HOME MIRROR THERAPY: A RANDOMIZED CONTROL STUDY COMPARING UNIMANUAL AND BIMANUAL MIRROR THERAPY FOR IMPROVED ARM AND HAND FUNCTION POST-STROKE

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ABSTRACT

HOME MIRROR THERAPY: A RANDOMIZED CONTROL STUDY COMPARING UNIMANUAL AND BIMANUAL MIRROR THERAPY FOR IMPROVED ARM AND HAND FUNCTION POST-STROKE

Daniel Lee Geller

Stroke is the leading cause of disability in the United States. The majority of stroke survivors have persistent arm dysfunction, which impedes their daily task performance. Mirror therapy (MT) as an adjunct to occupational therapy (OT) has been shown to be effective in upper extremity (UE) recovery post-stroke. Two protocols, unimanual mirror therapy (UMT) and bimanual mirror therapy (BMT), have been used in OT practice; however, research specifically comparing these two intervention protocols is absent. The purpose of this study was to compare: (a) home-based UMT and BMT protocols, and (b) both MT protocols to home-based traditional occupational therapy (TOT) regarding upper limb recovery post-stroke.

Twenty-two chronic stroke participants were randomized into one of three groups: UMT, BMT, or TOT. The Action Research Arm Test (ARAT), Fugl-Meyer Assessment (FMA), ABILHAND, grip strength, and the Stroke Impact Scale (SIS) were administered pre- and post-intervention. Participants received outpatient OT 2 days/week for 45 minutes, plus a home program 30 minutes a day, 5 days/week for 6 weeks. A repeated measure ANOVA, Kruskal-Wallis Test, and Wilcoxon Ranked-Signed Test were used to compare the three groups, and 95% confidence intervals (CI) and effect sizes were calculated.

There was a main effect of time for all groups, except for SIS-strength and activities of daily living (ADL); however, no group differences were noted on any of the measures. When comparing UMT and BMT, the effect size for all measures, except for grip strength, favored UMT. In comparing both mirror groups to TOT, UMT had a moderate to large effect size on the ARAT, FMA, and ABILHAND, as compared to the small effect size for BMT. Furthermore, 95% CI data for the ABILHAND showed clinical significance in favor of UMT compared to TOT, but not for BMT.

This study showed that all groups improved over time and UMT may be more beneficial for UE recovery in chronic stroke individuals, compared to either BMT or TOT. However, given the small sample size, future studies comparing the two mirror protocols are necessary for more definitive conclusions to better inform clinicians of the optimal mode of MT treatment.

DEDICATION

For my parents, my foundation

For my partner, my support

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I - INTRODUCTION

This dissertation is a report of a quantitative randomized controlled study designed to compare the efficacy of two home-based mirror therapy protocols as an adjunct to outpatient occupational therapy for upper limb recovery post-stroke. This study was carried out with adult subacute/chronic stroke patients in an urban outpatient occupational therapy setting. The first chapter of the dissertation presents the background, literature review, research aims, and hypotheses of the study.

Background

Stroke is the leading cause of adult disability in the United States, with over 7 million survivors. Each year, an estimated 795,000 people have a new stroke or recurrent stroke (Mozzafarian et al., 2016). The majority of stroke survivors have persistent hemiparesis, with over 85% experiencing upper limb dysfunction, which is a significant barrier to recovery of function and participation in life (Nakayama et al., 1994). There are several rehabilitation interventions for upper limb recovery post-stroke, all with a common premise that individualized and goal-directed tasks that promote repetition of movement are essential for improvement in motor function and daily activities (Kwakkel, Veerbeek, van Wegen, & Wolf, 2015; Nilsen et al., 2015). The premise of repetition and practice is fundamental in stroke rehabilitation and is a common theme through many disciplines, including occupational therapy, physical therapy, speech therapy, and psychology, across the continuum of care.

The most common clinical pathway of stroke rehabilitation begins at the acute stage, whereby the patient becomes medically stable, the weakened arm is mobilized, and basic activities of daily living (BADL) need to be relearned. This is followed by inpatient rehabilitation, where the patient receives at least 3 hours of intensive rehabilitation, including but not limited to upper limb retraining, BADL, safety, and family education. Home health follows, whereby the patient receives rehabilitation in the home setting, under the supervision of the therapist, that may include upper limb training, safety, functional mobility, self-care, and relearning instrumental activities of daily living (IADLs). The final step is the outpatient setting, where the patient receives intervention 2-3 times per week with a focus on maximizing independence with ADL and IADL through task practice and repetition of movement, elicited through a comprehensive home exercise/task-based program (Duncan et al., 2005; Wolf & Baum, 2016).

