee S. The effect of a task-oriented walking intervention on improving balance self-efficacy poststroke: a randomized, controlled trial. *J Am Geriatr Soc* 2005;53(4):576-82.
45. Kwakkel G. Impact of intensity of practice after stroke: issues for consideration. *Disabil Rehabil* 2006;28(13-14):823-30.
46. Krakauer JW. Motor learning: its relevance to stroke recovery and neurorehabilitation. *Curr Opin Neurol* 2006;19(1):84-90.
47. Yen CL, Wang RY, Liao KK, Huang CC, Yang YR. Gait training induced change in corticomotor excitability in patients with chronic stroke. *Neurorehabil Neural Repair* 2008;22(1):22-30.
48. Rossini PM, Dal Forno G. Neuronal post-stroke plasticity in the adult. *Restorative Neurology and Neuroscience* 2004;22:193-206.
49. Liepert J, Graef S, Uhde I, Leidner O, Weiller C. Training-induced changes of motor cortex representations in stroke patients. *Acta Neurol Scand* 2000;101(5):321-6.
50. Cho SH, Shin HK, Kwon YH, Lee MY, Lee YH, Lee CH, Yang DS, Jang SH. Cortical activation changes induced by visual biofeedback tracking training in chronic stroke patients. *NeuroRehabilitation* 2007;22(2):77-84.
51. Bayouk JF, Boucher JP, Leroux A. Balance training following stroke: effects of task-oriented exercises with and without altered sensory input. *Int J Rehabil Res* 2006;29(1):51-59.
52. Wannstedt GT, Herman RM. Use of augmented sensory feedback to achieve symmetrical standing. *Phys Ther* 1978;58(5):553-9.
53. Orrell AJ, Eves FF, Masters RS. Motor learning of a dynamic balancing task after stroke: implicit implications for stroke rehabilitation. *Phys Ther* 2006;86(3):369-80.

54. Boyd L, Winstein C. Explicit information interferes with implicit motor learning of both continuous and discrete movement tasks after stroke. *J Neurol Phys Ther* 2006;30(2):46-57; discussion 58-9.
55. Visintin M, Barbeau H, Korner-Bitensky N, Mayo NE. A new approach to retrain gait in stroke patients through body weight support and treadmill stimulation. *Stroke* 1998;29(6):1122-8.
56. Fung J, Richards CL, Malouin F, McFadyen BJ, Lamontagne A. A treadmill and motion coupled virtual reality system for gait training post-stroke. *Cyberpsychol Behav* 2006;9(2):157-62.
57. Rizzo AA, Cohen I, Weiss PL, Kim JG, Yeh SC, Zali B, Hwang J. Design and development of virtual reality based perceptual-motor rehabilitation scenarios. *Conf Proc IEEE Eng Med Biol Soc* 2004;7:4852-5.
58. Broeren J, Rydmark M, Bjorkdahl A, Sunnerhagen KS. Assessment and training in a 3-dimensional virtual environment with haptics: a report on 5 cases of motor rehabilitation in the chronic stage after stroke. *Neurorehabil Neural Repair* 2007;21(2):180-9.
59. Jang SH, You SH, Hallett M, Cho YW, Park CM, Cho SH, Lee HY, Kim TH. Cortical reorganization and associated functional motor recovery after virtual reality in patients with chronic stroke: an experimenter-blind preliminary study. *Arch Phys Med Rehabil* 2005;86(11):2218-23.
60. Kim J, Kim K, Kim DY, Chang WH, Park CI, Ohn SH, Han K, Ku J, Nam SW, Kim IY. Virtual environment training system for rehabilitation of stroke patients with unilateral neglect: crossing the virtual street. *Cyberpsychol Behav* 2007;10(1):7-15.
61. Merians AS, Poizner H, Boian R, Burdea G, Adamovich S. Sensorimotor training in a virtual reality environment: does it improve functional recovery poststroke? *Neurorehabil Neural Repair* 2006;20(2):252-67.
62. You S, Jang S, Kim Y-H, Hallett M, Ahn S, Kwon Y-H, Kim J, Lee M. Virtual reality-induced cortical reorganization and associated locomotor recovery in chronic stroke. *Stroke* 2005;36:1166 -1171.

63. Walker M, Ringleb S, Maihafer G, Walker R, Crouch J, Van Lunen B, Morrison S. Virtual reality-enhanced partial body weight-supported treadmill training poststroke: feasibility and effectiveness in 6 subjects. *Arch Phys Med Rehabil* 2010;91(1):115-22.
64. Kuan TS, Tsou JY, Su FC. Hemiplegic gait of stroke patients: the effect of using a cane. *Arch Phys Med Rehabil* 1999;80(7):777-84.
65. Beauchamp MK, Skrela M, Southmayd D, Trick J, Van Kessel M, Brunton K, Inness E, McIlroy WE. Immediate Effects of Cane Use on Gait Symmetry in Individuals with Subacute Stroke. *Physiotherapy Canada* 2009;61:154-160.
66. Laufer Y. The Effect of Walking Aids on Balance and Weight-Bearing Patterns of Patients With Hemiparesis in Various Stance Positions. *Physical Therapy* 2003;83(2):112-122.
67. Murray M, Seireg A, Scholz R. A survey of the time, magnitude and orientation of forces applied to walking sticks by disabled men. *Am J Phys Med* 1969;48(1):1-13.
68. Chen CL, Chen HC, Wong MK, Tang FT, Chen RS. Temporal stride and force analysis of cane-assisted gait in people with hemiplegic stroke. *Arch Phys Med Rehabil* 2001;82(1):43-8.
69. Milczarek JJ, Kirby RL, Harrison ER, MacLeod DA. Standard and four-footed canes: their effect on the standing balance of patients with hemiparesis. *Arch Phys Med Rehabil* 1993;74(3):281-5.
70. Tyson SF. The support taken through walking aids during hemiplegic gait. *Clin Rehabil* 1998;12(5):395-401.
71. Laufer Y. Effects of one-point and four-point canes on balance and weight distribution in patients with hemiparesis. *Clin Rehabil* 2002;16(2):141-8.
72. Lu CL, Yu B, Basford JR, Johnson ME, An KN. Influences of cane length on the stability of stroke patients. *J Rehabil Res Dev* 1997;34(1):91-100.

