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Mirror Therapy for the Lower-Extremities Post-Stroke

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A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Health and Rehabilitation Sciences

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Mirror Therapy for the Lower-Extremities Post-Stroke

by

Lucas David Crosby

Graduate Program in Rehabilitation Science

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master's of Science

The School of Graduate and Postdoctoral Studies
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Abstract

Despite extensive rehabilitation post-stroke gait remains slow, variable and asymmetric. There is a need for simple interventions to improve lower-extremity motor control and walking ability. Mirror therapy is a promising intervention though little attention has focused on its use on the lower-extremities post-stroke. This thesis investigates the feasibility and potential effects of a bilateral lower-extremity mirror therapy intervention (LE-MT) post-stroke. A case series involving three participants, who performed twelve 30 minute sessions of LE-MT over four weeks, is presented. Session duration and number of repetitions completed improved over the course of the intervention indicating LE-MT post-stroke is feasible. Some cases demonstrated improved motor recovery of the leg and clinically meaningful improvements to gait velocity and step variability post-intervention indicating some potential benefits of LE-MT. Future directions will identify who may respond best to LE-MT, investigate the dose-response relationship and the underlying mechanisms of the observed improvements associated with LE-MT.

Keywords

stroke, rehabilitation, leg, gait, motor impairment, mirror therapy

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Table of Contents

Abstract	ii
Acknowledgments	iii
Table of Contents	iv
List of Tables	vi
List of Figures	vii
List of Abbreviations	viii
List of Appendices	ix
Chapter 1	1
1 Overview	1
1.1 Background of stroke and stroke rehabilitation	2
Chapter 2	4
2 Mirror therapy	4
2.1 Mirror therapy and stroke	7
2.1.1 Upper-extremity	7
2.1.2 Lower-extremity	12
2.2 Mechanisms of mirror therapy	14
Chapter 3	17
3 A new mirror therapy device	17
3.1 Rationale for the current LE-MT device design	17
3.2 Prototype development and construction	18
3.3 Application of the current LE-MT	18
3.4 Demonstration and feedback on the current LE-MT	20
Chapter 4	21
4 Stroke outcome assessment: motor recovery, balance, gait	21
4.1 Stroke severity	21
4.2 Motor impairment	21
4.3 Balance	22
4.4 Spatiotemporal gait parameters	22
4.4.1 Measuring change in spatiotemporal gait parameters	23
Chapter 5	24
5 The feasibility of a novel bilateral lower-extremity mirror therapy intervention for individuals with stroke: a case series.	24
5.1 Abstract	24
5.2 Introduction	24
5.3 Methods	26
5.3.1 Bilateral Lower-Extremity Mirror Therapy Intervention	27
5.3.2 Outcome Measures and Outcome Assessment Protocol	28
5.3.3 Data analysis	29
5.3.4 Intervention feasibility	30
5.3.5 Case 1 description	30
5.3.6 Case 2 description	31
5.3.7 Case 3 description	31
5.4 Results	32
5.4.1 Intervention feasibility	32
5.4.2 Primary gait and secondary clinical outcomes	34
5.4.3 Case 1 results	34

5.4.4	Case 2 results	37
5.4.5	Case 3 results	38
5.5	Discussion	39
5.5.1	Limitations	43
5.5.2	Conclusions.....	43
Chapter 6	45
6	Discussion	45
6.1	Overview of findings	45
6.2	The current study offers a different approach to MT for the lower-extremities ...	46
6.3	Limitations of the current LE-MT study.....	49
6.3.1	Dose of LE-MT.....	49
6.3.2	Attributing observed improvements to LE-MT alone	50
6.4	Mechanisms underlying improvement observed with LE-MT	50
6.5	Future directions	51
References	53
Appendices	61
Curriculum Vitae	66

List of Tables

Table 1: Summary of clinical measures.....	32
Table 2: Summary of thesis findings	45

List of Figures

Figure 1: The current LE-MT device	19
Figure 2: The current LE-MT device in use for the point of view of the user	19
Figure 3: The device used for the LE-MT intervention (a). The recording view of the intervention (b)	28
Figure 4: Performance during LE-MT intervention. a. duration of each LE-MT session; b. number of repetitions completed per LE-MT session; and c. number of rest periods taken per LE-MT session for Participant 1 (solid line), Participant 2 (dotted line), and Participant 3 (dashed line)	33
Figure 5: Spatiotemporal gait parameters (a. gait velocity; b. step length variability (SD); c. swing time variability (SD); d. step length symmetry; e. swing time symmetry) measured at each of the 4 assessment time points for the preferred pace with usual walking aid condition for Participant 1 (solid line), Participant 2 (dotted line) and Participant 3 (dashed line)	35
Figure 6: Spatiotemporal gait parameters (a. gait velocity; b. step length variability (SD); c. swing time variability (SD); d. step length symmetry; e. swing time symmetry) measured at each of the 4 assessment time points for the fast pace with usual walking aid condition for Participant 1 (solid line), Participant 2 (dotted line) and Participant 3 (dashed line)	36

List of Abbreviations

ADLs	Activities of Daily Living
ARAT	Action Research Arm Test
BBA	Brunel Balance Assessment
BBS	Berg Balance Scale
BS	Brunnstrom Stages of Motor Recovery
CMSA	Chedoke McMaster Stroke Assessment
EEG	Electroencephalography
FAC	Functional Ambulation Categories
FIM	Functional Independence Measure
LE-MT	Mirror Therapy for the Lower-Extremities
LE	Lower-Extremity
FM	Fugl-Meyer Assessment
fMRI	Functional Magnetic Resonance Imaging
M1	Primary Motor Cortex
MEG	Magnetoencephalography
MT	Mirror Therapy
NIHSS	National Institutes of Health Stroke Scale
PET	Positron Emission Tomography
RCT	Randomized Controlled Trial
TMS	Transcranial Magnetic Stimulation
UE	Upper-Extremity
UE-MT	Mirror Therapy for the Upper-Extremities

List of Appendices

Appendix A: Equipment	61
Appendix B: Concept sketches	62
Appendix C: Ethical Approval.....	65

Chapter 1

1 Overview

Stroke is a serious health issue in Canada. Post-stroke impairments include communication and cognitive deficits, restriction of activities of daily living and reduced mobility. Of these impairments walking ability is the most commonly reported limitation following stroke.¹ Not surprisingly, improving gait is often stated as the number one goal of rehabilitation and therefore gait training receives the most attention in the rehabilitation setting.² However, after rehabilitation post-stroke gait remains slow, variable and asymmetric, so there is need for simple interventions to improve walking outcomes. Mirror therapy (MT) is a promising intervention that has potential as a beneficial adjunct therapy to existing gait rehabilitation protocols.

This thesis investigates a novel MT intervention that targets the lower-extremities (LE) of individuals following stroke, known from this point on as mirror therapy for the lower-extremities (LE-MT). The intervention presented here is the first to my knowledge that incorporates bilateral movements of the LEs during the therapy post-stroke. **The objective of this thesis is to determine the feasibility of a novel bilateral LE-MT intervention.**

The following section provides a brief background of stroke and stroke rehabilitation, and a summary of post-stroke gait measurement. Subsequent sections provide an overview of MT and its use in stroke rehabilitation. This is followed by a study designed to achieve the main objective of stated above.

1.1 Background of stroke and stroke rehabilitation

Stroke is a serious health issue in Canada. A new stroke occurs every ten minutes, amounting to approximately 50,000 new cases each year.³ A recent report from the Heart and Stroke Foundation estimates that there are 315,000 Canadians currently living with the effects of stroke.⁴ Globally, from 1990 to 2010 the absolute numbers of stroke survivors, people with first time stroke, stroke-related deaths, and disability-adjusted life years have significantly increased by 84, 68, 26 and 12 percent, respectively.⁵ Furthermore, the proportion of stroke burden is greater overall in people younger than 75 years of age than in those who are older.⁵

Most strokes are caused by an interruption of blood flow to the brain that can either result from a clot, blocking the normal blood flow, or blood vessel rupture, causing bleeding in the brain.⁶ The most common neurological deficits caused by stroke affect cognition, communication, sensation, activities of daily living (ADLs) and mobility.⁷ Rehabilitation after stroke often begins in the hospital and continues with community-based or home-based services once the patient is discharged.⁴ Discharges to inpatient rehabilitation is increasing with 25 percent of stroke patients being discharged to inpatient rehabilitation in Ontario.⁸ However, rehabilitation services are lacking. In Ontario only forty-two percent of acute stroke patients go to inpatient rehabilitation and too few have access to the services they require, as 41 percent of patients were discharged home without services.⁸ A report demonstrates that 87 percent of community-dwelling seniors who experienced stroke were restricted in their ADL's compared to 37 percent of seniors who had not experienced stroke.⁹ Cardiovascular fitness levels and walking

activity levels are exceptionally low¹⁰ with 42 percent of a population of seniors with stroke unable walk or requiring mechanical aid to do so.⁹ Balance deficits are associated with low walking activity.¹⁰ Other common causes of mobility deficits are muscle weakness and gait impairments,¹¹ such as reduced velocity¹², and increased variability¹³ and asymmetry.¹⁴ In fact, walking ability is the most commonly reported limitation following a stroke.¹ Not surprisingly then, it is also the deficit that receives the most attention in the rehabilitation setting with nearly 40 percent of time spent in physiotherapy focused on gait activities.² However, despite gains made in rehabilitation, post-stroke gait still remains slow, variable and asymmetric.^{7,11} Therefore, there is a significant need for the development of novel, effective and cost-efficient interventions that improve walking post-stroke.

Chapter 2

2 Mirror therapy

The use of MT in the rehabilitation setting dates back to the early 1990s. Dr. Vilayanur S. Ramachandran first proposed the use of a mirror to alleviate the pain associated with a phantom limb.¹⁵ Ramachandran theorized that the phantom pain experienced by amputees was the result of what he coined ‘learned paralysis.’¹⁶ When a motor command is sent to a muscle it is expected to be followed by proprioceptive sensory feedback from that muscle.¹⁷ In the case of an amputation the expected sensory feedback does not follow the motor command. The command will therefore be modified in an attempt to evoke the expected feedback. Additionally, the visual feedback received, after the motor command is sent to the muscle, informs the brain that the limb is not moving. This conflictive state between motor and sensory information causes a form of ‘learned paralysis.’¹⁶ Often this form of paralysis can be learned while the limb is still intact, but damaged due to peripheral nerve injury.¹⁶ After spending a period of time learning the intact limb is paralyzed, the learned paralysis transfers to the phantom once the limb is amputated.¹⁶ The proposal holds that if the paralysis could be ‘learned,’ then it could also be ‘unlearned,’ with the ultimate goal of mirror therapy to restore the motor command and sensory feedback loop that has been disrupted.¹⁷

Ramachandran and Altschuler¹⁶ postulate that a form of paralysis analogous to the ‘learned’ paralysis experienced by amputees may exist in patients with stroke. Apart from the permanent damage to the brain experienced after stroke, the swelling and edema that persists in the brain for days to weeks following stroke results in a temporary loss of corticofugal communication to the limb which also impairs sensorimotor function. This

may leave a form of learned paralysis behind after swelling subsides and signals are restored.¹⁶ Accordingly, in 1996 Ramachandran and colleagues suggested the use of mirror therapy for the rehabilitation of hemiparesis following stroke.¹⁵

The mirror therapy process is designed to trick the brain into experiencing movements in the paralyzed or ‘resurrected’ phantom limb.¹⁶ With a mirror situated at the midline of a patient, the affected limb is placed behind the mirror, out of view, and the intact limb is placed in front of the mirror’s reflective surface. Viewing the reflective surface, the patient sees the superimposition of their intact limb over their affected limb. When performing movements with the intact limb a visual illusion is created making it seem as though the affected limb is moving just as coordinated and fluid as the intact limb. Visual illusions are powerful because the brain prioritizes what is seen over what may actually be occurring via other sensory pathways.¹⁸ In healthy participants it has been shown that cortical activation stemming from visual feedback is present even when the proprioceptive information is not aligned with the visual information of their limb in space.¹⁹ With one hand held still behind the participant’s back, cortical activity in the contralateral hemisphere/primary motor cortex can be generated simply by viewing the an image of that hand moving in a mirror, even when it is the opposite hand actually performing the movement.¹⁹ The hypothesis that follows is that the visual feedback of coordinated and fluid movements observed in the reflected image of an affected limb is prioritized over the proprioceptive or somatosensory feedback concerning how the affected limb is actually performing behind the mirror.¹⁸ Therefore, since motor programming is dominated by how we see a limb moving,¹⁹ it can be theorized that even a brain damaged by stroke can be ‘tricked’ into recovery. Furthermore, in a study of

healthy participants using a single pulse of transcranial magnetic stimulation (TMS), the authors found that excitability in the primary motor cortex (M1) ipsilateral to unilateral movements is facilitated by a mirror reflection of the moving unilateral hand, leading them to suggest that “this finding provides neurophysiological evidence supporting the application of mirror therapy in stroke rehabilitation.”²⁰