Despite the continuum of care in stroke rehabilitation, it has been shown that the amount of upper limb movement training during traditional stroke rehabilitation is small, compared to animal models (Lang et al., 2009). Lang et al. (2009) conducted an observational study examining the amount of movement practice that occurred in stroke rehabilitation in the inpatient and outpatient setting. For the upper extremity, which included active and passive exercises, sensory therapy, and functional tasks, there were a total of 132 repetitions per session. More specifically in the outpatient setting, Lang, MacDonald, and Gnip (2007) showed that upper limb movement practice was an average of 85 repetitions per session. In comparison, in animal stroke models, monkeys who performed 600 repetitions of a pellet retrieval task per day had improved hand and arm function as well as neuroplastic changes in the brain (Nudo, Wise, SiFuentes, & Milliken, 1996). In human stroke research, specialized interventions with the same premise of intensive practice and repetition have also been shown to be beneficial for upper limb recovery post-stroke, such as constraint-induced movement therapy (CIMT). CIMT is an intervention whereby a mitt is placed on the unaffected limb, forcing the patient to use the affected limb during therapy and at home, thus increasing practice time and use of the limb (Kwakkel et al., 2015). Furthermore, research has also shown that larger amounts of therapy and movement practice result in better outcomes in motor relearning 2 to 3 months after the stroke, regardless of setting (outpatient or inpatient) or the target of rehabilitation (upper limb recovery or mobility) (Lang, Lohse, & Birkenmeir, 2015).

In addition, Schneider, Lannin, Ada, and Schmidt (2016) performed a systematic review with a meta-analysis of randomized controlled studies regarding dosage of traditional rehabilitation to reduce activity limitation after stroke. In this analysis, studies were included only if the additional training was traditional therapy. In order to compare the additional training between studies, the percentage increase per week was calculated. The results showed that increasing traditional therapy by at least an extra 240% improved activity performance. In contrast, Lang et al. (2016) reported that greater amounts of therapy post-stroke did not result in better outcomes; however, in this research, the group with the lowest dosage of 3,200 repetitions (100 repetitions per session) was still greater than the amount of upper limb repetition and practice typically reported in stroke outpatient rehabilitation. In this study, the participants received one hour of task specific upper limb training, 4 days a week for 8 weeks. Therefore, it may be possible that the movement dosage for the paretic limb in traditional OT is too low for motor recovery and improved activity.

Post-stroke upper limb interventions, such as robotic training (Péter, Fazekas, Zsiga, & Denes, 2011), constraint-induced movement therapy (CIMT) or modified constraint induced movement therapy (mCIMT) (Kwakkel et al., 2015), and functional electrical stimulation coupled with task training (Meadmore et al., 2014), have been used as an adjunct to traditional therapy. These interventions have been shown to promote motor recovery; however, they are costly, labor-intensive, and limited to specific groups of stroke individuals. For example, because upper extremity robotic devices are expensive, there are few devices in clinics or the home. Qualified personnel are required for set-up and assistance—thus the need for supervision. Furthermore, many robotic devices are not suitable for stroke individuals with limited passive range of motion of the arm/hand because the paretic limb cannot be placed in the device (Maciejasz, Eschweiler, Gerlach-Hahn, Jansen-Troy, & Leonhardt, 2014). There are similar issues with CIMT. Although CIMT has been shown to be effective for upper limb recovery, there is a minimal requirement of both voluntary wrist and finger extension of the paretic arm, thus excluding people who have minimal to no paretic hand movement (Kwakkel et al., 2015). Furthermore, many facilities do not offer CIMT because of the labor-intensive requirements and need for trained individuals—thus less access to the greater population.

Mirror therapy (MT) may be a suitable adjunct to occupational therapy (see Appendix A for definitions of terms), as it has been shown to improve upper limb recovery post-stroke (Thieme et al., 2012) and facilitate neuroplastic changes in the brain (Deconinck et al., 2014). Mirror therapy is an intervention in which a mirror box is placed in approximately the mid-sagittal plane to the seated participant and the affected hand is placed in the mirror box, while the unaffected hand is placed outside of the box facing the mirror (see Figures 1 and 2). During the intervention, the person moves the unaffected hand while watching the mirror reflection, which is superimposed on the affected limb, giving the visual illusion that the affected limb is moving. Thus, the mirror is providing augmented feedback, a motor learning principle, which is a term to describe information external from the person that can be used to facilitate learning or relearning a motor skill (Magill, 2011). Furthermore, MT also requires minimal one-on-one therapy, is simple to implement in the clinic and home environment, is low-cost (Michielsen et al., 2011a), and can be performed with stroke individuals with minimal to no upper limb movement (Thieme et al., 2012).