73. Bateni H, Maki BE. Assistive devices for balance and mobility: benefits, demands, and adverse consequences. *Arch Phys Med Rehabil* 2005;86(1):134-45.
74. Jeka JJ, Easton RD, Bentzen BL, Lackner JR. Haptic cues for orientation and postural control in sighted and blind individuals. *Percept Psychophys* 1996;58(3):409-23.
75. Maeda A, Nakamura K, Otomo A, Higuchi S, Motohashi Y. Body support effect on standing balance in the visually impaired elderly. *Arch Phys Med Rehabil* 1998;79(8):994-7.
76. Jeka JJ. Light touch contact as a balance aid. *Phys Ther* 1997;77(5):476-87.
77. Jeka J, Lackner J. Fingertip contact influences human postural control. *Exp Brain Res* 1994;100(3):495-502.
78. Jeka J, Lackner J. The role of haptic cues from rough and slippery surfaces in human postural control. *Exp Brain Res* 1995;103(2):267-76.
79. Holden M, Ventura J, Lackner JR. Stabilization of posture by precision contact of the index finger. *J. Vestib. Res.* 1994;4:285–301.
80. Lackner JR, Rabin E, DiZio P. Fingertip contact suppresses the destabilizing influence of leg muscle vibration. *J Neurophysiol* 2000;84(5):2217-24.
81. Baccini M, Rinaldi LA, Federighi G, Vannucchi L, Paci M, Masotti G. Effectiveness of fingertip light contact in reducing postural sway in older people. *Age Ageing* 2007;36(1):30-5.
82. Tremblay F, Mireault AC, Dessureault L, Manning H, Sveistrup H. Postural stabilization from fingertip contact: I. Variations in sway attenuation, perceived stability and contact forces with aging. *Exp Brain Res* 2004;157(3):275-85.
83. Nagano A, Yoshioka S, Hay DC, Fukushima S. Light finger touch on the upper legs reduces postural sway during quasi-static standing. *Motor Control* 2006;10(4):348-58.

84. Rogers MW, Wardman DL, Lord SR, Fitzpatrick RC. Passive tactile sensory input improves stability during standing. *Exp Brain Res* 2001;136(4):514-22.
85. Lackner JR, DiZio P, Jeka J, Horak F, Krebs D, Rabin E. Precision contact of the fingertip reduces postural sway of individuals with bilateral vestibular loss. *Exp Brain Res* 1999;126(4):459-66.
86. Krishnamoorthy V, Slijper H, Latash ML. Effects of different types of light touch on postural sway. *Exp Brain Res* 2002;147(1):71-9.
87. Rabin E, Bortolami SB, DiZio P, Lackner JR. Haptic stabilization of posture: changes in arm proprioception and cutaneous feedback for different arm orientations. *J Neurophysiol* 1999;82(6):3541-9.
88. Rabin E, DiZio P, Lackner JR. Time course of haptic stabilization of posture. *Exp Brain Res* 2006;170(1):122-6.
89. Vuillerme N, Isableu B, Nougier V. Attentional demands associated with the use of a light fingertip touch for postural control during quiet standing. *Exp Brain Res* 2006;169:232-236.
90. Dickstein R, Laufer Y. Light touch and center of mass stability during treadmill locomotion. *Gait Posture* 2004;20(1):41-7.
91. Fung J, Boonsinsukh R, Rapagna M. Postural responses triggered by surface perturbations are task-specific and goal directed. In: Latash M, Levin M (eds.) *Progress in Motor Control III, Human Kinetics* 2003:169-181.
92. Trivino M, Lamontagne A, Fung J. Postural Strategies To Maintain Balance During Lateral Walking After Stroke. XVth International Society for Electrophysiology and Kinesiology (ISEK). Boston, USA; 2004.
93. Boonsinsukh R, Panichareon L, Phansuwan-Pujito P. Light touch cue through a cane improves pelvic stability during walking in stroke. *Arch Phys Med Rehabil* 2009;90(6):919-26.
94. Shaffer SW, Harrison AL. Aging of the Somatosensory System: A Translational Perspective. *Phys Ther* 2007;87(2):193-207.

95. Schmid A, Duncan, PW, Studenski, S, Min Lai, S, Richards, L Perrera, S. and Wu, SS. Improvements in speed-based gait classifications are meaningful. *Stroke* 2007;38:2096.
96. Folstein MF, Folstein S, McHugh P. Mini-mental state: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research* 1975;12(3):189-198.
97. Backlund Wasling H, Norrsell U, Gothner K, Olausson H. Tactile directional sensitivity and postural control. *Exp Brain Res* 2005;166(2):147-56.
98. Callisaya M, Blizzard L, McGinley J, Schmidt M, Srikanth V. Sensorimotor Factors Affecting Gait Variability in Older People — A Population-Based Study. *Journal of Gerontology* 2009:1-7.
99. Hausdorff J. Gait variability: methods, modeling and meaning. *Journal of NeuroEngineering and Rehabilitation* 2005;2(19).
100. Gabel A, Nayak U. The effect of age on gait variability. *J Gerontology* 1984;39(6):662-666.
101. Hausdorff JM, Rios DA, Edelberg HK. Gait variability and fall risk in community-living older adults: a 1-year prospective study. *Arch Phys Med Rehabil* 2001;82(8):1050-6.
102. VICON Motion Systems. <<http://www.vicon.com/>>. Accessed 2007.
103. Heitmann D, Gossman M, Shaddeau S, Jackson J. Balance performance and step width in noninstitutionalized, elderly, female fallers and nonfallers. *Phys Ther* 1989;69(11):923-931.
104. Inter Link Electronics. <www.interlinkelectronics.com/>. Accessed 2008.
105. AMTI <<http://amti.biz/>>.
106. CAREN-ComputerAssistedREhabilitationENvironment. <www.motekmedical.com>. Accessed 2007