As previously noted, MT was initially proposed as a treatment to alleviate the pain and discomfort associated phantom limbs. Ramachandran and Rogers-Ramachandran authored a break-through study, introducing the mirror box device to the field of neurorehabilitation.¹⁵ In this study, 10 individuals with upper limb amputation, ranging from 19 days to 9 years post-amputation, were studied. The patients were instructed to imagine mirror symmetric movements in their minds with their eyes closed. Nine out of 10 patients self-reported that the phantom limb would remain frozen when performing this task. Patients were then asked to perform the same task while looking into a mirror which reflected their unaffected limb superimposed over the phantom limb. Tactile stimuli (eg. touching the hand) were delivered to the unaffected limb while they performed the task. Varying protocols with minor testing differences were used between patients, as testing was done in a clinical setting, however the following main findings were documented after the initial use of the mirror box. Six patients reported the sensation of their phantom limb moving. Four patients who reported experiencing involuntary ‘clenching spasms’ in the phantom were relieved of the spasms. Referral of touch sensations to the phantom limb was documented in 4 patients, especially when they saw their phantom being touched in the mirror. Repeated uses of the mirror box, ranging from 8 sessions in some cases to allowing the participant to take the mirror box home for

a few weeks in other cases, yielded similar results. Astonishingly, one patient experienced a complete disappearance of the phantom limb after 3 hours of repeated practice.¹⁵ The authors also tested the mirror box on healthy control participants and found no referral of sensations, leading to the conclusion that the effects they had discovered were unique to phantom limbs.¹⁵ This study demonstrated that MT could alter what was believed, at the time, to be a permanent cortical representation of a painful, clenched phantom limb.¹⁵ The authors proposed that the study provided supporting evidence for the formation of new pathways and cortical reorganization in the adult brain.¹⁵ The authors also highlighted the therapeutic implications for the use of MT in the seemingly irreversible neurological conditions following a stroke.

2.1 Mirror therapy and stroke

2.1.1 Upper-extremity

MT post-stroke has been examined in a number of clinical case series and randomized controlled trials. A recent systematic review of the literature performed by Rothgangel and coworkers²¹ outlines the clinical aspects of use of MT post-stroke. The following section will describe the findings of a number of studies investigating the use of MT in post-stroke rehabilitation.

The first placebo-controlled cross-over trial for the use of mirror therapy in stroke was conducted in 1999.²² Nine participants were randomized to spend 4 weeks of mirror therapy performing bilateral movements of the upper-extremities (UE) or 4 weeks of control therapy which included the same movements while using a transparent sheet of plastic in place of the mirror. The participants then switched groups. Subjectively, the

participants enjoyed using the mirror more and thought is more helpful than the transparent plastic. Two blinded raters, found that significantly more patients improved in movement ability, such as range of motion, speed and accuracy, while using the mirror than the control.²²

The following year a case study was published that followed a male, approximately 6 months post-stroke, who experienced profound sensory deficits.²³ After beginning a treatment regimen involving MT, the patient became so influenced by its perceived effect on his recovery that he constructed his own MT device for home use.²³ After 3 months of MT the patient exhibited marked increases in motor recovery and function including improved grip strength , range of motion and functional reach.²³ Interestingly, with severe somatosensory deficits that patient heavily relied on vision to guide movements, which may account for his heightened response to the illusory visual feedback created by the mirror.²³

In 2003 a case series of two chronic stroke patients was conducted.²⁴ The authors were interested in motor imagery training and therefore combined MT, which they termed ‘mirror box-facilitated imagery,’ with computer-facilitated imagery of movements made by the UE over a period of 4 weeks with three 1-hour sessions per week. For the MT portion of the study, the patients were told to “imagine that the reflected limb is in fact your limb moving about physically in space.”²⁴ Complexity of the tasks performed during MT was increased as the study progressed. A battery of upper-extremity functional tests was conducted pre-treatment, three times throughout the intervention period and twice during the follow-up period. Over the course of the intervention period motor impairment, as measured by the Fugl-Meyer assessment (FM), consistently

improved with small increases continuing at follow-up. Both participants improved by 1 point on the arm and hand dimensions of the Chedoke-McMaster Stroke Assessment (CMSA) during the intervention period. Finally, speed of arm movements increased post-treatment, even though the intervention focused on movement accuracy, not speed.²⁴ The authors suggested that the MT-related motor imagery creates visual feedback of successful performance of the imagined action with the impaired limb.²⁴

A second RCT of 18 chronic stroke patients was conducted by Rothgangel et al.²⁵ Gross arm and hand movements and fine motor movements of the fingers were performed using a mirror at that patient's midline. Patient's replicated the movements with the affected limb behind the mirror, however the movements were facilitated by a therapist. The control group performed the same movements, facilitated by a therapist, without the mirror. Both inpatients and outpatients participated in the study. The treatment protocol for the inpatient group was 60 minutes a day, for 4 days a week, for 5 weeks. Outpatients only performed the treatment for 2 days a week over the same 5 weeks. Outcomes were measured at pre-test, mid-test, post-test and at follow-up 5 weeks after treatment. Significant differences in upper limb function, as measured by the Action Research Arm Test (ARAT), were found favoring the inpatients of the MT group (+8.4 score increase compared to a +1.2 score increase). For the outpatients, there were clinically relevant differences between the MT and control groups, though these were not significant. No effects between groups on spasticity were found.²⁵

In the late 2000's a group of researchers from Ankara University, Turkey, performed a larger RCT of MT post-stroke, focusing on the UE.²⁶ This study included 40 patients in the sub-acute phase of stroke. Half were assigned to the mirror group

performed MT for 30 minutes a day, 5 days a weeks, for 4 weeks in addition to their conventional stroke rehabilitation program. The control group received a sham therapy that consisted of an opaque divider in place of the mirror. In this form of MT the non-affected hand was obstructed from view so that the participant could only see the reflection of the noninvolved hand superimposed over the affected hand. Motor recovery, spasticity and self-care as measured by the Functional Independence Measure (FIM) were the outcomes of interest, measured at pre-treatment, post-treatment and at a 6 month follow-up. Following treatment, motor recovery of the UE as measured by the Brunnstrom stages (BS) showed significant improvement in the mirror group over the control and the self-care scores showed a significant difference as well.²⁶ Moreover, these improvements remained significant at follow-up. No differences to spasticity were uncovered.²⁶ Of note three participants in the mirror group and one in the control group dropped out of this study because of economic reasons.

Another RCT, conducted in 2009, performed an upper-extremity mirror therapy intervention on 48 patients less than 8 weeks post-stroke who were currently in inpatient rehabilitation.²⁷ The intervention lasted 6 weeks with the two groups performing 30 minutes of training a day, 5 days a week, in addition to their standard therapy. Both groups performed the movements bilaterally, with the control group having complete view of the affected limb. Patients, unaware of group allocation because of an unknown hypothesis, had their motivation and cooperation controlled for during the treatment sessions by documentation of the patient's vigilance and alertness to remove treatment bias.²⁷ Outcome measures included the FM a 5-point neglect test, the ARAT, and motor sections of the FIM. Motor recovery scores, range of motion, pain scores and functional

independence scores showed no therapy effect. However, a subset of patients with the most severe distal hemiparesis in the MT group regained more distal function than those in the control group. Moreover, recovery of neglect and surface sensibility (light touch subscore of the FM) did significantly improve in favour of the MT group.²⁷ With the most profound improvements noted in densely hemiplegic patients with little distal function, the authors concluded that the effect of MT on recovery may be most noticeable in this population and even more profound if applied in the early phase after stroke.²⁷ It should be noted that 25% of patients, equal between groups, dropped out from this study, for reasons such as medical worsening (control =1), withdrawal of consent (control = 2, mirror =1), lack cost approval by health insurance (control = 1, mirror = 4) and transfers to acute care (control =2, mirror = 1). No indication was reported as to whether the medical worsening or transfers to acute care were related to the treatment.

In summary, upper extremity MT post-stroke is associated with improvements in motor function such as range of motion,²² speed^{21,23} and accuracy of movements,²² and enhanced motor recovery.^{23,25} MT is also associated with reduced neglect, improved sensation²⁷ and greater functional independence.²⁶

This variability in reported outcomes of MT is at least partly explained by the following factors upon which studies differ (1) outcome measures; (2) phase of stroke studied and (3) different treatment protocols in terms of frequency, duration and the movements practiced. Studies to date have not provided sufficient information on clinical protocols in order to drive clinical recommendations for the use of MT.²¹ However, MT should be regarded as a safe intervention. In some cases participants were unable to attend follow-up assessments due to socioeconomic reasons,²⁶ lack of insurance funding,

or medical worsening²⁷ but none of the reviewed studies above indicated any side effects of the MT treatment, nor did the investigators report any observed adverse events during the treatment protocols. Therefore, it has been concluded that at the very least MT could be applied as an adjunct intervention in the rehabilitation of patients post-stroke.²⁸

2.1.2 Lower-extremity

While UE-MT post-stroke has received considerable attention, to date, only two studies have investigated the effects of MT on lower-extremity function. With a group of 40 patients less than 12 months post-stroke, Sütbeyaz and coworkers set out to determine if MT would help restore function in the paretic lower-extremity.²⁹ This RCT followed the patients through a conventional stroke rehabilitation program with a duration of up to 5 hours a day, 5 days a week, for 4 weeks. The experimental group received 30 minutes of MT per day, in addition to their conventional therapy that consisted of non-paretic ankle dorsiflexion movements only. The control group performed the same movements however the non-reflecting side of the mirror was used. Outcomes assessed were motor recovery, as measured by BS, spasticity, as measured by the Modified Ashworth Scale, motor functioning, as measured by FIM, and walking ability, as measured by Functional Ambulation Categories (FAC). Assessments were conducted pre-treatment, post-treatment and at follow-up. Seven patients (3 in the mirror group and 4 in the control group) did not attend follow-up assessments. All outcomes significantly improved post-treatment over baseline and continued to improve at follow-up.²⁹ Motor recovery scores and FIM motor scores showed significantly more improvement at follow-up in the mirror group over control, whereas spasticity and walking ability showed no differences.²⁹

A more recent RCT, conducted in 2013, also examined the effectiveness of mirror therapy to improve function of the lower-extremities post-stroke.³⁰ A sample of 22 patients (mirror group = 11, control group = 11) in the acute phase of stroke underwent a two week rehabilitation program that spanned 1 hour a day, 6 days per week. The mirror group received an additional 30 minutes of MT per day. The MT consisted of functional movement synergies using of the hip, knee and ankle joints in half-lying position and sitting position of the non-paretic limb only. The control group performed the same movements in the same positions for the same duration but used the non-reflective side of the mirror. Primary outcomes, measured at baseline and at the end of the two week treatment period, were motor recovery (as measured by LE section of FM), balance as measured by the Brunel Balance assessment (BBA) and mobility (FAC). Secondary outcomes measures were the BS and modified composite spasticity index. Both groups completed all sessions without adverse events during treatment. After treatment all outcome parameters significantly improved in both groups. Between groups the change score of FAC was only outcome that showed significantly more improvement in the mirror group. It was suggested that this finding to potentially be a result of improved FM scores in the mirror group post-treatment,³⁰ as FM lower-extremity score is positively correlated to change in FAC score.³¹

Neither study of post-stroke LE-MT reported any side effects of the treatment, nor did the authors observe any adverse events, although 18% of participants missed the follow-up assessment due to socioeconomic reasons in the Sütbeyaz *et al.* study.²⁹

2.2 Mechanisms of mirror therapy

Researchers have attributed the positive effects of MT to three interconnected hypotheses:

- (1) Motor networks may become activated because of increased attention towards the affected limb, which is mediated by the illusion of a paretic/amputated limb that has been “healed.” Stroke patients may end up in a state of “learned non-use” of the paretic limb,³² therefore similar to the rationale for constraint-induced therapy MT is said to increase the patient’s attention toward the affected limb,¹⁷ which in turn increases use of that limb and enhances limb function.
- (2) There are motor pathways that originate in the unaffected hemisphere and project ipsilaterally to the paretic side of the body. These ipsilateral projections may become unmasked and MT may promote the recruitment of these pathways for movement of the affected limb.³³
- (3) Mirror neurons are unique neurons in the premotor cortex that activate when an individual performs an action and when that individual observes that action being performed. Since MT is a form of action observation, it is therefore believed to activate the mirror neuron system.¹⁷ Areas of the brain that include the mirror neuron system activated through action observation excite the corticospinal pathway inducing motor learning and neurorehabilitation.³⁴