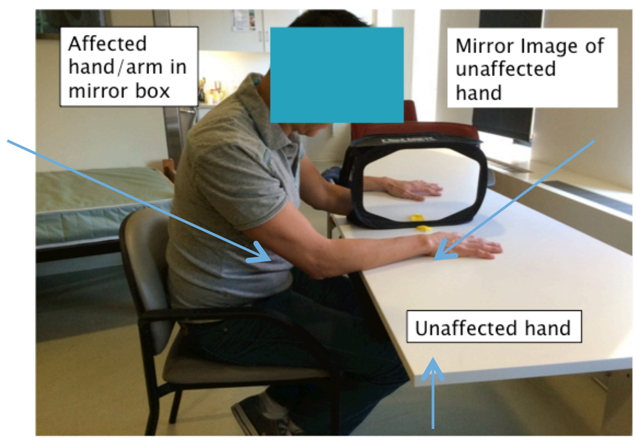

Figure 1. Mirror therapy set-up

Mirror therapy was first introduced to relieve phantom limb pain after amputation in 1995. It was speculated that the decrease in phantom pain was due to the mirror reflection acting as a visual illusion and tricking the person into the idea that the amputated limb was intact, thus causing cortical reorganization and decrease in pain (Ramachandran & Hirstein, 1998; Ramachandran, Rogers-Ramachandran, & Cobb, 1995). Mirror therapy was later introduced to treat hemiparesis post-stroke (Altschuler et al., 1999). Altschuler et al. (1999) examined the effectiveness of MT in nine chronic stroke participants, using a randomized crossover design. Participants were randomly assigned to the MT group or the control group (transparent plastic replacing the mirror) and were instructed to move the affected limb as best as possible to match the unaffected limb (bilateral movements). In other words, the MT group viewed the mirror reflection of the unaffected limb, while the control group had direct view of the affected limb through the plastic. After 4 weeks, all participants crossed over to the other group. Results showed that substantially more participants in the MT group improved in movement ability, as compared to the control. In addition, all participants reported favoring the mirror intervention, as compared to the use of plastic (Altschuler et al., 1999).

Since the introduction of MT, two different protocols have been used: unimanual mirror therapy (UMT) and bimanual mirror therapy (BMT). During UMT, the affected hand is placed in the mirror box and is static, while the patient views the mirror reflection of the unaffected hand performing various activities. During BMT, the affected hand is also placed in the mirror box; however, the patient attempts to move the affected hand as best as possible to duplicate the movements of the unaffected hand, while viewing the mirror reflection of the unaffected hand (see Figure 2).

a)

b)

Figure 2. UMT and BMT therapy
(a) UMT; hand in mirror box not moving.
(b) BMT; bilateral movements with cup in both hands.

Mirror therapy research studies have shown improvements in upper limb recovery with both MT protocols (Peréz-Cruzado, Merchán-Baeza, González-Sánchez, & Cuesta-Vargas, 2017; Thieme et al., 2012); however, the results have been inconsistent across the spectrum of functioning and disability. According to the International Classification of Functioning, Disability and Health (ICF), there are three levels of human functioning, which include the body parts (body structure and function), the whole person (activity), and the whole person in the context of society (participation). Body function refers to the physiological functions of the body, while body structure refers to the anatomical parts of the body; impairment refers to the loss of body functions or structures. Activity refers to executing tasks, and activity limitations are difficulties a person has with performing the task. Participation refers to experiencing different life situations, and participation restrictions are problems one may encounter in the life situation (World Health Organization [WHO], 2001.

The three levels of human functioning (body structure and function, activity and participation) interact with one another, although not necessarily in a linear fashion, and are influenced by the health condition and contextual factors. For example, after a person has a stroke (health condition), he/she may have considerable impairments, such as loss of range of motion or sensation in the arm (body functions), which may negatively affect his/her performance with dressing and bathing (activity), thus causing activity limitations. The person's inability to dress may therefore impact his/her ability and desire to go to a movie (participation), thus resulting in participation restrictions (WHO, 2001). Mirror therapy has been shown to be effective in improving impairments, such as range of motion and motor function, and activities, such as self-care (Thieme et al., 2012), in people post-stroke. However, it is less effective in improving the person's ability to participate in life scenarios (Michielsen et al., 2011a; Thieme et al., 2013).

Literature Review

The challenges in upper extremity post-stroke rehabilitation entail inaccessibility to upper limb recovery technologies (Maciejasz et al., 2014) and low dosage of upper limb practice (Lang et al., 2009). Thus, there is an urgent need to develop innovative rehabilitation interventions targeting upper limb recovery that can be self-directed and adhered to, and that are accessible to chronic stroke survivors, with a broad range of impairments, who are living in the community. Mirror therapy requires minimal one-on-one therapy, is simple to implement in the clinic and home environment (Michielsen et al., 2011a), and has been shown to be beneficial for upper limb recovery post-stroke (Thieme et al., 2012). In addition, mirror therapy combined with task practice, as an adjunct to traditional therapy, has been shown to be more beneficial than mirror therapy or task practice alone (Khandare, Singaravelan, & Khatri, 2013), thus suggesting the importance of not only task practice but also augmented visual feedback. Furthermore, mirror therapy has been shown to facilitate neuroplastic changes in the brain (Deconinck et al., 2014).