107. Canada Mortgage and Housing Corporation - Accessible Housing-Ramps.
<http://www.cmhc-schl.gc.ca/en/co/renoho/refash/refash_025.cfm>.
Accessed 2008.
108. Powell LE, Myers AM. The Activities-specific Balance Confidence (ABC) Scale. *J Gerontol A Biol Sci Med Sci* 1995;50A(1):M28-34.
109. Salbach N, Mayo N, Hanley J, Richards C, Wood-Dauphinee S.
Psychometric evaluation of the original and Canadian French version of the activities-specific balance confidence scale among people with stroke. *Arch Phys Med Rehabil* 2006;87(12):1597-604.
110. Schmid A, Duncan PW, Studenski S, Lai SM, Richards L, Perera S, Wu SS. Improvements in speed-based gait classifications are meaningful. *Stroke* 2007;38(7):2096-100.
111. Mann WC, Llanes C, Justiss MD, Tomita M. Frail older adults' self-report of their most important assistive device. *OTJR: Occupation, Participation & Health* 2004;24(1):4-12.
112. Hesse S. Rehabilitation of gait after stroke: evaluation, principles of therapy, novel treatment approaches, and assistive devices. *Topics in Geriatric Rehabilitation* 2003;19(2):109-126.
113. Allet L, Leemann B, Guyen E, Murphy L, Monnin D, Herrmann FR, Schnider A. Effect of different walking aids on walking capacity of patients with poststroke hemiparesis. *Arch Phys Med Rehabil* 2009;90(8):1408-13.
114. Laufer Y. The use of walking aids in the rehabilitation of stroke patients. *Reviews in Clinical Gerontology* 2004;14(2):137-144.
115. Perez C, Oates A, McFadyen BJ, Fung J. Enhanced somatosensory input and gait stability. In: Chiari L, Nardone A, editors. *International Society for Posture and Gait Research* 2009. June 21-25; Bologna, Italy.
116. Perez C, Oates A, McFadyen BJ, Fung J. Enhanced somatosensory input improves gait stability during slope walking post-stroke. *Society for Neuroscience* 2009. Chicago, USA.

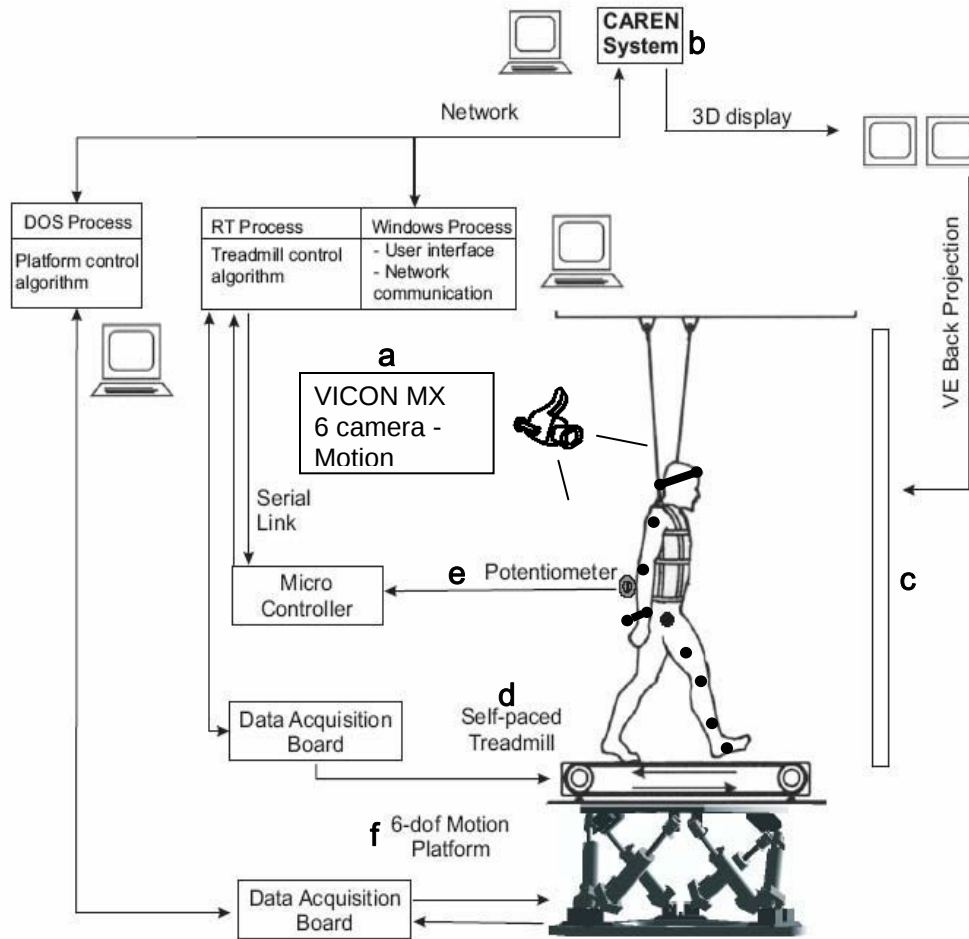
117. Oates A, Perez C, McFadyen BJ, Fung J. Effects of haptic information on postural stability and coordination post-stroke while walking in a virtual environment. In: Chiari L, Nardone A, editors. International Society for Posture and Gait Research 2009. June 21-25; Bologna, Italy.
118. Holden MK. Virtual environments for motor rehabilitation: review. *Cyberpsychol Behav* 2005;8(3):187-211; discussion 212-9.
120. Botner EM, Miller WC, Eng JJ. Measurement properties of the Activities-specific Balance Confidence Scale among individuals with stroke. *Disabil Rehabil* 2005;27(4):156-63.
121. De Bujanda E, Nadeau S, Bourbonnais D, Dickstein R. Associations between lower limb impairments, locomotor capacities and kinematic variables in the frontal plane during walking in adults with chronic stroke. *J Rehabilitation Med* 2003;35(6):259-64.
122. Perez C, Fung J. An instrumented cane devised for gait rehabilitation and research. *Journal of Physical Therapy (Education)* 2010 (in press).