A number of neuroimaging studies have been conducted giving rise to a systematic review published in 2014 that summarizes the effect of mirror therapy (referred to as mirror visual feedback by the authors) on the brain.¹⁷ The sample of

studies reviewed examined MT on both healthy subjects and stroke patients using fMRI, MEG, EEG and PET neuroimaging modalities. The usual type of MT employed was bilateral, meaning both the active UE and its reflection were visible to the participant. Some studies assessed the neuroplastic changes in response to a single bout of practice or an MT intervention. The conditions being compared were often normal visual feedback of the two limbs to mirror visual feedback using a real mirror or virtual reality environment, though some studies use only visual feedback of the active or static limb only as a control. Some studies, but not all, used measures to avoid systematic variation, such as metronome paced movements or an EMG recording. Main findings reveal that MT activates a broad neural network dedicated to attention and action monitoring, exploits ipsilateral control of the affected limb, and appears to exert a modulatory effect (an increase in activity) on the motor network.¹⁷ Post-stroke bilateral mirror visual feedback increases activity in M1 and the precuneus ipsilateral to the moving limb reflected in the mirror, and in the posterior cingulate cortex and precuneus contralateral to the moving limb reflected in the mirror.¹⁷ Furthermore, when measured while performing MT this activation becomes significant during bimanual movements (the affected limb matching the unaffected limb movements behind the mirror) whereas no significant activation is achieved with unilateral movements.³⁵ The precuneus is known to be associated with visuospatial information processing and directing spatial attention.³⁶ The cingulate cortex becomes activated during spatial navigation and processes information about spatial positioning of the limbs.^{36,37} Evidence based on a bout of practice or a MT intervention suggests a shift in brain activation during affected limb movement toward the M1 of the affected hemisphere.³⁹ This indicates increased activation of the affected

cortex and/or decreased activation of the contralateral cortex,^{39,40} meaning restoration of the hemispheric balance disrupted by the stroke.¹⁷ In addition there is accumulating evidence that suggests the motor threshold of the M1 ipsilateral to the active hand is decreased by MT enhancing corticospinal output of the ipsilesional M1 in stroke patients, mediated through a reduction in interhemispheric and/or intracortical inhibition.¹⁷ Although, complete reversal of lateralization is unlikely¹⁷ and is less than ideal for promoting motor recovery post-stroke compared to increased activation of M1 of the affected hemisphere.⁴² The authors of the review concluded that MT may impact a number of different networks in the brain and thus can serve as a versatile intervention to promote recovery with the actual mechanism being dependent on the specific condition or damage.¹⁷

Chapter 3

3 A new mirror therapy device

3.1 Rationale for the current LE-MT device design

Mirror therapy is a promising intervention for improving limb function and managing pain after hemiparesis. MT can be performed with the only requirement being the mirror.²² However, to maintain the illusion of MT it is desirable to keep the affected side of the body obstructed from the patient's view. While easily accomplished for the UE by angling the patient in such a way that they cannot see the affected side,^{25,26} in long-sitting the paretic LE is more difficult to obstruct from view. Nonetheless, a LE-MT device can be constructed by simply using a mirror tilted on a stand.³⁰ The following section will describe the rationale for a new design of a MT device designed to train bilateral movement and thus includes a means to guide paretic leg movement.

The original application of MT was with amputees where there was no affected limb to actually move. For individuals post-stroke, applying MT to meaningful and fluid movements of the paretic lower-extremity can be difficult because of the associated physical deficits that occur after a stroke. Following a stroke, abnormal timing of muscle activation reduces limb function and increased passive tone and spasticity act to resist joint movement,⁴³ presenting challenges for stroke patients in controlling the paretic LE. This may explain why previous studies^{28,29} chose to perform unilateral LE-MT with the unaffected limb only, as performing movements with a paretic limb in a sitting position without a means to guide those movements would be a difficult and taxing task for a stroke patient. However, bimanual MT produces significant activation in brain processes whereas unimanual MT does not,³⁵ and when compared to unilateral exercise, bilateral

exercise leads to greater improvements post-stroke.⁴⁴ To accomplish bilateral LE movements with a means to facilitate the movements in long-sitting, it was then determined that slider boards could be used. Additionally, cloth straps were included on the heel blocks of the slider boards to secure the LE's to the device to prevent the limb from falling from the slider board during movement. To complete the device and create the required illusion of the paretic LE moving correctly a 'box' was designed containing a black curtain which housed the paretic leg slider board, obstructing the patient's view of their leg once in long-sitting. To my knowledge this is the first MT device to incorporate slider boards within a concealment box alongside the standard mirror.

3.2 Prototype development and construction

Design and physical construction of the prototype LE-MT device was undertaken by me and co-advisor Janet Brown (JB). The device includes a base constructed of wood that securely houses the mirror in a vertical position and two slider boards on either side. The base also houses a vertical wall made of Styrofoam. Attached to the mirror and draped over the wall is a black curtain. (See Appendices for concept sketches and Figure 1 for an image of the final device).

3.3 Application of the current LE-MT

Participants use the LE-MT device in long-sitting. The mirror is located along the midline of the body between the participant's LEs. The participant then performs bilateral and simultaneous flexion-extension movements of the LEs, whilst viewing the movements of the unaffected limb on the mirror's reflective surface (see Figure 2).

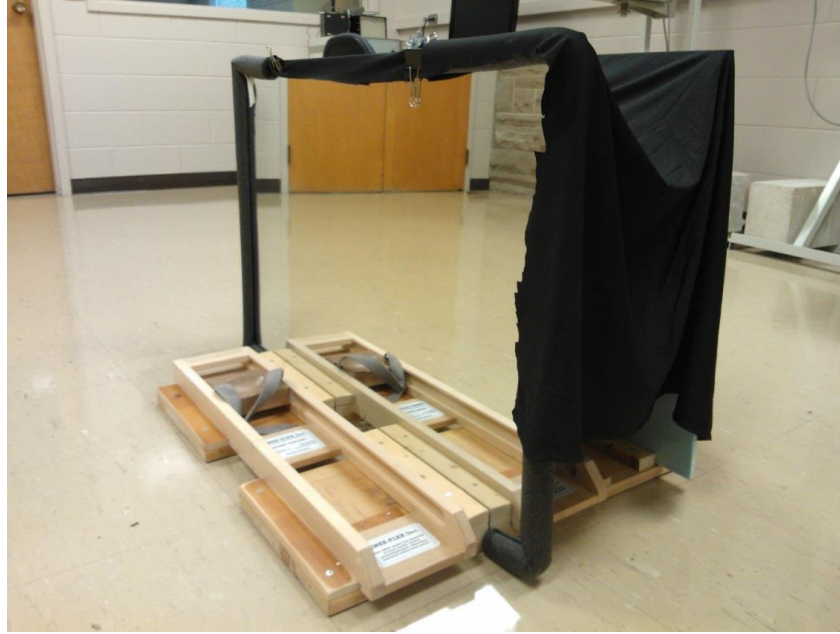


Figure 1. The current LE-MT device.

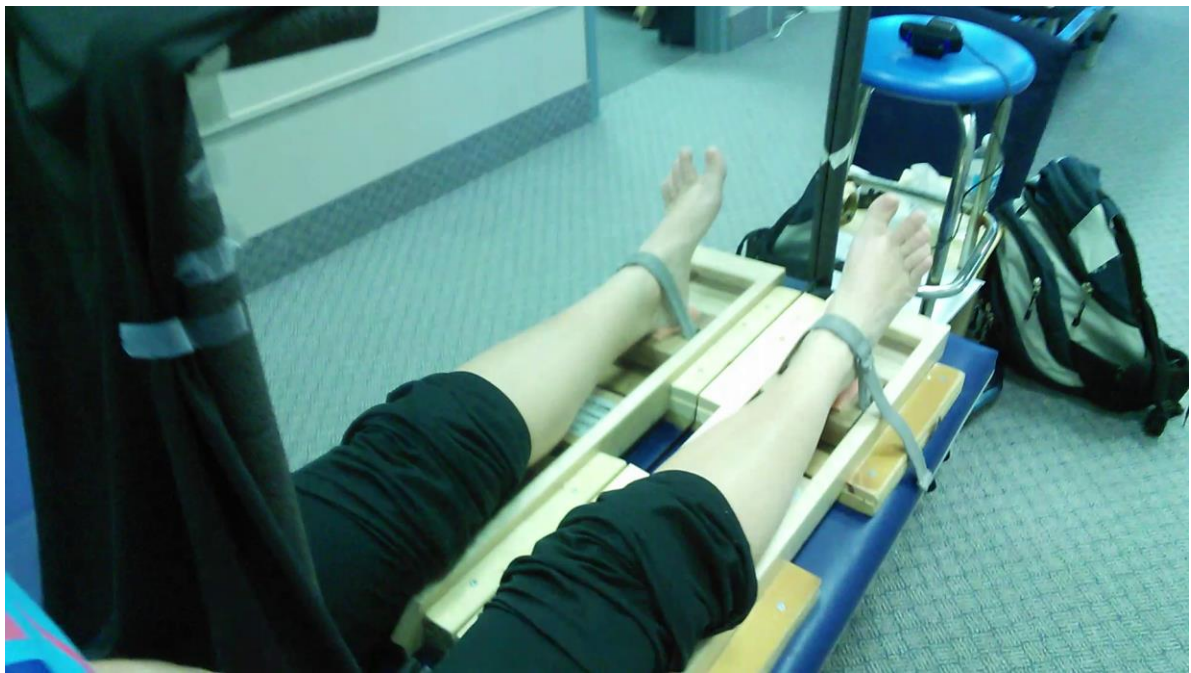


Figure 2. The current LE-MT device in use from the point of view of the user.

3.4 Demonstration and feedback on the current LE-MT

After completion, the prototype was brought to Neuphysio Rehabilitation in London, Ontario for trial and feedback prior to use for study purposes. The aim of the trial period was to determine: (1) if the desired movements could be performed on the device; (2) if the mirror's reflective surface was able to be viewed by the user while performing the movements, and; (3) if the therapists had any ideas about improving the device for better use. A volunteer was able to easily perform the desired movements and see the reflected image of their limb while performing those movements. There were two main comments from the therapists. First, the therapists noted the possibility of the affected limb making contact with the outer wall of the concealment box. They speculated that if this were to occur, the tactile sensation received by the affected limb could interfere with the intended visual illusion. This feedback was used to guide observations of patient performance during the study presented in Chapter 5, to ensure the contact did not occur. Second, the therapists noted the possibility of training compensatory movements of the affected limb, such as the affected limb falling into hip abduction, when the desired movements (and visually perceived movements) are hip flexion and extension. However, the goal of MT is less concerned about how successful the movement behind the mirror is or how it is achieved and more concerned about providing a visual illusion of the affected limb moving well to induce some neuroplastic change that, in turn, is associated with improved motor control and movement. More specifically, the goal of MT is to couple the motor command sent to the affected limb with the visual feedback of the movement expected by the motor command.

Chapter 4

4 Stroke outcome assessment: motor recovery, balance, gait

The following chapter will describe some the measurement methods employed in the stroke rehabilitation. Clinical measures include the National Institutes of Health Stroke Scale, which characterizes stroke severity, the Chedoke McMaster Stroke Assessment which measures motor impairment following stroke, and the Berg Balance Scale which assesses balance.

4.1 Stroke severity

The National Institutes of Health Stroke Scale (NIHSS) is a tool used to objectively measure the impairment caused by a stroke. It contains 11 items, each with an ordinal grading scale of 0 to 2, 3, or 4. A score 0 indicates normal function for the specific item, while a higher score indicates an increasing level of impairment. A score of 21 to the maximum possible score of 42 indicates a severe stroke and on the opposite end of the spectrum a score of 1 to 4 indicates a minor stroke or no stroke symptoms at a score of 0. The NIHSS is a valid and reliable measure of stroke severity.⁴⁵

4.2 Motor impairment

Motor impairment can be assessed using the Chedoke McMaster Stroke Assessment (CMSA). The impairment inventory incorporates seven stages of motor recovery, ranging from flaccid hemiparesis at stage 1 to normal functioning at stage 7.

The CMSA is a valid and reliable measure of both motor impairment and disability following stroke.⁴⁶

4.3 Balance

Balance can be assessed in stroke rehabilitation using the Berg Balance Scale (BBS). The BBS is comprised of 14 balance-related tasks. Each task is objectively rated on a 5-point scale ranging from unable to balance oneself (score of 0) to independent balance (score of 4). The interpretation of a complete score of 41 to 56 indicates independent walking, 21 to 40 indicates walking with assistance, and 0 to 20 indicates the patient should be wheelchair-bound. The BBS is a useful and psychometrically sound measure of balance impairment for use in post-stroke balance assessment.⁴⁷ When used to assess change in balance function in stroke patients a difference in score of 6 between assessments would indicate genuine change.⁴⁸

4.4 Spatiotemporal gait parameters

Spatiotemporal gait parameters are frequently used to characterize post-stroke gait.^{10,48,49} Gait parameters are commonly measured using a pressure sensitive mat⁵¹ which individuals walk across while timing and placement of footfall events are recorded. Analysis software then computes the gait parameter mean scores of the walks and exports the data in a spreadsheet.⁵²

Typical parameters to provide useful information on gait, and those of interest to this thesis, are gait velocity, spatial variability (step length), temporal variability (swing time), spatial symmetry (step length ratio), and temporal symmetry (swing time ratio).