Mirror Therapy

As indicated earlier, mirror therapy was first introduced to treat hemiparesis post-stroke in 1999 (Altschuler et al., 1999). Since its introduction, both UMT and BMT have been used in therapy with positive benefits in upper limb recovery. Thieme et al. (2012) performed a systematic review and meta-analysis of the mirror therapy literature from 1999 to 2011, which yielded 12 randomized controlled studies and 2 crossover studies. The studies examined the effectiveness of mirror therapy for improving impairments, such as decreased motor function, pain, and neglect, as well as activity limitations, such as decreased performance of activities of daily living (ADL). Time post-stroke varied for each study and consisted of individuals who were either in the acute and subacute stage (within 3 months post-stroke) or the chronic stage (>3 months post-stroke). For all studies, regardless of the mirror protocol, the mirror box was placed in the mid-sagittal plane to the participant. The MT intervention durations varied between studies and included intensities that ranged from 10 to 60 minutes per session, frequencies of 1, 2, 5, or 7 days per week, and intervention time periods ranging from 2 to 6 weeks. In addition, the control groups varied from no additional intervention other than traditional rehabilitation, to sham MT and direct view of the affected hand.

The results of this review provided evidence in support of MT compared to control groups with respect to motor function, pain, neglect, and activities of daily living. For example, 11 studies were pooled regarding motor function post-intervention, which included 234 participants in the mirror group and 247 in the control group. Mirror therapy had significant effects on motor function post-stroke, as compared to all other types of interventions (SMD 0.61; 95% CI, 0.22 to 1.0; $p = 0.002$). Furthermore, motor function data at 6-month follow-up were pooled from four studies, which included 78 patients in the MT group and 79 in the control group. At 6 months, the MT group had a significant lasting effect on motor function, as compared to the control interventions

(SMD 1.09; 95% CI, 0.30 to 1.87; $p = 0.007$). For activities of daily living, four studies were pooled with 90 participants in the MT group and 98 in the control group. Results showed significant effect of MT on ADLs, as compared to the control group (SMD 0.33; 95% CI, 0.05 to 0.60; $p = 0.02$). One study not only examined the effect of MT on motor function and activities of daily living, but also on participation; however, the participation results were not included in the review (Michielsen et al., 2011a). The results of the Michielsen et al. (2011a) study showed no main effect of time or between-group interactions for the participation outcome measure. Furthermore, the researchers of the review reported that six studies used the UMT protocol, while five used the BMT; however, there was no further analysis comparing the two protocols (Thieme et al., 2012). Thus, conclusions could not be drawn about the benefit differences of the two mirror therapy protocols.

A literature review was conducted for randomized controlled MT studies after 2012 to examine the effectiveness of MT on upper limb recovery in stroke (>2 weeks post-stroke) individuals. Studies with participants who were 2 weeks to 6 months post-stroke were defined as subacute, while studies with participants who were greater than 6 months post-stroke were defined as chronic. Studies that included participants whose range post-stroke was greater than 2 weeks until 2 years were defined as subacute/chronic. Studies were excluded when MT was combined with other modalities such as neuromuscular stimulation, brain stimulation, action observation, mental practice, sensory treatment, and robotics, or consisted of group MT. In addition, MT studies were excluded when examining the effectiveness of MT on lower limb recovery post-stroke, complex regional pain syndrome, or phantom pain (Table 1).

As seen in Table 1, between the years of 2012-2017, 15 randomized controlled studies were published that examined the effectiveness of MT on upper limb recovery.