Appendix I Summary of Haptic Studies Involving Postural Control (1997 – 2010)

AUTHOR	YEAR	INPUT	POSITION	CONDITION	POPULATION	N	FINDINGS
Jeka	1997	fingertip	standing	compared to cane			
Jeka et al	1997	fingertip	standing	tandem & eyes closed with moving touch bar	healthy (20-30yr)	5	reduced head/body sway frequency
Rabin et al	1999	fingertip	standing	narrow support base varied arm positions	healthy	12	reduced COP sway
Jeka et al	2000	finger tip	standing	touch and visual			
Slijper & Latash	2000	index finger	standing	stable or unstable rapid arm flexion	healthy	8	improved anticipatory adjustments (LE EMG)
Lackner et al	2000	fingertip	standing	vibrating Achilles and tandem	healthy	10	reduced COP & body sway
Dickstein et al	2001	fingertip	standing	firm/compliant	neuropathy healthy	8 8	reduction of COM sway similar to visual input
Rogers et al	2001	passive touch	standing	firm/foam shoulder or leg	young healthy diabetic old 70-80 yrs	8 14 25	reduced % body sway
Oie et al	2002	touch	standing	oscillating somato- sensory and visual input	healthy		inter & intra modal re- weighting of sensory inputs
Krishnamoorthy et al	2002	fingertip		various textures	healthy	10	reduction in postural sway
Dickstein et al	2003	fingertip	standing	no, light or heavy eyes closed	diabetic neuropathy healthy	8 10	latency of response reduced CoP movement (AP& ML velocity)
Fung et al	2003	fingertip	standing & walking	sudden surface perturbation	stroke healthy	11 8	reduced CoM sway stroke > healthy

AUTHOR	YEAR	INPUT	POSITION	CONDITION	POPULATION	N	FINDINGS
Dickstein et al	2004	fingertip	treadmill walking	no, light or heavy side of input (L/R) no vision	young healthy	20	stabilizing effect of touch equal to vision, no effect of side of input
Tremblay et al	2004	fingertip	standing	eyes open & closed firm/foam surface smooth/rough	young (19-32) old (60-86)	10 35	reduced sway amplitude
Patla et al	2004	cane use	walking	obstacle avoidance vision reduced	healthy	6	effective avoidance with haptic input from cane
Trivino et al	2005	fingertip	walking	sideways stepping	stroke	10	reduced CoM sway
Backlund et al	2005	finger	standing	directional sensitivity		8	skin stretch & spatio-temp features
Tremblay et al	2005		standing	below knee	young healthy	10	
Menz et al	2006	passive (velco)	standing	calf ankle	older neuropathy	10 10	reduced sway
Nagano et al	2006	finger	standing	touch onto upper leg same person			reduced sway
Rabin et al	2006	fingertip	standing	tandem position & eyes closed	healthy	12	300ms timecourse for postural response
Vuillerme et al	2006	fingertip	standing		healthy		attention required
Baccini	2007	fingertip	standing		old healthy young healthy		more effective in older than in young
Johannsen et al	2007	sh contact	standing	eyes closed	healthy	11	faster predictive/ reactive balance responses, reduced CoP movement
Boonsinsukhet al	2009	cane use	walking	light touch vs. force contact	stroke	45	improved pelvic stability

Appendix II Experimental Set-up



Setup. Schematic view showing computer connections involved: (a) Vicon 3-D motion analysis system, (b) CAREN control computer, (c) large rear projection screen placed in front of the subject, (d) motorized, self-paced treadmill with (e) potentiometer attached to subject to regulate walking speed, and (f) motion platform providing treadmill movement (5 ° slopes). Adapted from Fung et al.(33)

Appendix III The Activities-specific Balance Scale

The Activities-specific Balance Confidence (ABC) Scale*

For each of the following activities, please indicate your level of self-confidence by choosing a corresponding number from the following rating scale:

0% 10 20 30 40 50 60 70 80 90 100%
no confidence completely confident

“How confident are you that you will not lose your balance or become unsteady when you...

...walk around the house? %

...walk up or down stairs? _____ %

...bend over and pick up a slipper from the front of a closet floor _____ %

...reach for a small can off a shelf at eye level? %

...stand on your tiptoes and reach for something above your head?

%

...stand on a chair and reach for something? %

...sweep the floor? %

...walk outside the house to a car parked in the driveway? %

...get into or out of a car? %

...walk across a parking lot to the mall? %

...walk up or down a ramp? %

...walk in a crowded mall where people rapidly walk past you? _____ %

...are bumped into by people as you walk through the mall? %

... step onto or off an escalator while you are holding onto a railing?

%

... step onto or off an escalator while holding onto parcels such that you cannot hold onto the railing? %

...walk outside on icy sidewalks? %

*Powell, LE & Myers AM. The Activities-specific Balance Confidence (ABC) Scale. *J Gerontol Med Sci* 1995; 50(1): M28-34

Échelle de confiance en l'équilibre, spécifique aux activités (Version française « The Activity Specific Balance Scale »)

Directives aux participants :

Pour chacun des points suivants, veuillez indiquer votre niveau de confiance quant à votre capacité à faire l'activité sans perdre l'équilibre ou sans devenir chancelant(e) en choisissant un chiffre sur l'échelle de 0% à 100%. Si vous ne faites pas présentement l'activité en question, essayez d'imaginer quel serait votre niveau de confiance si vous aviez à faire cette activité. Si vous utilisez d'habitude une canne ou une marchette, ou si vous devez vous appuyer sur quelqu'un pour cette activité, évaluez votre niveau de confiance comme si vous utilisiez ces supports. Si vous avez quelque question que ce soit, veuillez la poser à l'évaluateur.