Gait velocity is measured in centimeters per second. Standard deviation (SD) is recommended for calculation of gait variability for post-stroke gait.¹³ The gait symmetry ratio between the lower limbs is measured by dividing the larger length (or larger time) by the smaller length (or time). A ratio of 1 is indicative of perfect gait symmetry.⁵³

4.4.1 Measuring change in spatiotemporal gait parameters

The measurement of meaningful improvement in outcome measures is described as the minimal clinically important difference (MCID), which is said to be the smallest difference in an outcome score that is considered worthwhile or important.⁵⁴ To improve the interpretability and meaningfulness of change scores derived from outcome measure scores, it is recommended to report case patient progress relative to MCID values.^{54,55} MCID values have been published for the above gait parameters. Gait velocity, step length variability and swing time variability have MCID values of 6 cm/s, 0.25 cm, and 0.01 s, respectively.^{56,57} MCID values have not been published for gait symmetry. However it is possible to compare symmetry ratio scores to published symmetry ratio thresholds for post-stroke gait. Step length symmetry and swing time symmetry have a symmetry ratio threshold of 1.08 and 1.06 respectively.⁵³ A symmetry ratio score of greater than the threshold is considered asymmetric gait.⁵³

Chapter 5

5 The feasibility of a novel bilateral lower-extremity mirror therapy intervention for individuals with stroke: a case series.

5.1 Abstract

The purpose of the study was to investigate the feasibility and potential effects of a bilateral lower-extremity mirror therapy (LE-MT) intervention on motor impairment, balance and gait after stroke.

A case series with three individuals post-stroke is presented. Twelve 30 minute LE-MT sessions were delivered as an adjunct to conventional physiotherapy. Outcomes assessed at baseline, post-intervention and follow-up included the National Institutes of Stroke Scale (NIHSS), Chedoke McMaster Stroke Assessment (CMSA), Berg Balance Scale (BBS) and spatiotemporal gait parameters. Changes in gait parameters were reported in multiples of meaningful clinically important differences (MCIDs).

All participants performed a greater number of movement repetitions at the last LE-MT session compared to the first. One participant reported an acute episode of pre-existing low back pain outside of the LE-MT sessions. Gait velocity improved in one case (2.6 MCIDs) with trends for improvement in the others. Step variability improved in two cases (7.1 and 2.0 MCIDs). Motor control of the leg improved as measured by CMSA (1 case) and the NIHSS ataxia item (2 cases).

A LE-MT adjunct intervention for stroke is feasible. However, a history of low back pain may be a precaution. LE-MT may have positive effects on motor impairment and gait. Future work will explore the dose-response relationship and the relationship of movement strategy employed during LE-MT and outcomes.

5.2 Introduction

Impairments in strength, coordination and balance lead to gait complications post-stroke⁵⁸ and improving gait is the number one rehabilitation goal stated by individuals

with stroke.¹ Despite improvements made with rehabilitation, post-stroke gait remains limited at discharge. For example, post-stroke gait is slower and more asymmetric compared to healthy adults.^{3,4} Therefore, new interventions are needed to improve walking outcomes post stroke. Mirror therapy (MT), has promise as a beneficial adjunct treatment to existing gait rehabilitation protocols and could lead to improved walking function after stroke.

First used in the mid 1990's by Dr. Ramachandran as a means to treat phantom limb pain,¹⁵ MT is an intervention designed to superimpose unaffected limb movements over the affected extremity using a mirror's surface, thus "tricking" the brain with the perception of intact movements of an affected limb. MT is associated with improvements in the upper limb post stroke. Greater gains in motor recovery,^{25,26,38} decreased pain,^{9,10} improved sensation and neglect²⁷ and improved speed and accuracy of movement²² are some of the associated benefits. (See Thieme et al.²⁸, Rothgangel et al.²¹ and Ezendam et al.³³ for reviews).

Despite success with MT in the upper limb post-stroke, there is little work on the benefits of MT for the lower-extremities (LE-MT). Two previous studies have examined the impact of LE-MT on gait and balance post-stroke. Sütbeyaz and colleagues performed a randomized controlled trial (RCT) of ankle dorsiflexion LE-MT with 40 individuals with chronic stroke.²⁹ Participants demonstrated motor recovery on the BS and improved functional independence scores measured by the FIM compared to the control group, but no difference was observed in functional ambulation category (FAC). Mohan *et al.* conducted a RCT of six LE-MT exercises with 22 individuals with acute

stroke.³⁰ Findings included improved ambulation with LE-MT as measured by FAC but no differences between groups in BBA scores or motor recovery measured with the FM.

Both of these studies demonstrate the potential for LE-MT to improve stroke outcomes. However, there are some limitations that could be improved on. The findings from the study by Sütbeyaz and colleagues may have been limited by the use of FAC as a gait measure which is insensitive to change and would not reveal subtle walking changes associated with LE-MT.⁶³ Spatiotemporal gait assessment, including velocity, spatiotemporal symmetry and variability has been recommended to capture more detailed information about gait and may be more sensitive to change.^{10,48,62} Moreover, in both studies, LE-MT involved unilateral non-paretic LE movements, yet research shows that bilateral exercise can lead to greater improvements post-stroke.⁴⁴ Therefore, bilateral movements during LE-MT might further improve outcomes.

The overall objective of this case series is to describe the feasibility of a novel, bilateral, multi-joint LE-MT intervention. A secondary objective is to investigate potential effects of the LE-MT intervention on LE motor recovery, gait and balance function post stroke.

5.3 Methods

Participants were individuals with stroke receiving outpatient physiotherapy from a private clinic. The study was approved by the local Research Ethics Board and all participants provided written informed consent.

5.3.1 Bilateral Lower-Extremity Mirror Therapy Intervention

The LE-MT intervention involved 12 sessions completed over a 4 week period. The intervention was conducted as an adjunct to each participant's conventional physiotherapy which continued throughout the study. The MT device (Figure 1a) was positioned so that the mirror was between the LEs with the affected extremity obstructed from view by a black curtain. The participant's feet were secured in heel blocks of slider boards. In long-sitting, the participants performed simultaneous bilateral LE flexion-extension movements while viewing the reflection of unaffected limb on the mirror's surface. Participants were instructed to perform the repetitions at their own pace and take rests as needed. The goal for session duration was 30 minutes but ultimately depended upon participant tolerance. A study investigator (LC) observed all sessions for every participant. Sessions were also recorded with a digital video camera positioned at the individual's midline in such a way that both LEs were in view (Figure 1b). The recordings were later viewed by a study investigator (LC) who recorded the number of repetitions completed and the amount of rest periods taken. A repetition was defined as one simultaneous and synchronous flexion and extension movement of both LEs. Comparable range of motion in the affected limb to the unaffected limb was not expected but some activation in the affected limb was required. A rest period was defined as a stop from repetitions for any amount of time in excess of 10 seconds. A second study investigator (SM) viewed 3 randomly selected recordings (one from each participant) and recorded repetitions and rest periods using the same criteria. The average percent difference in recorded repetitions and rest periods between investigators was 1.1% and 5.7% respectively.



Figure 3. The device used for the LE-MT intervention (a). The recording view of the intervention (b).

5.3.2 Outcome Measures and Outcome Assessment Protocol

The primary outcomes were over-ground spatiotemporal gait parameters measured with a pressure-sensitive mat.^a Participants performed 4 walking trials each at

their preferred and fastest possible pace with their customary gait aid (if applicable). The parameters were averaged over the 4 trials and included gait velocity, step length and swing time variability (standard deviation, SD),¹³ and step length and swing time symmetry ratios.⁵³ Secondary outcomes were clinical measures. Stroke severity was characterized with the National Institutes of Stroke Scale (NIHSS).⁴⁵ Functional balance was measured with the Berg Balance Scale (BBS)⁴⁷ and motor impairment of the LEs was measured with the Chedoke McMaster Stroke Assessment leg and foot.⁴⁶

Primary gait outcomes were measured twice at baseline; once immediately prior to LE-MT (BASE 2) and once 5 to 30 days earlier (BASE 1). Secondary outcomes were measured once at baseline. All outcomes were measured after completion of the LE-MT intervention (POST 1), and then once again at a follow-up assessment 4 to 6 weeks later (POST 2).

5.3.3 Data analysis

To investigate the potential effects of LE-MT we calculated changes scores for each of the primary outcomes over the time periods of interest; baseline, during LE-MT intervention and a follow-up. Change scores were calculated by subtracting the value at the earlier time point from the later time point as follows:

$$\text{BASE} = \text{BASE 2} - \text{BASE 1};$$

$$\text{TREAT} = \text{POST 1} - \text{BASE 2};$$

$$\text{FOLLOW-UP} = \text{POST 2} - \text{POST 1}.$$

Changes in velocity and variability were reported in terms of multiples of the meaningful clinical importance difference (MCID) values; 6cm/s for velocity, 0.25cm for step length variability and 0.01 sec for swing time variability.^{25,26} Since MCIDs were not available for gait symmetry, changes were analyzed in reference to the reported upper thresholds for symmetry in step length (1.08) and swing time (1.06).⁵³ Ratios greater than these thresholds are indicative of asymmetric gait. A symmetry ratio of 1.0 is considered perfect symmetry.

5.3.4 Intervention feasibility

Finally, we were also interested in the feasibility of the LE-MT intervention which we defined as ‘sessions well tolerated by individuals with hemiparesis with no adverse events’. We assumed evidence that the intervention was well tolerated would be maintenance or increase in number of repetitions and/or session duration over the 4 week intervention period.

5.3.5 Case 1 description

Participant 1 was a 56 year old female 43 months post-stroke with left hemiparesis and walked with a cane. Baseline scores for secondary outcome measures are outlined in Table 1. Her physiotherapy goals included improved balance and left LE function. She was enrolled in the study for 96 days: 30 day BASE period followed by a 38 day TREAT period and a 28 day FOLLOW-UP period. During BASE she received 4 sessions of physiotherapy which included LE exercise aimed at strengthening and range of motion and balance training in parallel bars and on steps. During TREAT she received 7 sessions of physiotherapy which included treadmill, bike and elliptical training, balance

training and strengthening of the LEs. During FOLLOW-UP she received 7 sessions of physiotherapy which included the same activities as her treatment during TREAT.

5.3.6 Case 2 description

Participant 2 was a 48 year old female 54 months post-stroke with left hemiparesis and walked with a cane. Secondary outcome measure values at baseline are summarized in Table 1. Her therapy goals were to improve gait and walk without her cane. She was enrolled in the study for 87 days: 11 day BASE period followed by a 34 day TREAT period and a 42 day FOLLOW-UP period. During BASE she received 3 sessions of physiotherapy which included mobilization, treadmill and bike training, and LE strengthening exercises. During TREAT she received 8 sessions of physiotherapy which included LE strengthening and stretching exercises, treadmill and bike training, mobilization with activator pole and balance training including yoga. During FOLLOW-UP she received 5 sessions of physiotherapy including LE stretching and strengthening exercises, treadmill training and mobilization.

5.3.7 Case 3 description

Participant 3 was a 69 year old male 58 months post-stroke left hemiparesis and walked without an aid. Baseline values for secondary outcome measures are outlined in Table 1. He was enrolled in the study for 74 days: 5 day BASE period followed by a 41 day treat period and a 28 day FOLLOW-UP period. He received 4 sessions of physiotherapy during that time. We were unable to conduct a chart review for Participant 3 as he discontinued his conventional physiotherapy for personal reasons and therefore we were unable obtain consent for the review.

5.4 Results

Table 1. Summary of clinical measures

	NIHSS			CMSA (leg / foot)			BBS		
	BASE 1	POST 1	POST 2	BASE 1	POST 1	POST 2	BASE 1	POST 1	POST 2
Participant 1	4	3	2	5 / 4	6 / 4	5 / 4	40	40	41
Participant 2	4	3	1	5 / 4	5 / 4	5 / 2	55	53	52
Participant 3	5	4	4	5 / 5	5 / 5	5 / 5	49	53	50
NIHSS = National Institutes of Health Stroke Scale, CMSA = Chedoke McMaster Stroke Assessment, BBS = Berg Balance Scale									

5.4.1 Intervention feasibility

The LE-MT intervention was completed with 100% adherence by Participants 1 and 2 with no adverse events observed during the sessions or reported by the participants. Participant 3 completed 83% of sessions. He missed the final 2 sessions due to an acute recurrence of pre-existing back pain but did attend POST 1 and POST 2 assessments.