Table 1

Comparison of Recent UMT and BMT Efficacy Studies

	Recovery Stage	Intervention	Outcome Measures	
			Impairment	Activity
UMT studies				
Arya et al. (2015)	Chronic	CG: TT EG: TT + UMT	Brunnstrom FMA*	
Colomer et al. (2016)	Chronic	CG: TT + passive mobilization	FMA NSA*	WMFT
Gurbuz et al. (2016)	Subacute	CG: TT + sham UMT EG: TT + UMT	Brunnstrom FMA*	FIM
Invernizzi et al. (2013)	Subacute	CG: TT + sham UMT EG: TT + UMT	Motricity Index*	ARAT* FIM*
Khandare et al. (2013)	Subacute/ Chronic	CG: TSE EG 1: UMT EG 2: UMT + TSE*	FMA*	ARAT*
Kim et al. (2016)	Chronic	CG: TOT EG: UMT	FMA*	ARAT* BBT* FIM*
Park et al. (2015)	Subacute/ Chronic	CG: Sham UMT EG: UMT	MFT*	FIM*
BMT studies				
Cristina et al. (2015)	Subacute	CG: TT EG: TT + BMT	Brunnstrom FMA Ashworth Bhakta Test*	
Lee et al. (2012)	Subacute	CG: TT EG: TT + BMT	Brunnstrom* FMA* MFT*	
Lim et al. (2016)	Subacute	CG: TT + sham BMT EG: TT + BMT	Brunnstrom FMA*	MBI*
Rajappan et al. (2015)	Subacute/ Chronic	CG: TT + sham BMT EG: TT + BMT	FMA*	UEFI*
Rodrigues et al. (2016)	Chronic	CG: sham BMT EG: BMT		TEMPA
Samuelkamal-eshkumar et al. (2014)	Subacute	CG: TT EG: TT + BMT	FMA* Brunnstrom* MAS	BBT*
Wu et al. (2013)	Chronic	CG: TT EG: TT + BMT	FMA* Kinematics* rNSA*	MAL ABILHAND
UMT & BMT				
Hajializade et al. (2017)	Chronic	CG: TT EG: TT + UMT&BMT	MMDT*	Jebsen Taylor BI* BBT*

*Denotes significant difference in favor of mirror therapy

Abbreviations: CG, control group; EG, experimental group; UMT, unimanual mirror therapy; BMT, bimanual mirror therapy; TT, traditional therapy; ARAT, Action Research Arm Test; BBT, Box and Blocks Test; BI, Barthel Index; FMA, Fugl-Meyer Assessment; FIM, Functional Independence Measure; MAL, Motor Activity

Log; MAS, Modified Ashworth Scale; MBI, Modified Barthel Index; MFT, Motor function test; MMDT, Minnesota manual dexterity test; NSA, Nottingham Sensory Assessment; rNSA, Revised Nottingham Sensory Assessment; TSE, task specific exercises, UEFI, Upper Extremity Functional Index; TEMPA, Test d'Evaluation des Supérieurs de Personnes Agées; WMFT, Wolf Motor Function Test

Seven of the studies reported using the unimanual protocol (Arya, Pandian, Kumar, & Puri, 2015; Colomer, Noé, & Llorens, 2016; Gurbuz, Afsar, Ayaş, & Cosar, 2016; Invernizzi et al., 2013; Khandare et al., 2013; Kim, Lee, Kim, Lee, & Kim, 2016; Park, Chang, Kim, & An, 2015); seven studies reported using the bimanual protocol (Cristina, Matei, Ignat, & Popescu, 2015; Lee, Cho, & Song, 2012; Lim, Lee, Yoo, Yun, & Hwang, 2016; Rajappan, Abudaheer, Selvaganapathy, & Gokanadason, 2015; Rodrigues, Farias, Gomes, & Michaelsen, 2016; Samuelkamaleshkumar et al., 2014; Wu, Huang, Chen, Lin, & Yang, 2013); and one study used a combination of UMT and BMT as the intervention protocol (Hajializade et al., 2017).

All but one study (Arya et al., 2015) that utilized the unimanual protocol included at least one impairment level outcome measure and one activity level outcome measure. With respect to the impairment level outcome, all of the studies (100%) reported positive findings in favor of UMT on at least one of the included outcome measures. With regard to the activity level measures, 67% of the studies reported positive findings in favor of UMT on at least one of the included outcome measures. Furthermore, no studies examined the impact of UMT on participation restrictions. Thus, there is evidence in support of UMT's positive effects at the impairment level; however, the findings are inconsistent with regard to improvements in the activity level domain, and no studies have investigated the effects on participation outcomes.

There were similar findings in seven randomized controlled studies examining the efficacy of the BMT protocol in stroke participants. As seen in Table 1, four studies (Lim et al., 2016; Rajappan et al., 2015; Samuelkamaleshkumar et al., 2014; Wu et al., 2013) included at least one impairment and one activity level outcome measure; two studies (Cristina et al., 2015; Lee et al., 2012) included only impairment level outcome measures, while one study (Rodrigues et al., 2016) included only an activity level outcome measure. With respect to the impairment level outcome, all of the studies (100%) reported positive findings in favor of BMT on at least one of the included outcome measures, while 60% of the studies reported positive findings in favor of BMT on at least one of the activity level outcome measures. Similar to the UMT findings, there is evidence in support of BMT's positive effects at the impairment level; however, the findings are inconsistent with regard to improvements in activity level domains. In addition, no studies in this review (2012-2017) examined the impact of BMT on participation restrictions.