Pour chacune des activités suivantes, veuillez indiquer votre niveau de confiance en vous-même en choisissant un chiffre sur l'échelle:

0%	10	20	30	40	50	60	70	80	90	100%
Pas										Pleinement
Confiant(e)										Confiant(e)

*À quel point êtes-vous confiant(e) de **ne pas** perdre l'équilibre ou de **ne pas** devenir chancelant(e) lorsque vous...*

- | | | |
|-----|---|---------|
| 1. | ... marchez dans la maison? | _____ % |
| 2. | ... montez ou descendez les escaliers? | _____ % |
| 3. | ... vous penchez et ramassez une pantoufle sur le plancher, à l'entrée du garde-robe? | _____ % |
| 4. | ... étendez le bras pour atteindre une petite boîte de conserve placé sur une tablette à la hauteur des yeux? | _____ % |
| 5. | ... montez sur la pointe des pieds et étendez le bras pour atteindre quelque chose au-dessus de votre tête? | _____ % |
| 6. | ... vous tenez debout sur une chaise et étendez le bras pour atteindre quelque chose? | _____ % |
| 7. | ... balayez le plancher? | _____ % |
| 8. | ... sortez de la maison et marchez jusqu'à une voiture stationnée dans l'entrée? | _____ % |
| 9. | ... entrez ou sortez de la voiture? | _____ % |
| 10. | ... marchez dans un stationnement de centre d'achat? | _____ % |
| 11. | ... montez ou descendez une rampe d'accès? | _____ % |
| 12. | ... marchez dans un centre d'achat plein de monde où les gens vous croisent rapidement? | _____ % |

13. ... vous faites bousculer par des gens en marchant dans un centre d'achat? _____%
14. ... montez ou descendez d'un escalier roulant en tenant la rampe? _____%
15. ... montez ou descendez d'un escalier roulant tout en tenant des paquets qui vous empêchent de tenir la rampe? _____%
16. ... marchez sur des trottoirs glacés? _____%

Appendix IV VISUAL ANALOG SCALES

Date:

Subject ID: _____

- walking on the *level* surface:



- walking *uphill*.



- walking *downhill*.

Easy

Difficult

- *touching the sensor strip* while walking:

Easy

Difficult

- *using the cane* while walking:

Easy

Difficult

- *seeing the slope changes* while walking:

Easy

Difficult

- generally, I paid *more attention* to:

Walking

Touching the strip

- generally, I paid *more attention* to:

Walking

Cane Use

CONSENT FORM FOR PARTICIPATING IN A RESEARCH PROJECT

Effects of light touch on stability during locomotion in a virtual environment

Project investigators

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Introduction:

We are asking you to participate in a research project involving walking on a self-paced treadmill in a virtual environment. Before agreeing to participate in this project, please take the time to read and carefully consider the following information.

This consent form explains the aim of the study, the procedures, advantages, risks and inconveniences as well as the persons to contact, if necessary.

This consent form may contain words that you do not understand. We invite you to ask any question that you deem useful to the researchers and the other members of the staff assigned to the research project and ask them to explain any words or information which is not clear to you.

Background:

The ability to maintain balance is often compromised after a stroke or spinal cord injury. Light touch involves gentle contact with a surface and has been shown to be beneficial in assisting the control of balance during standing and walking. Anticipatory postural adjustments (APAs) are the changes we make to our posture and movements when encountering a predictable disturbance to balance. Virtual reality (VR) offers the ability to provide repeated practice of a movement in a safe, controlled environment. The training capabilities of VR allow someone, through controlled practice, to learn or re-learn a motor skill. A combination of visual information from the VR and enhanced sensory information through light touch may create an optimal rehabilitation environment.

Objectives:

1. To test the effect of haptic information from different devices (load-sensor strip versus instrumented cane) on balance while walking in a virtual environment (VE).
2. To compare the effect of stroke and spinal cord injury on the ability to use haptic information during APAs while walking.

Nature of my participation:

This evaluation will take place at the Posture and Gait Research Laboratory of the Jewish Rehabilitation Hospital. I shall be attending one experimental session that will take approximately three and a half (3.5) hours of my time. This includes collection of baseline measures (30 minutes), preparation time (up to two hours) and the testing time (1 hour).

Preparation:

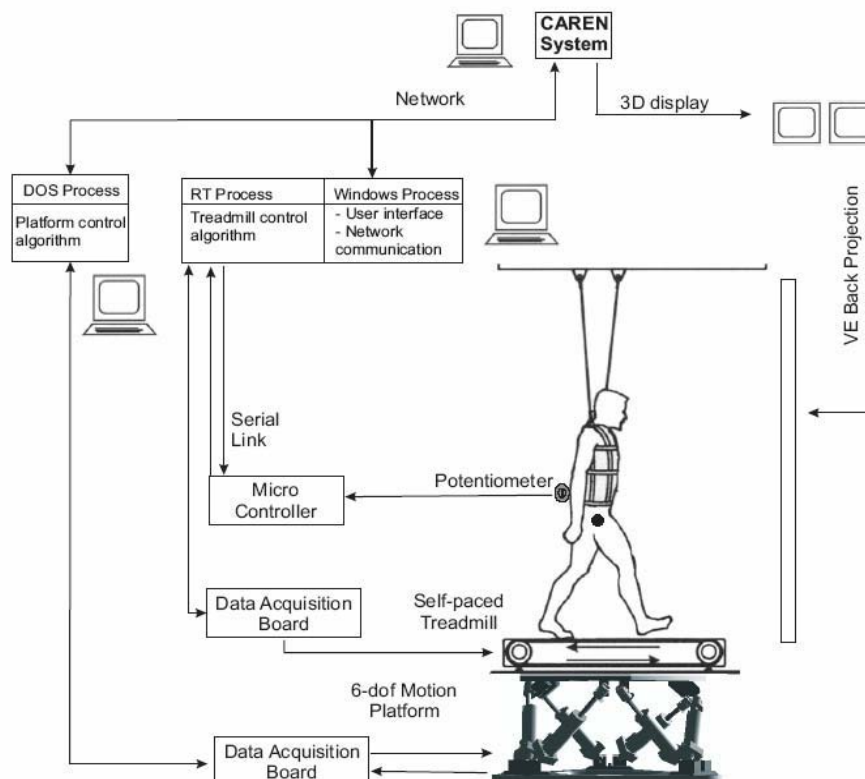
In order to record the movements of my body and limbs as I walk, small reflective markers will be placed onto my head, upper and lower body, arms, forearms, wrists, thighs, legs and feet using medical-grade adhesive tape. In order to record the activity of my muscles as I walk, small electrodes (similar to those used to monitor heart rate) will be placed on my skin over different muscles in my body. Before the electrodes are placed on the skin, the area where the electrodes will be placed will be shaved to remove any hair and cleaned with a mild alcohol solution in order to get the best possible signal from my muscles. Razors used in this experiment are disposable and used only once. A heart-rate monitor and blood-pressure monitor will be attached to me in order to evaluate my physiological status during the evaluation. Finally, a custom-made, body-harness will be worn and attached to the ceiling and a spotter will always be by my side while I am walking on the treadmill for my safety.

Evaluation:

During the testing session I will be presented with a questionnaire about my confidence in my ability to maintain my balance while performing certain daily activities. Additionally, my walking ability and speed will be tested over-ground. I will then practice walking on the treadmill until I feel comfortable walking on a self-paced treadmill. The practice will also include walking with the index finger of my unaffected or dominant hand lightly touching a load-sensor strip placed at fingertip level. I will also practice walking with an instrumented cane on the treadmill.

Following the walking practice on the treadmill with and without using the load-sensor strip and cane, I will then wear specialized glasses which will allow me to see the virtual environment in 3-D which is projected on a screen in front of the treadmill. I will walk through this virtual environment which will contain changes in the slope of the surface. The changes in the slope of the surface on the screen will be matched by the changes in the slope of the treadmill under my feet. I will perform the walking tasks with and without haptic information (sensor strip or cane) according to instructions.

I will be walking for approximately 25 minutes combined and I may take as much time to rest in between trials as I would like.



Risks and disadvantages:

Risks associated with my participation in this study are minimal. I may have a slight skin irritation from the adhesive glue/tape used to fix the electrodes and markers to my skin. This irritation should disappear within 3 days. During and after the evaluation, I may feel tired from the walking and possibly nauseous from the virtual environment. The tiredness and nausea will wear-off with rest. There is a possibility that I may fall during this experiment, however, the safety harness and spotter will prevent me from falling to the ground.

Benefits:

This study does not provide any direct benefit beyond extra practice walking in a safe, controlled environment. The results of this study will provide information that will help researchers better understand the relationship between light touch and stability during walking in a VE.

Compensation:

Transportation and parking costs incurred through my participation in this project will be reimbursed up to a maximum of \$30.

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 research 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 in the Gait and Posture Laboratory at the Jewish Rehabilitation Hospital in Laval. 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. However, for control purposes, my file could be consulted by a person mandated by the Research Ethics Board for member institutions of CRIR who adhere to a strict confidentiality policy. The research data will be kept for a period of 5 years following the end of the study after which time it 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.

Withdrawal of participation:

My participation in this project as described above is completely voluntary. It is understood that I may withdraw my participation at any time throughout the study. My participation or refusal to participate will in no way affect the treatment

I receive in this hospital. If I withdraw from this study all documents relating to me will be kept unless otherwise requested.

Questions concerning the study:

Should I have any question or require further information regarding the study, I can contact Alison Oates, Ph.D: 450-688-9550 ext. 4810 or by email: alison.oates@mail.mcgill.ca. I can also contact Claire Perez, PT: 450-688-9550 ext. 4821 or by email: claire.perez@mail.mcgill.ca.

If I have any questions regarding my rights and recourse concerning my participation in this study, I can contact Ms. Anik Nolet, Coordinator of the Research Ethics Board for member institutions of CRIR: 514-527-4527 ext. 2649, or by e-mail: anolet.crir@ssss.gouv.qc.ca. You may also contact Mr. Michael Greenberg, Commissioner of complaints and quality of services at the Jewish Rehabilitation Hospital at 450-688-9550 ext. 232.

CONSENT:

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.

The purpose, procedure, risks and benefits that concern my participation in this research, as well as the confidentiality of my personal information, which will be used during this study have been well explained to me.

I have had the opportunity to ask all the questions concerning the different aspects of the study and I have received satisfactory answers.

I, the undersigned, understand and voluntarily accept to participate in this research as a subject in the experiment. I can withdraw at any time without any consequence to my relationships with my doctor and other professionals.

I attest that I received a signed copy of this information and consent form.

Subject:	Date:
_____	_____
Signature	

	Tel:
_____	_____
Name	

Witness:	Date:
_____	_____
Signature	

	Tel:
_____	_____
Name	

Responsibility of the researcher:

I, the undersigned, certify that I have:

- a) Explained to the subject the terms of the present agreement
- b) Responded to all questions posed to me
- c) Clearly indicated that the subject is free to leave the study described above at any time, and
- d) Provided a signed and dated copy of this consent document to the subject.