The number of movement repetitions, rests and session duration per LE-MT session are displayed for each participant in Figure 2. The number of repetitions was greater in the final session compared to the first session for all three participants with a mean (standard deviation) difference of 406 (185) repetitions between these two sessions. The number of rests for the first and last session was 6 and 31 for Case 1, 10 and 1 for Case 2 and 12 and 11 for Case 3 respectively.

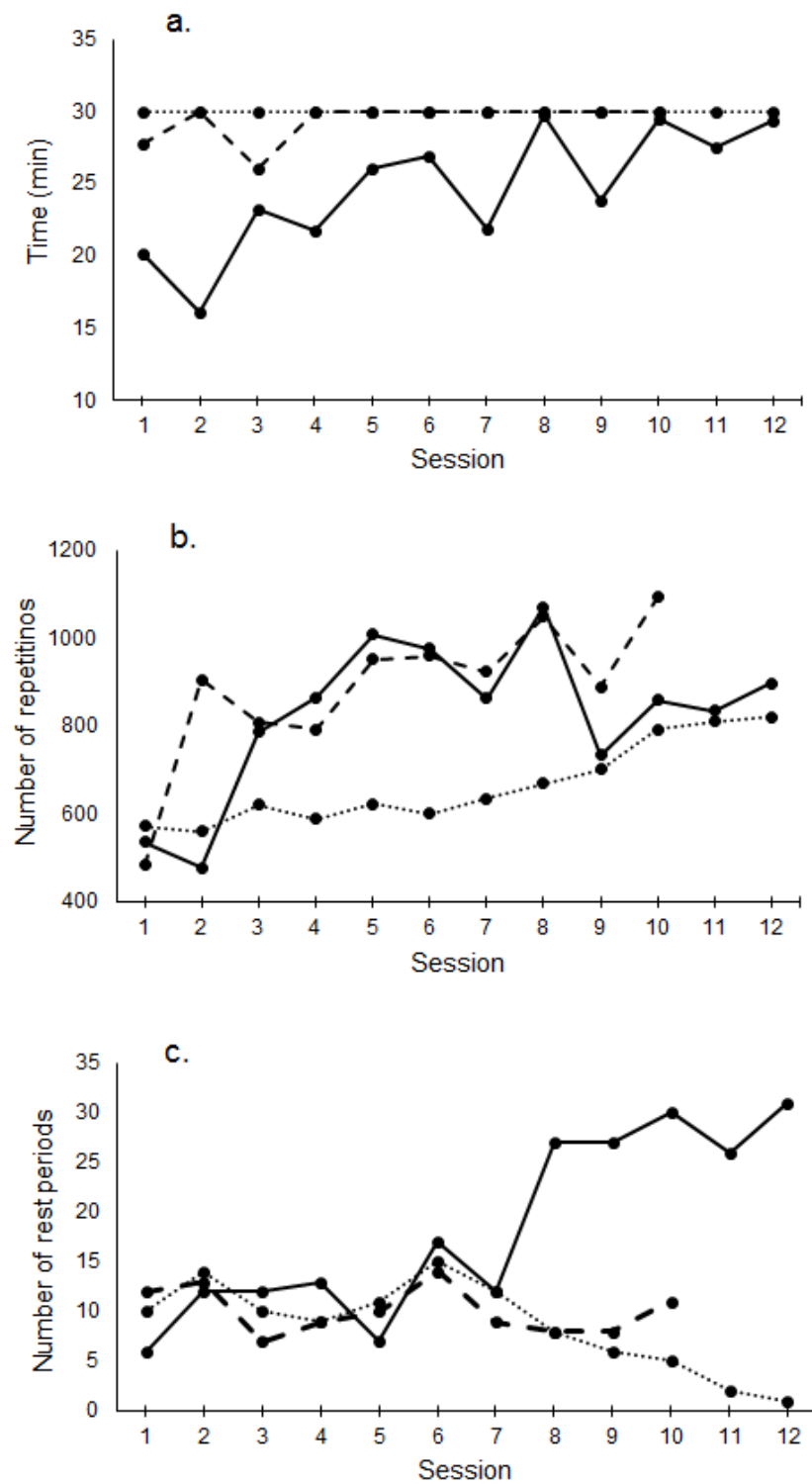


Figure 4. Performance during LE-MT intervention. a. duration of each LE-MT session; b. number of repetitions completed per LE-MT session; and c. number of rest periods taken per LE-MT session for Participant 1 (solid line), Participant 2 (dotted line), and Participant 3 (dashed line).

5.4.2 Primary gait and secondary clinical outcomes

Primary outcomes including gait velocity, variability and symmetry measured at each assessment time point over the course of the investigation are summarized in Figures 3 (preferred pace condition) and 4 (fast pace condition) for all three cases. Secondary outcome measures (NIHSS, CMSA and BBS) taken at POST 1 and POST 2 are summarized for each participant in Table 1. Secondary outcome measures that exhibited change from BASE and changes in gait variables that were equal to or greater than the MCIDs are described in greater detail for each participant below.

5.4.3 Case 1 results

5.4.3.1 Observed performance during LE-MT

For Sessions 1 through 7 Participant 1 completed movement repetitions and took rests as needed until she ultimately terminated the session due to fatigue. For Sessions 8 through 12 Participant 1 performed repetitions in blocks of 25 which was always followed by a rest. This pattern would carry on until she terminated the session due to fatigue.

5.4.3.2 Primary gait outcome measures

During BASE, preferred pace gait exhibited an increase in step length variability of 3.2 MCIDs. The step symmetry ratio moved from below (1.01) to above (1.09) the ST threshold indicating a change from spatially symmetric to asymmetric gait. The swing symmetry ratio remained below the ST threshold. Fast pace gait exhibited an increase in step length variability by 5.8 MCIDs. Both step and swing symmetry ratios remained below the respective ST thresholds indicating spatially and temporally symmetric gait.

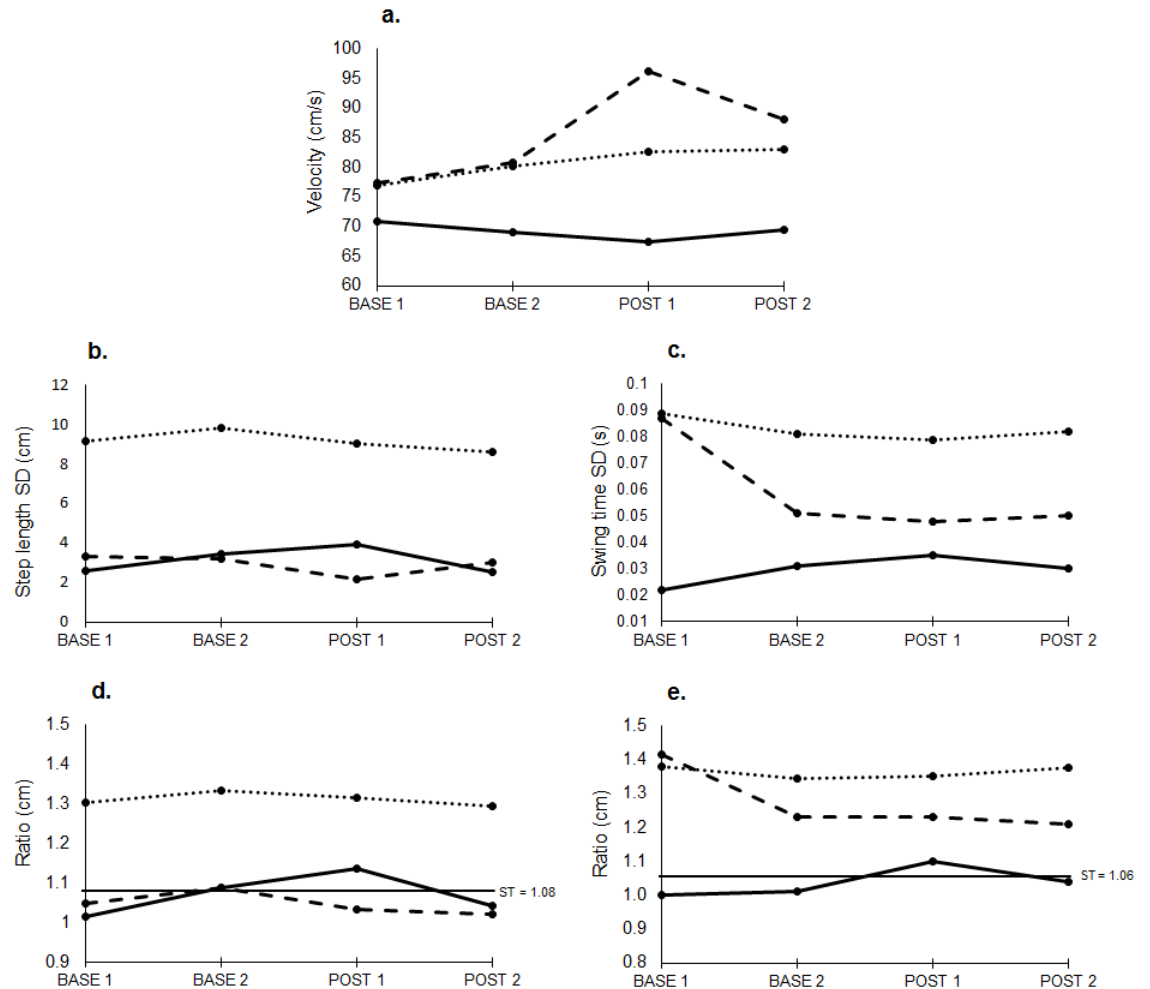


Figure 5. Spatiotemporal gait parameters (a. gait velocity; b. step length variability (SD); c. swing time variability (SD); d. step length symmetry; e. swing time symmetry) measured at each of the 4 assessment time points for the preferred pace with usual walking aid condition for Participant 1 (solid line), Participant 2 (dotted line) and Participant 3 (dashed line). SD = standard deviation; ST = symmetry threshold.

During TREAT, preferred pace gait exhibited an increase in step length variability of 2.0 MCIDs. Step symmetry ratio continued to increase away from the ST threshold (by 0.05) and the swing symmetry ratio increased to cross the threshold indicating a change from temporally symmetric to asymmetric gait. Fast pace gait exhibited an increase in

swing time variability of 1.0 MCIDs. Step and swing symmetry ratios remained below the respective ST thresholds indicating spatially and temporally symmetric gait.

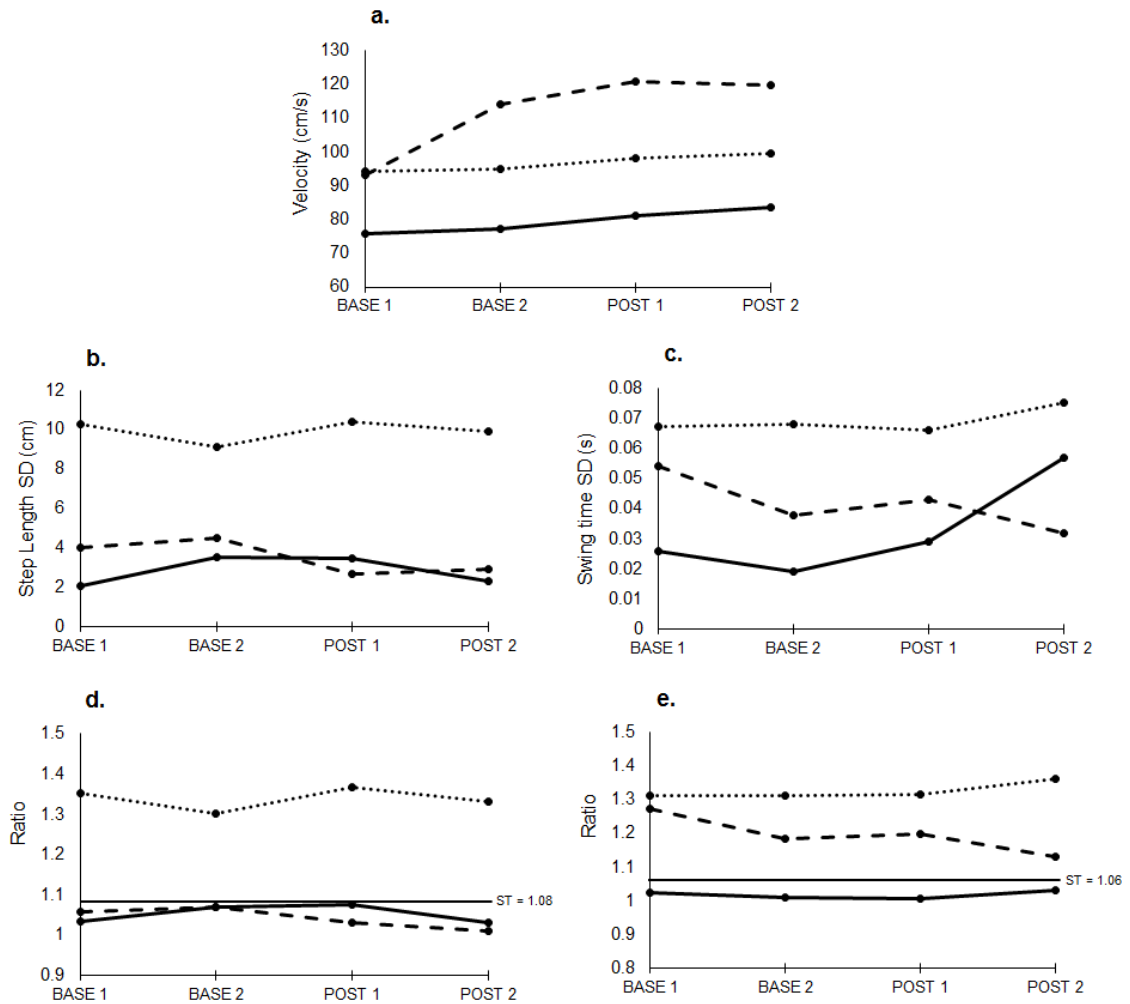


Figure 6. Spatiotemporal gait parameters (a. gait velocity; b. step length variability (SD); c. swing time variability (SD); d. step length symmetry; e. swing time symmetry) measured at each of the 4 assessment time points for the fast pace with usual walking aid condition for Participant 1 (solid line), Participant 2 (dotted line) and Participant 3 (dashed line). SD = standard deviation; ST = symmetry threshold.