One study examined the effectiveness of a combined BMT and UMT protocol (Hajializade et al., 2017). The intervention consisted of 5 minutes of exercise with the UMT protocol, followed by 10 minutes of exercise with the BMT protocol, and ending with 15 functional tasks with the UMT protocol. The results showed gains at both the impairment and activity levels in favor of MT. Possibly, a combination of both UMT and BMT protocols would be most beneficial for upper limb improvements post-stroke. However, there are no intervention studies comparing UMT to BMT or comparing either protocol to the combined protocol.

It is apparent that both mirror therapy protocols are beneficial for upper limb recovery in subacute and chronic stroke patients; however, no studies to date have directly compared the two intervention protocols for clinical application. Selles et al. (2014) compared UMT and BMT during a short-term (1 session) motor learning study with chronic stroke patients during a simple reaching task. In this study, 93 stroke subjects at least 6 months post-stroke were randomly allocated to one of five experimental groups: (a) direct view of the affected hand with no mirror, (b) direct view of the unaffected hand with no mirror, (c) UMT, (d) BMT, and (e) BMT sham (mirror was covered preventing view of the affected arm). The session consisted of 70 reaching trials as per group allocation, while kinematic data were collected pre- and post- session with movement time being the primary outcome measure. The results showed that the direct view of the paretic limb group (no mirror) improved the most with respect to movement time and improved significantly more than the BMT group. In addition, the UMT group was not significantly different from the direct view group (Selles et al., 2014).

In the aforementioned study, the researchers argued that BMT might not be the optimal protocol because the effect of the visual feedback decreases when the paretic hand movement (behind the mirror) is incongruent with the visual mirror image of the unaffected hand. In other words, the visual feedback from the mirror image of the intact hand is incongruent with the proprioceptive feedback from the paretic hand in the mirror box. Research on healthy adults has supported this argument. Holmes, Crozier, and Spence (2004) examined the impact of visual and proprioceptive conflict during a reaching task with a mirror. Participants were seated with a mirror placed mid-sagittal plane on the table, with their left hand placed 12 cm facing the mirror and the right hand behind the mirror. During the reaching trials, the right hand was placed at four different positions behind the mirror. When the right hand was placed 12 cm behind the mirror, thus both hands were equidistant from the mirror, participants perceived the mirror reflection (visual feedback) as the same as the actual position of the right hand (proprioceptive feedback). When the right hand was placed at any other distance behind the mirror, the perceived mirror reflection was different than the actual position of the right hand—thus the visual/proprioceptive conflict. Results showed that reaching error was significantly greater when there was visual-proprioceptive conflict.

In summary, both BMT and UMT have been shown to be effective in improving upper limb recovery in post-stroke individuals (Thieme et al., 2012). However, preliminary evidence has suggested that UMT may be more beneficial than BMT for impairment level gains (Selles et al., 2014). Therefore, comparing these two mirror protocols as an intervention study is important for clinical application and best practice.

Feasibility and Effectiveness of Home-Based Mirror Therapy

Home-based MT and MT in the clinic are identical, except for the amount of direct supervision of the therapist. Home-based MT is self-directed and entails limited supervision, while MT in the clinic entails more continuous feedback and instruction. There is limited research on the effectiveness and feasibility of home-based mirror therapy programs on upper limb recovery post-stroke. Michielsen et al. (2011a) examined the efficacy of a home-based BMT program in chronic stroke survivors across the disability spectrum (impairment, activity, and participation levels) as well as cortical reorganization. Participants were randomized to the BMT group or the control group (direct view) and were instructed to perform all tasks bilaterally. All subjects participated in a 6-week program, which included a home program of 1 hour a day five times per week, plus one session per week under the supervision of a therapist. Subjects were provided with home practice material as well as regular phone calls to assure compliance of the home program. The results showed significantly greater improvement post-intervention in the FMA (impairment level domain) in favor of the MT group, but not at the six-month follow-up. In addition, there was no transfer from impairment gains to activity or participation level domains. On the other hand, fMRI results showed a shift in activation toward the affected hemisphere in the primary motor cortex of MT group participants, suggesting cortical reorganization. In addition, there were no differences between the groups in total home-based practice time, which averaged a total of 30 hours per participant. This study showed the feasibility and adherence of a home MT program as well as impairment level changes and cortical reorganization.

Amasyali and Yaliman (2016) examined the effects of home-based UMT and electromyography-trigged neuromuscular stimulation (ES) on hand function in post-stroke individuals. Participants were randomized into a control group, UMT group, or ES group for a 3-week intervention. All participants received conventional therapy; however, the experimental groups (UMT and ES) received an additional 7.5 hours of treatment according to group allocation. In addition, the MT group participants were educated to practice their MT at home after each supervised session and were questioned with regard to properly performing the home MT program; however, there was no mention of the adherence or practice time at home. Results showed that all groups improved pre-post intervention; however, the MT group improved significantly more than the control group on motor performance (FMA), manual dexterity (BBT), wrist extension AROM and grip strength.