**Signature of the principal researcher
or representative**

Signed on _____, the _____ 20__

**The researchers can be contacted at the Jewish Rehabilitation Hospital,
3205 place Alton Goldbloom, Chomedey, Laval, H7V 1R2, Tel : (450) 688-
9550, extension 4810, 4821 or 529.**

FORMULAIRE DE CONSENTEMENT

Effets du toucher léger sur la stabilité lors de la marche dans un environnement virtuel

Chercheurs:

Alison Oates, Ph.D., Stagiaire postdoctorale
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Tel: 450-688-9550 # 529

Préambule :

Nous vous demandons de participer à un projet de recherche qui implique de marcher à son rythme sur un tapis roulant dans un environnement virtuel. Avant d'accepter de participer à ce projet de recherche, veuillez prendre le temps de comprendre et de considérer attentivement les renseignements qui suivent.

Ce formulaire de consentement vous explique le but de cette étude, les procédures, les avantages, les risques et inconvénients, de même que les personnes avec qui communiquer au besoin.

Le présent formulaire de consentement peut contenir des mots que vous ne comprenez pas. Nous vous invitons à poser toutes les questions que vous jugerez utiles au chercheur et aux autres membres du personnel affecté au projet de recherche et à leur demander de vous expliquer tout mot ou renseignement qui n'est pas clair.

Description du projet :

L'habileté de maintenir l'équilibre est souvent compromise suivant un accident vasculaire cérébral (AVC) ou une blessure à la moelle épinière. Il a été démontré que le toucher léger, c'est-à-dire un léger contact avec une surface, est bénéfique au contrôle de l'équilibre lors de la marche. Les ajustements posturaux anticipés (APA) sont des changements que nous faisons au niveau de notre posture et de nos mouvements lorsque nous rencontrons une perturbation prévisible de notre équilibre. La réalité virtuelle (RV) offre la possibilité d'entraîner un mouvement de manière répétée dans un environnement sûr et contrôlé. La capacité d'entraînement de la RV permet à l'aide de pratique dans un environnement contrôlé, d'apprendre ou de réapprendre une habileté motrice. La combinaison d'informations visuelles de la RV et d'informations sensorielles par le toucher léger pourrait créer un environnement de réadaptation optimal.

Objectifs :

1. Examiner les effets de l'information sensorielle du toucher léger sur l'équilibre au moyen d'un capteur et d'une canne pendant la marche dans un environnement virtuel (EV).
2. Comparer l'effet de l'AVC et de blessure à la moelle épinière sur l'habileté à utiliser l'information sensorielle du toucher léger lors d'APA pendant la marche.

Nature de ma participation:

Cette évaluation aura lieu au Laboratoire de Posture et marche de l'Hôpital juif de réadaptation. Je participerai à une session d'environ trois et demi (3,5) heures. Ceci inclut la collecte des mesures de base (0,5 heure), le temps de préparation (2 heures), et le temps d'évaluation (1 heure).

Préparation:

Afin d'enregistrer les mouvements de mon corps lors de la marche de petits marqueurs réfléchissants seront collés sur ma tête, mon tronc, mon bassin, mes bras, mes avant-bras, mes mains, mes cuisses, mes jambes et mes pieds. Afin d'enregistrer l'activité de mes muscles lors de la marche, de petites électrodes (semblables à celles utilisées pour surveiller la fréquence cardiaque) seront placées sur ma peau. Avant de placer les électrodes sur ma peau, une petite surface sera rasée et nettoyée avec une solution d'alcool afin d'obtenir le meilleur signal possible de mes muscles. Les rasoirs utilisés, dans le présent projet, sont à usage unique. Un moniteur de fréquence cardiaque et de tension artérielle sera utilisé afin de s'assurer que mes battements cardiaques et que ma tension artérielle demeurent stables. Finalement, je porterai un harnais lequel sera attaché au plafond et un membre de l'équipe

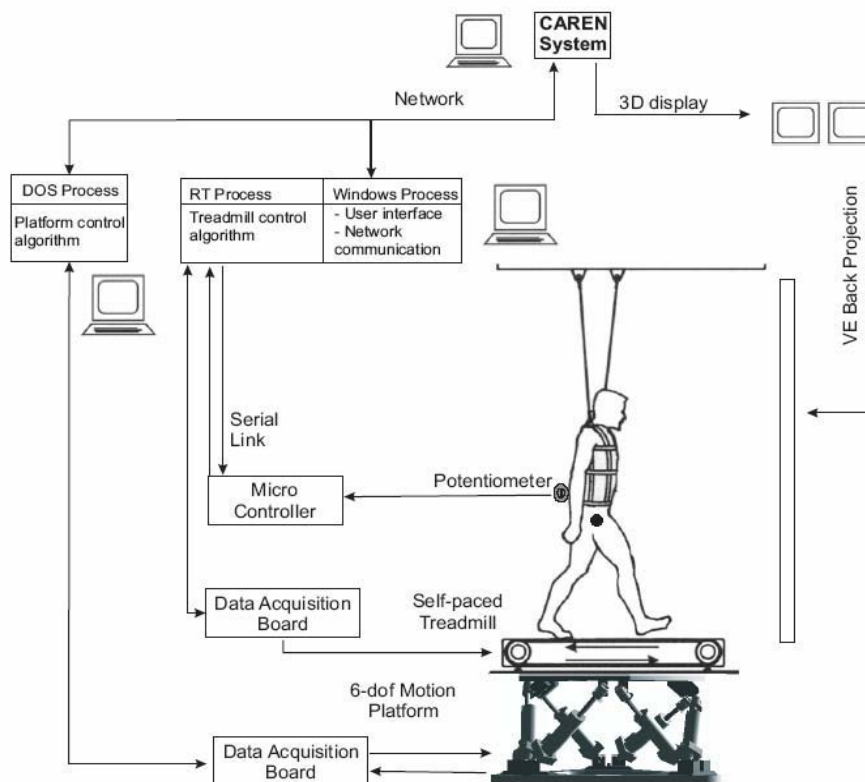
de recherche sera à mes côtés en tout temps afin d'assurer ma sécurité lorsque je marcherai sur le tapis roulant.