During FOLLOW-UP, preferred pace gait exhibited a decrease in step length variability of 5.4 MCIDs and step and swing symmetry ratios became symmetrical again (crossing under the respective ST thresholds). Fast pace gait exhibited a decrease in step length variability of 4.7 MCIDs and an increase in swing time variability of 2.8 MCIDs. Step and swing symmetry ratios remained below the respective ST thresholds indicating symmetric gait.

5.4.3.3 Secondary clinical outcome measures

At the POST 1 time point the NIHSS had decreased to 3 and the CMSA leg score had increased to 6. At the FOLLOW-UP time point the NIHSS had decreased again to 2 and the CMSA leg score had decreased back to the baseline value (5).

5.4.4 Case 2 results

5.4.4.1 Observed performance during LE-MT

For all Sessions, Participant 2 completed movement repetitions and took rests as needed until the session duration goal of 30 minutes was reached.

5.4.4.2 Primary gait outcome measures

During BASE, preferred pace gait exhibited an increase in step length variability of 2.6 MCIDs. The step and swing symmetry ratios remained above the respective ST thresholds indicating asymmetric gait. Fast paced gait exhibited a decrease in step length variability of 4.7 MCIDs and both symmetry ratios remained above the ST thresholds.

During TREAT, preferred pace gait exhibited a decrease in step length variability of 3.2. Step and swing symmetry ratios remained above the ST thresholds. Face paced

gait increased in step length variability by 5.2 MCIDs and the symmetry ratios remained above the ST thresholds.

During FOLLOW-UP, preferred pace gait exhibited a further decrease in step length variability of 1.7 MCIDs. Step and swing symmetry ratios continued above the thresholds. Fast paced gait decreased in step length variability by 2.1 MCIDs and symmetry ratios continued above the ST thresholds.

5.4.4.3 Secondary clinical outcome measures

At the POST 1 time point the NIHSS had decreased to 3 and at the FOLLOW-UP time point the NIHSS had decreased again to 1. The CMSA foot score had also decreased to 2 at FOLLOW-UP.

5.4.5 Case 3 results

5.4.5.1 Observed performance during LE-MT

Participant 3 completed movement repetitions and took rests as needed until he either terminated the session due to fatigue (sessions 1 and 3) or until the session duration goal of 30 minutes was reached.

5.4.5.2 Primary gait outcome measures

During BASE, preferred pace gait exhibited a decrease in swing time variability of 3.6 MCIDs. The step symmetry ratio moved from below (1.05) to above (1.09) the ST threshold indicating spatially asymmetric gait while the swing symmetry ratio moved closer to the ST threshold (by 0.18) but still remained above it indicating temporally asymmetric gait. Fast paced gait increased in velocity by 3.5 MCIDs. Step length variability increased by 2.0 MCIDs and swing time variability decreased by 1.6 MCIDs.

The step symmetry remained below the ST threshold indicating spatial symmetry. The swing symmetry ratio moved closer to the ST threshold (by 0.09) but still remained above it indicating temporal asymmetry.

During TREAT, preferred pace gait velocity increased by 2.6 MCIDs and step length variability decreased by 4.2 MCIDs. The step symmetry ratio moved from above (1.09) to below (1.03) the ST threshold indicating a return to spatially symmetric gait. Swing symmetry ratio remained above the threshold. Fast paced gait velocity increased by 1.1 MCIDs and step length variability decreased by 7.1 MCIDs. The step symmetry ratio remained below and the swing symmetry ratio remained above the respective ST thresholds.

During FOLLOW-UP, preferred gait velocity decreased by 1.3 MCIDs and step length variability increased by 3.5 MCIDs. The step symmetry ratio remained below and the swing symmetry ratio remained above the respective ST thresholds. Fast paced gait decreased in swing time variability by 1.1 MCIDs. The step symmetry ratio remained below and the swing symmetry ratio remained above the respective ST thresholds.

5.4.5.3 Secondary clinical outcome measures

At the POST 1 time point the NIHSS had decreased to 4.

5.5 Discussion

This case series demonstrated that a 4 week bilateral LE-MT adjunct intervention is feasible to administer to individuals with chronic stroke. By the last LE-MT session all participants performed a greater number of repetitions compared to their initial session. This demonstrates that tolerance and endurance during LE-MT improved. Minor fatigue

but no pain was reported during LE-MT sessions. Unfortunately, one participant experienced an acute recurrence of pre-existing back pain outside of the LE-MT sessions. Although the exact cause that precipitated this acute episode was not identified, it is possible that it was related to the long-sitting position and repeated bilateral hip flexion movements required to perform LE-MT. Future work will consider pre-existing back pain as a possible precaution for the LE-MT intervention.

There was variation in the movement performance strategy employed by participants during the LE-MT sessions. Participants 2 and 3 exhibited a similar strategy which appeared to gradually build tolerance and was associated with a steady increase in movement repetitions and session duration over the 4 weeks. Although Participant 1 appeared to start out with this movement strategy, she eventually switched to performing movements in set blocks followed by rests which may explain the sharp increase in the number of rest periods from Session 7 to 8. It is important to note that while participants received standardized instructions to focus on the mirror image of their leg and perform the movements to the best of their ability, they were not instructed as to the number of repetitions to perform or a given movement strategy to employ. This raises the question about what are the critical elements for ensuring the effectiveness of mirror therapy; is it the movement strategy employed, the number of repetitions performed or the focus on the mirror image that matters?

This case series also demonstrated some interesting potential effects on gait. The interpretation of these changes is complicated by the fact that in some cases, participants exhibited change in gait variables during baseline. However, some of those baseline

changes reflected a decrement or decline in gait which were then reversed during the period of LE-MT (e.g. initial increase then decrease in step variability in Participant 2).

LE-MT appeared to have a positive effect on gait velocity and step length variability. Preferred and fast paced gait velocity increased with some of those effects seemingly lost at follow-up for Participant 3. Gait velocity showed a trend for improvement in Participant 1 (fast) and Participant 2 (preferred and fast) but none of these changes reached the level of MCID. LE-MT also appeared to have a positive effect on step length variability of preferred gait. Both Participant 2 and 3 exhibited decreased variability after the intervention. This decrease continued after the intervention but the magnitude of change was less. Participant 1 exhibited an increase in step length variability after LE-MT but this variability was already increasing (by a greater magnitude) during the baseline period.

LE-MT does not appear to have an effect on swing time variability, step symmetry or swing symmetry. Although Participant 1 exhibited an increase in swing time variability of fast paced gait after the intervention, this increase continued (and to a greater extent) during the follow-up period indicating that perhaps it was unrelated to the LE-MT intervention. The step and swing symmetry ratios for Participants 2 and 3 remained largely unchanged with respect to the ST thresholds throughout the duration of the study. Unfortunately, Participant 1 exhibited increased step and swing asymmetry of preferred pace gait after LE-MT but these values dropped below the ST thresholds by follow-up.

The results of this case series also revealed some potential effects on motor recovery of the leg after stroke. Participant 1 exhibited improved leg motor control as measured by the CMSA. Interestingly, both this participant and Participant 2 also exhibited improved NIHSS scores after LE-MT which was achieved in both cases by an improvement on Item 7 – Limb Ataxia.

Ultimately, analysis on an individual basis in this case series revealed variability in the extent of change in gait and motor recovery outcomes with the LE-MT intervention across the three participants. Variability in individual responsiveness to a MT intervention post-stroke has been reported in a previous case series of MT for the upper extremity.²⁴

This case report differs from two previous studies on LE-MT in two important ways. First we measured gait outcomes with a pressure sensitive mat which may have been more sensitive to subtle changes in the gait pattern associated with LE-MT compared to the FAC used by both Sütbeyaz and colleagues²⁹ and Mohan and colleagues.³⁰ The second difference is the intervention itself which combined mirror therapy with bilateral, multi-joint LE movements. Previous work suggests that MT with bilateral movements is more effective and is associated with increased activation of the motor cortex during paretic limb movements post-intervention compared to unilateral movements.^{21,27,28} It is possible that some of the observed improvements in gait and motor control of the leg in the current study were associated with cortical reorganization. This possibility should be investigated in the future with neural imaging before and after LE-MT.

5.5.1 Limitations

There are some limitations to our study. First the dose of the present MT intervention is less than that reported by studies which demonstrated both functional recovery and/or brain activation changes. Although the 4 week duration of our intervention aligns with previous studies, the frequency and duration of each session may have been too short. Previous work employed interventions delivered 30-90 minute MT sessions 5-6 days per week.^{15,16,28} It is possible that greater frequency and duration of sessions with the current intervention may have resulted in greater gains that could also have been maintained at follow-up. The study is also limited in the ability to attribute the gains and motor recovery and gait solely to the LE-MT intervention is complicated by the concurrent conventional physiotherapy. However, we are proposing LE-MT as an adjunct intervention and hence we feel pairing the intervention with conventional physiotherapy in the current study is reflective of how LE-MT would eventually be employed in clinical practice.

5.5.2 Conclusions

Mirror therapy is a simple and inexpensive adjunct intervention. The device we employed cost approximately \$500 and took 4 hours to construct. The current case series demonstrates that a bilateral LE-MT intervention is well tolerated by individuals with chronic stroke and may have the potential to improve motor control of the leg and gait velocity and step variability. Further investigation of this adjunct intervention is warranted while considering pre-existing back pain as a precaution. Future research should explore the dose-response relationship and the relationship of movement strategy

during LE-MT and outcomes. Another line of inquiry is to examine cortical reorganization and brain activation changes associated with the benefits of LE-MT.

Chapter 6

6 Discussion

6.1 Overview of findings

This thesis presented an investigation of a novel intervention for post-stroke rehabilitation. The main finding is that a mirror therapy intervention designed as an adjunct for the rehabilitation of the lower-extremities following a stroke is feasible. There are indications that the intervention has positive effects on gait velocity and step variability, motor recovery of the paretic leg and improved lower limb ataxia. The specific findings are summarized in Table 2.

Table 2. Summary of thesis findings

Objectives	Main findings	Interpretation
(a) to determine the feasibility to a novel mirror therapy intervention for the lower-extremities post-stroke	Number of repetitions at the final sessions was greater than the first sessions. Session duration was maintained or increased throughout the intervention period.	Increase in repetitions and duration implies participant tolerance improved over the course of the LE-MT intervention. A LE-MT intervention is feasible.
	One participant experienced recurrence of pre-existing low back pain.	Low back pain should be considered a precaution for this type of LE-MT.
(b) to identity potential effects the intervention may have on motor recovery, balance and gait velocity, variability	Motor recovery of the leg improved in 1 participant post-treatment; lower limb ataxia improved in 2 participants post-treatment	Improved motor recovery and reduced ataxia implies an improvement to motor control, with the possibility that cortical reorganization has occurred.
	Gait velocity improved as much as 2.6 times the meaningful clinically important difference (MCID); step variability as much as 7.1 MCIDs after treatment	Improved gait parameters implies LE-MT has the potential to improve gait function, albeit adjunct to conventional gait training techniques

Mirror therapy is a promising intervention in stroke rehabilitation. Since its inception in the late 1990s, mirror therapy interventions have been associated with positive effects on a number of clinical aspects,²¹ which include motor function, activities of daily living and the management of pain.²⁸ The use of MT for lower-extremity recovery post-stroke has received little attention in the literature. This thesis sought to investigate LE-MT using a uniquely constructed device to allow for bilateral multi-joint movement of the LEs. The following sections will briefly expand on the implications and the future directions of LE-MT.