Hajializade et al. (2017) examined the effectiveness of a combined clinic and home-based mirror therapy program for upper limb recovery in chronic stroke individuals. Twenty-one participants were randomly assigned to the mirror group or the control group for a 4-week intervention. Both groups received conventional rehabilitation, while the mirror group also received a combination UMT and BMT protocol. The clinic mirror intervention consisted of a 1- hour session, 3 days a week, while the home-based program consisted of a 1-hour session, 4 days a week. Participants were provided with a training video clip of the home-based MT exercises as well as a timetable to track the home sessions. Results showed that both groups improved on all outcome measures; however, the MT group significantly improved on the impairment level outcome measures (BBT, Minnesota manual dexterity test) and the activity level measures (Jebsen Taylor Test and Barthel Index), as compared to the control group.

In summary, it is feasible to administer a home-based mirror therapy program with minimal supervision as long as the home program is structured and includes handouts, photos, logs, or a video clip of the home program. Furthermore, there is evidence that UMT, BMT, or a combination of both protocols are feasible and effective for upper limb recovery in chronic post-stroke individuals.

Stroke Mechanism and Recovery

In healthy individuals, the left hemisphere of the brain controls the right side of the body, while the right hemisphere controls the left side of the body. More specifically, the primary motor cortex is an important area for execution of movement; however, other areas of the brain contribute to movement coordination and control. For instance, the posterior parietal cortex is responsible for movement planning, the premotor cortex for movement observation, the parietal lobe for somatosensory function, the parietal-occipital lobes for visuomotor processing, and the cerebellum for motor control and coordination.

A stroke occurs when there is lack of blood—thus oxygen—to an area of the brain, which leads to brain cell death (Arya, 2016; Bartels, Duffy, & Beland, 2016). In global terms, a stroke to the right hemisphere of the brain affects the left side of the body and vice versa. Furthermore, the location of the stroke dictates the deficits of the person. For example, a stroke in the occipital cortex will affect vision, while a stroke in the motor cortex will affect movement. As a result of a stroke, many individuals may have an array of impairments, such as decreased strength, range of motion, and sensation in the body parts, which negatively affect their ability to perform activities such as dressing, bathing, cooking, and walking.

Research has suggested a relationship between motor deficits and an imbalance in the hemispheres, presenting as decreased activation in the ipsilesional hemisphere and excessive activation in the contralesional hemisphere (Calautti et al., 2006; Zhang et al., 2016) and/or interhemispheric disruptions (Murase, Duque, Mazzocchio, & Cohen, 2004). Caluatti et al. (2006) examined the relationship between motor deficits and hemisphere activation in 19 right-handed first-time unilateral stroke participants, using an index thumb-tapping task of the affected hand during fMRI. Results showed that the greater the hemispheric shift toward the contralesional side in the primary motor and sensory areas, and therefore greater imbalance between the two hemispheres, the worse the performance of the index thumb-tapping task. Thus, the degree of recovery may be linked to the activation balance of the hemispheres. Zhang et al. (2016) examined the structural and functional connectivity between the bilateral primary motor cortex in 24 unilateral subcortical stroke participants and 25 health controls with multimodal magnetic resonance imaging. Results showed significantly decreased connectivity between the primary motor areas in stroke participants, compared to controls. In addition, there was higher activation in the contralesional hemisphere in stroke subjects, suggesting the imbalance of the two hemispheres.

Similarly, Murase et al. (2004) examined the influence of interhemispheric connectivity with regard to motor function in chronic stroke participants. Nine stroke participants and eight age- and sex-matched healthy controls performed index finger movements with their affected or right hand, respectively, to examine the interhemispheric inhibition (IHI) from the intact hemisphere to the lesioned hemispheres with TMS. Results showed that IHI in controls decreased progressively by the voluntary index finger movement, while stroke participants showed no changes in the IHI prior to voluntary movement. This suggested high interhemispheric inhibition from the intact to lesioned hemispheres. This increased inhibition may adversely affect motor recovery of the hand post-stroke. Thus, interventions that re-establish or promote a normal balance between the motor cortices may optimize upper limb recovery post-stroke.

It is well known that the affected hemisphere after a stroke is able to reorganize itself structurally or functionally as a result of repetition and practice of sensory-motor tasks and exercises, which is known as neuroplasticity (Arya, 2016). Warraich and Kleim (2010) defined neuroplasticity as “any change in the neuron structure or function that is observed either directly from measures of individual neurons or inferred from measures taken across populations of neurons” (p. S209), and is not limited to an area of the central nervous system (CNS). Despite the complexity of the brain, there is evidence that new learning and persistent behavior changes suggest neural circuitry changes and neuroplasticity. Furthermore, the brain is immensely interconnected, which plays an important role in supporting functional reorganization following disease or injury. The interconnectedness creates redundancy, which contributes to the ability of the brain to adapt and change after injury, thus possibly re-establishing a normal balance between the motor cortices after stroke.