Évaluation:

Lors de la session expérimentale, je répondrai à un questionnaire sur ma confiance en mon habileté à maintenir mon équilibre lors de tâches quotidiennes. De plus, mon habileté et ma vitesse de marche au sol seront testées. Je me pratiquerai ensuite sur le tapis roulant jusqu'à ce que je me sente à l'aise à marcher sur un tapis roulant qui s'ajustera automatiquement à ma vitesse de marche confortable. Ensuite, je me pratiquerai à marcher avec l'index de la main du côté non affecté par l'AVC ou du côté dominant qui touche légèrement un rail fixé à la hauteur de la hanche. Je vais également m'exercer à marcher sur le tapis roulant à l'aide d'une canne instrumentée.

Suite aux exercices de marche sur le tapis roulant, avec et sans les capteurs et la canne, , je porterai des lunettes spéciales me permettant de voir l'environnement virtuel projeté en 3-D sur l'écran face au tapis roulant. Je marcherai à travers cet environnement virtuel où il y aura des changements dans l'inclinaison du plancher. Ces changements d'inclinaison du plancher à l'écran seront simultanés aux changements dans l'inclinaison du tapis roulant sous mes pieds. Je ferai des essais de marche avec et sans l'information du toucher léger (capteurs ou canne) selon les instructions.

Je marcherai pour un total d'environ 25 minutes et je pourrai prendre tout le temps de repos dont j'aurai besoin entre chaque essai.



Risques et désavantages :

Les risques associés à ma participation à cette étude sont minimes. Il est possible qu'une irritation cutanée se manifeste suite à l'utilisation de l'adhésif des marqueurs réfléchissants et des électrodes sur ma peau. Si cela se produit, un membre de l'équipe de recherche appliquera une lotion calmante, sur ma peau. Il est aussi possible que je ressente de la fatigue et des nausées pendant et après l'évaluation en EV. Ceux-ci disparaîtront lorsque je me reposerai. Enfin, il est possible que je tombe pendant l'expérience mais le harnais de sécurité et le membre de l'équipe m'accompagnant, m'éviteront une chute au sol.

Bénéfices

Je ne bénéficierai pas directement des avantages reliés à ma participation à cette étude. Cependant, ma participation fournira de l'information qui aidera les chercheurs à mieux comprendre la relation entre le toucher léger et la stabilité lors de la marche dans un environnement virtuel.

Indemnité compensatoire

Les frais de déplacement et de stationnement associés à ma participation à ce projet me seront remboursés jusqu'à un maximum de 30,00\$.

Accès à mon dossier médical

J'autorise l'accès à mon dossier médical aux personnes responsables de ce projet. Je comprends que seulement l'information concernant mon historique médical sera utilisée.

Confidentialité

Tous les renseignements personnels recueillis à mon sujet au cours de l'étude seront codifiés afin d'assurer ma confidentialité. Ces données seront conservées sous clé au centre de recherche de l'Hôpital juif de réadaptation par un responsable de l'étude pour une période de 5 (cinq) ans suivant la fin du projet, après quoi elles seront détruites. Seuls les membres de l'équipe de recherche y auront accès. Cependant, à des fins de contrôle du projet de recherche, mon dossier pourrait être consulté par une personne mandatée par le Comité d'éthique de la recherche des établissements du CRIR qui adhère à une politique de stricte confidentialité. Les données relatives à mes évaluations seront transférées dans un dossier informatique sur un serveur où l'accès sera protégé par des mots de passe. En cas de présentation de résultats de cette recherche dans des publications scientifiques ou à des fins d'enseignement, rien ne pourra permettre de m'identifier.

Retrait de ma participation

Ma participation au projet de recherche est tout à fait libre et volontaire. Il est entendu que je pourrai, à tout moment, mettre un terme à ma participation sans que cela n'affecte les soins et les services de santé que je reçois ou recevrai de l'Hôpital juif de réadaptation. Je comprends que malgré mon retrait de cette étude, toutes les données me concernant, seront conservées à moins d'indication contraire de ma part.

Questions concernant cette étude

Si j'ai des questions ou que je désire de l'information supplémentaire sur cette étude, je peux contacter Alison Oates, Ph.D :450-688-9550 poste 4810 ou par courriel alison.oates@mail.mcgill.ca. Je peux contacter aussi Claire Perez, PT : 450-688-9550 poste 4821 or par courriel claire.perez@mail.mcgill.ca.

Si j'ai des questions sur mes droits et recours ou sur ma participation à ce projet de recherche, je peux communiquer avec Anik Nolet, Coordinatrice à l'éthique de la recherche des établissements du CRIR: 514-527-4527 ext. 2649, ou par courriel : anolet.crir@ssss.gouv.qc.ca. Vous pouvez également contacter Mr. Michael Greenberg, Commissaire des plaintes et de la qualité des services au l'Hôpital Juif de Réadaptation: 450-688-9550 ext. 232.

CONSENTEMENT :

Je déclare avoir lu et compris le présent projet, la nature et l'ampleur de ma participation, ainsi que les risques auxquels je m'expose tels que présentés dans le présent formulaire. J'ai eu l'occasion de poser toutes les questions concernant les différents aspects de l'étude et de recevoir des réponses à ma satisfaction.

Je, soussigné(e), accepte volontairement de participer à cette étude. Je peux me retirer en tout temps sans préjudice d'aucune sorte. Je certifie qu'on m'a laissé le temps nécessaire pour prendre ma décision et je sais qu'une copie de ce formulaire figurera dans mon dossier médical.

Une copie signée de ce formulaire d'information et de consentement me sera également remise.

Subject: _____ **Date:** _____

Signature

Tel: _____

Nom

Témoin: _____ **Date:** _____

Signature

Tel: _____

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 est, 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.

Signature du responsable du projet
ou de son représentant

Signé à _____, le _____ 20__

Appendix VI Plug-in-Gait Marker Placement