6.2 The current study offers a different approach to MT for the lower-extremities

This study differs from previous studies investing LE-MT (Sütbeyaz *et al.*²⁶ and Mohan *et al.*³⁰) in three important ways: (1) the measurement methods for gait outcomes, (2) type of movements performed during LE-MT, and (3) the involvement of the paretic limb. These important differences will be addressed in succession.

- (1) *Outcome Measures for Gait* | Both previous LE-MT studies measured gait outcomes using FAC. The suitability of FAC for research purposes has been commented on previously,⁶⁵ and the scale may be insensitive to subtle, but clinically meaningful changes to gait recovery.⁶³ By measuring the spatiotemporal parameters of over-ground gait a much more precise measurement of gait function can be achieved compared to the subjective observations of gait as measured with FAC. It also allows for an interpretation of what aspects of gait improved (e.g. forward progression, stability) rather than just an overall assessment of gait

function with respect to the need for assistance (which is measured by the FAC). A spatiotemporal gait parameter assessment also allows small, but potentially clinically relevant, changes in gait associated with the intervention be measured. As such, the measurement of spatiotemporal parameters allows for comparison to the minimal clinically important difference scores for gait parameters such as velocity and variability. Clinically meaningful changes to over-ground gait may be overlooked when using observational outcome measures with gross scales.

(2) *Training of Multi-joint Movements* | Gait is a complex, multi-joint movement involving many muscles of the LEs.⁶⁶ Sütbeyaz and colleagues²⁹ employed ankle dorsiflexion movements of the non-paretic LE, whereas Mohan and colleagues³⁰ used several movement exercises including hip and knee flexion and hip abduction and adduction of the non-paretic LE. Interestingly, Mohan *et al.*³⁰ found significantly improved functional ambulation in favour of the mirror group, whereas Sütbeyaz *et al.*²⁹ found no difference between groups. The difference in findings suggests that a LE-MT intervention that involves exercise of the entire LE may be more beneficial for improving gait outcomes.

Similarly to Mohan *et al.*,³⁰ this study had participants perform movements involving the entire LE, and found clinically meaningful improvements to gait after the intervention in some cases. Although, for successful motor learning to occur, the training task should mimic the desired outcome as closely as possible.⁶⁷ It is obvious that the seated, LE movements used in the Mohan study³⁰ and the present study do not directly mimic the reciprocal LE movements or balance requirements associated with gait. However, it is

possible the multi-joint movements utilized in the present report targeted the muscles and joints involved in gait and, when combined with the bilateral training (see point (3) below), led to clinically meaningful changes in the spatiotemporal parameters of gait in comparison to previous work by Sütbeyaz and colleagues.²⁹

(3) *Training of Bilateral LE Movements* | Both interventions of previous studies investigating LE-MT post-stroke involved unilateral movements performed by the non-paretic limb only. The paretic leg remained motionless behind the mirror, and participants were only given the visual representation of their paretic limb moving. However, research shows that exercising bilaterally post-stroke is more effective than unilateral exercise for improving functional ability of the UE.⁴⁴ Moreover, there is a significant increase in neural activity while performing UE-MT bilaterally, whereas unilateral MT does not elicit the same neural response.³⁵ The present study and the LE-MT design was guided by this supporting evidence to have participants perform simultaneous bilateral movements of the LEs during the intervention.

Speculation can be made on why bilateral movements during MT would be an advantage. With bilateral movements the participant is sending the motor command to the non-paretic limb as well as the paretic limb. Therefore the combination of both the motor command and the visual feedback of the limb moving the way the command instructed the limb to move may be more effective than just illusory visual feedback without a motor command sent to the paretic limb (as is the case with unilateral MT). Moreover, the mismatch between the movement performed and the illusory movement perceived seems to drive the

neural activation, increasing alertness and spatial attention towards the paretic limb.³⁵ Thus, coupling intended actions with visually perceived actions gives the impression of actually performing the actions with the paretic limb, possibly leading to the more significant therapeutic effects.¹⁶

6.3 Limitations of the current LE-MT study

6.3.1 Dose of LE-MT

In the present study, some of the outcome measures did not show improvement (e.g. BBS) and for other outcome measures the observed improvements were limited to one or two participants. For example, in the current study following the LE-MT intervention only one participant improved in motor recovery scores (as measured by CMSA) and another single participant improved in gait velocity (although there was a trend for improvement in the others). In addition this this improvement was lost at FOLLOW-UP. However, variability in individual responsiveness to a MT intervention post-stroke has been reported in a previous case series of MT for the upper extremity.²⁴

Differences in findings of improved motor recovery between the current study and previous LE-MT studies may be related to length of the intervention and amount of MT received. In previous work by Sütbeyaz *et al.*,²⁹ 20 sessions of LE-MT demonstrated significant improvements to motor recovery scores as measured by Brunnstrom stages,²⁹ whereas 12 sessions of LE-MT in both the current study and the Mohan study³⁰ elicited little to no changes. Increased dose of therapy is associated with increased benefit to motor function post-stroke.⁶⁸ Taken together, the current results with previous work, suggests that MT delivered for a longer period of time would result in improvements in

motor control, gait and balance with greater magnitude and in a greater number of participants. Interestingly, it is often stated that the optimum treatment protocol with regard to frequency, duration and intervention characteristics for MT remains to be established. Studies to date have not provided sufficient information on clinical protocols in order to drive clinical recommendations for the use of MT.²¹ Thus determining the dose-response relationship for LE-MT should be a focus of future work.

6.3.2 Attributing observed improvements to LE-MT alone

The results of the present study found that in some cases baseline measures were variable. For example, in some cases gait velocity and variability changed by a score of greater than 1 MCID, and gait symmetry moved from symmetric to asymmetric during the baseline period. Notably, in some cases the change in baseline was indicative of a decline in gait which was reversed following the intervention (for example, Participant 2's increase in step length variability at baseline was followed by a larger decrease in variability following LE-MT). However, this baseline variability, combined with that fact that all participants were receiving concurrent physiotherapy at the time of the intervention, limits the ability to attribute gains in gait and motor function to the LE-MT intervention alone. However, the current LE-MT intervention is proposed as an adjunct to conventional physiotherapy post-stroke and thus the protocol is reflective of how LE-MT would eventually be used in clinical practice.

6.4 Mechanisms underlying improvement observed with LE-MT

It is possible that the observed improvements in gait and motor control of the leg in the current study were associated with cortical reorganization. Performance of

bimanual mirror therapy exercises is associated with increased activity in the precuneus and posterior cingulate cortex which is thought to reflect increased spatial attention towards the affected hand.³⁵ Interestingly, this activation pattern is evident only when MT is performed with bilateral movements, not unilateral movements.³⁵ This increased spatial awareness of the affected limb is proposed to help patients overcome learned non-use post-stroke leading to increased use of the limb and in turn, motor recovery.³⁵ In addition, a bilateral mirror therapy intervention for the hand post-stroke was associated with both motor recovery and increased activation of the motor cortex during paretic limb movements post-intervention.⁴⁰ In order to determine if changes with the current LE-MT intervention is mediated by a similar cortical reorganization, future work should incorporate neural imaging in a randomized controlled trial.

6.5 Future directions

LE-MT has been shown to enhance motor recovery in a subacute stroke cohort,²⁹ and functional ambulation in an acute cohort,³⁰ and may have a positive effect on gait parameters and motor recovery in the chronic phase of stroke. MT can be incorporated into a conventional physical therapy program at any stage of stroke recovery and should be applied for a long-period of time to enhance motor recovery and function. The relatively compact size and cost of the LE-MT device described in this study means it can be incorporated into an in home exercise program for continued use outside the clinic.

In the present study the participants were allowed to perform the LE-MT intervention at their own pace, using their own strategies, as they only received standardized instructions to focus on the mirror image of their leg while performing bilateral movements to the best of their ability. Participant 2 and 3 used a strategy that

involved completing repetitions and taking rests as needed until session termination due to fatigue or until the session duration goal of 30 minutes was reached. Participant 1 employed the same strategy during the initial sessions of the intervention but changed strategies during the final 5 sessions where she performed repetitions in blocks of 25, which was followed by a rest. This introduces a new line of inquiry regarding the critical elements needed to ensure effective use of LE-MT. Is it the attention to the visual feedback of the mirror image that matters? Is it the number of repetitions performed or is the effectiveness of LE-MT ultimately dependent on the movement strategy employed? Future work should investigate these questions.

The optimum MT treatment protocol has yet to be established. MT studies often investigate different phases of stroke, use different outcome measures, and employ interventions that vary in length and intensity.²¹ A logical next step would be to determine the dose-response relationship of LE-MT.

Finally, the present study produced mixed results in some cases. For example, post-treatment Participant 1 showed no changes in gait velocity, worsened in step variability and symmetry, but improved in ataxia and motor recovery of the leg. This raises the notion of responders versus non-responders; is MT good for all individuals with stroke or are there some that will benefit and others who do not? It has been previously stated that future studies should attempt to identify patients who might benefit more from MT than others.²¹ Identifying responders and the optimum protocol for the responders will guide more specific and effective intervention through MT.

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Appendices

Appendix A. Equipment.

^a GaitRite MatTM, CIR Systems, 376 Lafayette Ave, Suite 202, Sparta, NJ, 07871.

Appendix B. Concept sketches. The following images are concept sketches that were drawn during the design process of the LE-MT device used in the present study.

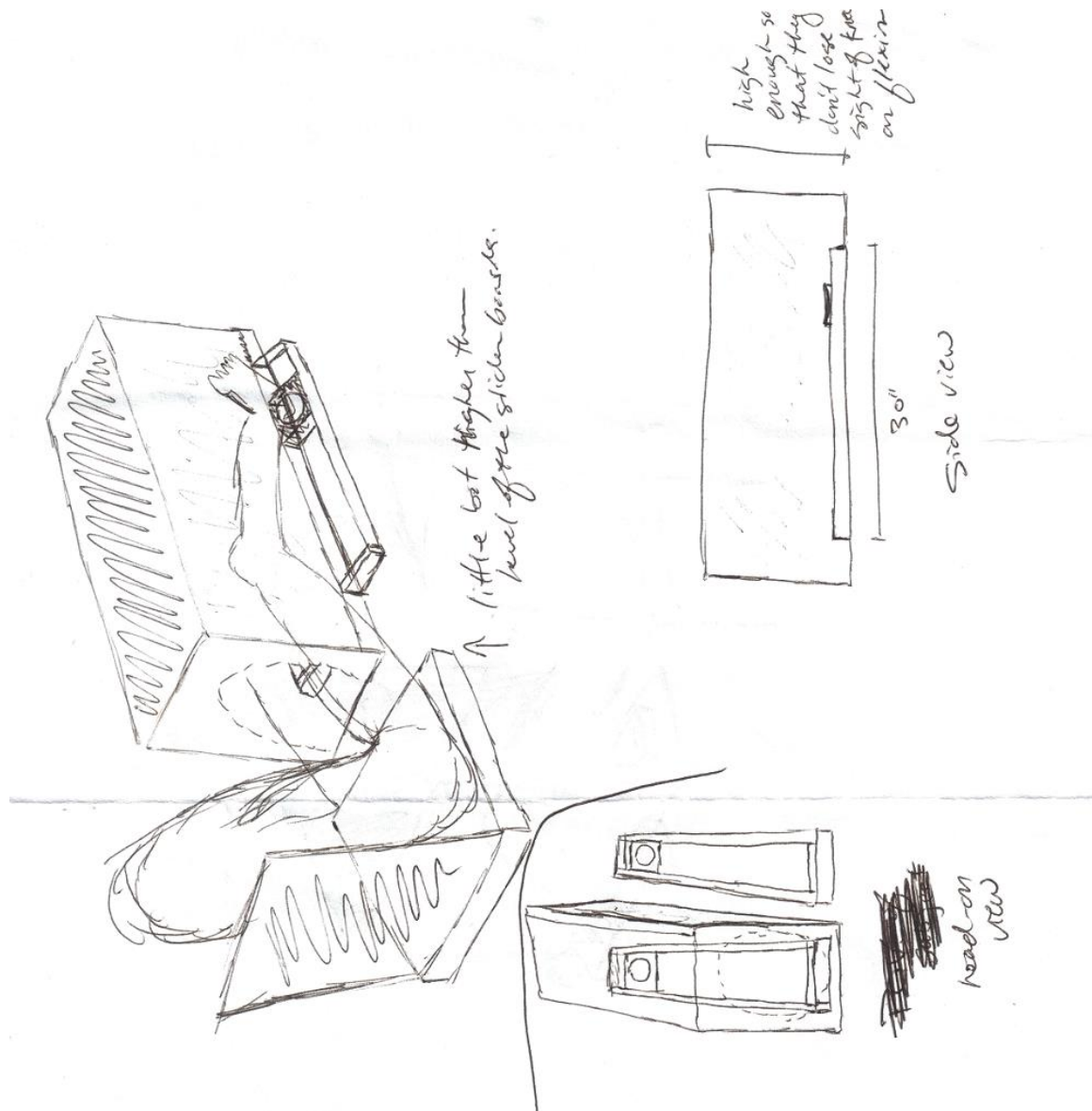


Image 1.

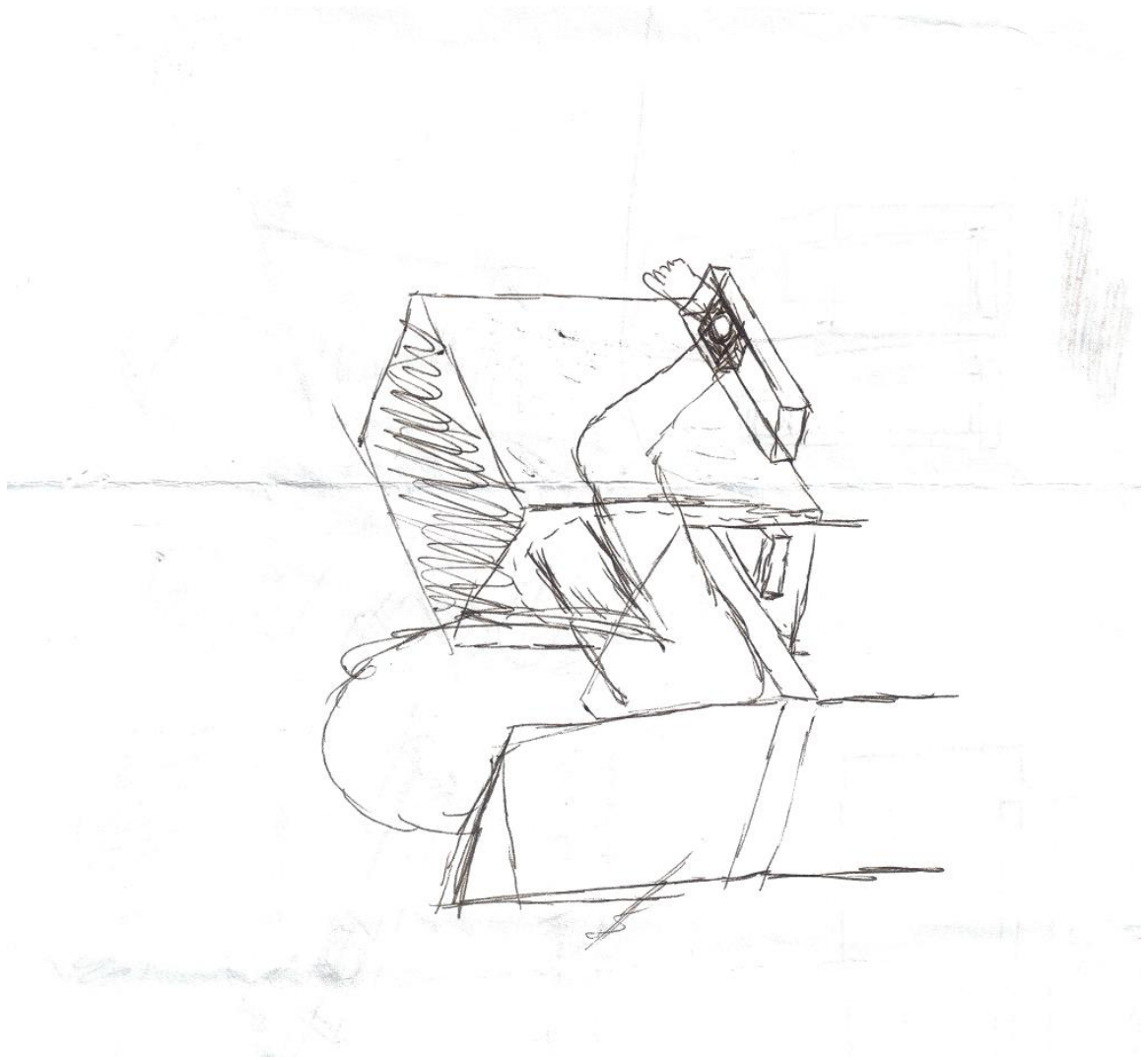


Image 2.

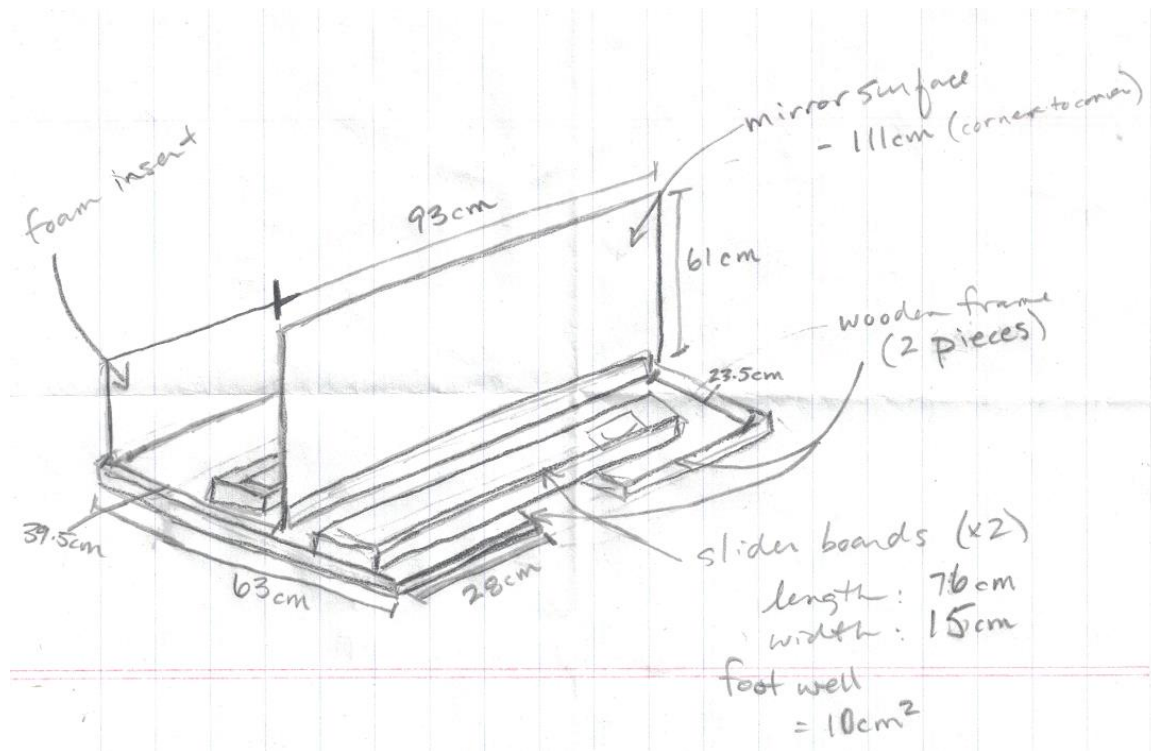


Image 3.

Appendix C. Ethical Approval



Use of Human Participants - Ethics Approval Notice

Principal Investigator: Dr. Kara Patterson

File Number: 104063

Review Level: Delegated

Approved Local Adult Participants: 20

Approved Local Minor Participants: 0

Protocol Title: Mirror therapy for the lower extremity post stroke

Department & Institution: Health Sciences/Physical Therapy, Western University

Sponsor:

Ethics Approval Date: August 14, 2013 **Expiry Date:** July 31, 2014

Documents Reviewed & Approved & Documents Received for Information:

Document Name	Comments	Version Date
Recruitment Items	recruitment poster	2013/07/17
Instruments	clinical scales to be used	2013/07/17
Other		2013/07/17
Other	instructions for sensors	2013/07/17
Western University Protocol		2013/07/17
Response to Board Recommendations	Response to REB recommendations	2013/08/01
Instruments	Clinical measurement instruments	2013/08/01
Instruments	Questionnaires	2013/08/01
Response to Board Recommendations		2013/08/02
Revised Letter of Information & Consent		2013/08/06

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced revision(s) or amendment(s) on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the University of Western Ontario Updated Approval Request Form.

Members of the HSREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the HSREB.

The Chair of the HSREB is Dr. Joseph Gilbert. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

This is an official document. Please retain the original in your files.

Curriculum Vitae

Lucas David Crosby

EDUCATION

UNIVERSITY OF WESTERN ONTARIO

MSc Candidate, Rehabilitation Science, Sept 2014
 Faculty of Health & Rehabilitation Science
 Western Graduate Research Scholarship

UNIVERSITY OF WESTERN ONTARIO

BSc, Honors Specialization in Kinesiology, June 2011
 Dean's List Honors: 2008, 2010, 2011
 Cumulative average: 82.35%; Final year average:
 85.70%; UWO Entrance Scholarship

RESEARCH EXPERIENCE

Graduate student

- Collection and analysis of data with pressure sensitive gait mat and wireless activity sensors (Zenomat, Acti-Life pedometer, 3-axis accelerometer)
- Clinical testing of motor recovery, balance and gait individuals with stroke using standardized outcome measurement tools
- Running pilot clinical trial for gait rehabilitation post-stroke
- Design of novel therapy device for hemiparesis

FUNDING

Year(s) granted	Agency	Title	Amount	Principal /Co- investigators
2013	Physiotherapy Foundation of Canada	Mirror, mirror, in therapy, whose leg moves with the most dexterity? A pilot study of a lower	\$3000	Kara Patterson/Lucas Crosby

		extremity, multi-joint mirror therapy intervention after stroke		
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PUBLICATIONS & PRESENTATIONS

Crosby LD. Patterson KK. “Mirror, mirror in therapy whose leg moves with most dexterity? A pilot study of a lower-extremity multi-joint mirror therapy intervention post-stroke.” Faculty of Health Science Graduate Research Forum. Western University, London, ON. Mar 01, 2013.

Oral Presenter - 1st prize, Master’s level

Crosby LD. Patterson KK. “Mirror, mirror in therapy whose leg moves with most dexterity? A pilot study of a lower-extremity multi-joint mirror therapy intervention post-stroke” Toronto Rehabilitation Institute Research Day, Toronto ON. Nov 25, 2013.

Poster Presenter

Crosby LD. Patterson KK. “Mirror Therapy Device for the Lower-extremities.” University of Buffalo Technovation Award 2013, Toronto ON. Nov 25, 2013.

Finalist

Crosby LD., Marrocco S., Brown, J., Patterson KK. “Mirror therapy for the lower-extremities post-stroke: a case series” 91st Annual American Congress of Rehabilitation Medicine Conference: Progress in Rehabilitation Medicine, Toronto ON. Oct 09, 2014.

Poster Presenter

COURSES

SPiN Attendee – Canadian Stroke Network Trainee Association

McGill University, Montreal PQ - October, 2013

Ottawa University, Ottawa ON - June, 2014

WORK EXPERIENCE

Graduate Teaching Assistant Jan 2014 – Apr 2014

Western University, London ON

- Student tutoring, exam proctoring, multiple choice exam question generation, marking

Assistant Office Administrator & Physiotherapy Aide Oct 2012 – Sept 2014

Neuphysio Rehabilitation, London ON

- Payment intake, filing responsibilities, appointment booking, telephone services, client reception as an assistant to office administration. Client treatment application including ultrasound, IFC, stretch and exercise assisting, and cleaning responsibilities as an aide to the physiotherapists and PTA's

Office Administrator & Secretary April 2012 – Sept 2012

Princeton & Etonia U.C., ON

- Responsible for overlooking day-to-day activities and announcements between the two churches in the district; Compiled, printed and delivered each week's bulletin to both churches; Responsible for answering calls and general office tidiness

Model 2009 - present

Anita Norris Models, London ON

- Commercial, live-television, fashion and runway modeling

Roofer 2007- 2009

R&B Roofing, Paris

- Application of asphalt/fiberglass shingles, sheeting and other roofing materials in residential housing; Labour and clean-up responsibilities, equipment maintenance; safety precautions taken seriously by all employees

Softball Ontario Umpire

2005 – present

Softball Ontario, Toronto

- Officiating of rural and urban softball leagues and tournaments
- Canadian Championships:
Novice Girls August 2013 – Montreal, PQ
Bantam Boys August 2015 – Prince Albert, SK