There are three neural strategies with regard to motor improvement that take advantage of the redundancy in the brain: restoration, recruitment, and retraining (Warraich & Kleim, 2010). The concept of restoration involves the encouragement of "normal" movement during rehabilitation that can re-engage neglected neural networks, thus improving movement and functional outcomes. Recruitment refers to engaging motor areas that have the capacity to perform a motor movement, but were not originally designed for that movement prior to injury. Finally, retraining involves training intact brain areas to take on additional functions to improve movement and function. These strategies play a role in cortical reorganization and functional improvement post-stroke (Warraich & Kleim, 2010).

Studies have shown that repetition of movement and practice can affect cortical reorganization after stroke and improve behavioral outcomes. Liepert, Bauder, Miltner, Taub, and Weiller (2000) examined the effect of a 12-day constraint-induced movement therapy intervention (intensive practice and repetition intervention) in 13 chronic stroke patients regarding function and cortical organization. Results showed significant improvements in function and significantly larger motor output in the affected hemisphere, while at 6 months, the cortical areas in both hemispheres were almost identical, suggesting a balance of activation between the two hemispheres. Veldema, Bösl, and Nowak (2017) examined the relationship between motor recovery of the affected hand post-stroke and cortical hand motor representation in 17 first-time unilateral subacute stroke participants with hemiplegia. Results showed that participants with poor motor improvement of the affected hand showed an increase in the motor map area (MMA) size and volume in the contralesional primary motor area, while motor improvement in the affected hand was associated with a decrease in MMA size and volume in the contralesional primary motor area.

In summary, many individuals post-stroke present with upper limb dysfunction, which impedes their ability to care for themselves and participate in the community. Research has shown that after a stroke, the affected hemisphere has the ability to reorganize itself structurally or functionally as a result of repetition and practice of sensory-motor tasks and exercises (Liepert et al., 2000; Veldema et al., 2017). More specifically, it has been shown that the activation balance between the two hemispheres is an important element for better recovery post-stroke (Calautti et al., 2006; Zhang et al., 2016). Possibly, mirror therapy can promote preferable patterns of reorganization of the brain post-stroke for optimal upper limb recovery.

Mirror Therapy Underlying Mechanisms

The use of MT has been shown to be effective in upper limb recovery post-stroke; however, the underlying mechanisms of MT have been disputed. Brain imaging studies, predominantly in healthy subjects, have shown that MT can lead to neuroplastic changes, thus leading to improved arm/hand function post-stroke. Deconinck et al. (2014) performed a systematic review to identify the underlying mechanisms of mirror visual feedback on the brain. An extensive literature review with regard to the underlying mechanisms of both mirror therapy protocols was performed by Deconinck et al. (2014)

from 1972 to January 2014, which was limited to: (a) experimental studies or clinical trials, (b) healthy and/or motor-impaired subjects, and (c) use of imaging techniques. Studies that were excluded focused only on pain and tactile perception with MT, not on sensorimotor control. Thirty-three studies were deemed eligible by two independent researchers, with the majority of the studies examining healthy adults and eight on stroke patients. Of the eight stroke studies, five examined the immediate modulatory effects of MT, while three investigated the neuroplastic changes after a period of training. Furthermore, the researchers suggested that BMT may be a special case of bilateral training and would therefore have similar underlying mechanisms; however, no analysis compared possible differences in the underlying mechanisms of UMT and BMT.

According to Deconinck et al. (2014), there are three possible hypotheses for the underlying mechanisms of MT: (a) perceptual motor control process, whereby there is activation of attention and spatial areas in the brain; (b) direct facilitation of the motor network by means of facilitation of the affected primary motor cortex or unmasking of dormant ipsilateral pathways that are normally inhibited; and (c) activation of the mirror neuron system (MNS) that is associated not only with movement but also action observation. While these are three distinct hypotheses, it is possible that it could be a combination of all three; however, there is still no clear understanding of the underlying mechanism of MT.

The results of the systematic review suggested that MT increases activation of attention and cognitive control areas of the brain, such as the dorsolateral prefrontal cortex, the superior posterior parietal cortex and its medial extension, and the posterior aspect of the parietal and cingulate cortex (Deconinck et al., 2014), thus supporting the first hypothesis. One study from the review examined the neural correlates of MT in stroke participants with the use of a functional MRI (Michielsen et al., 2011b). Twenty-two participants, who were eligible to be scanned, were randomized into the experimental group (mirror) or control group. In the first experiment, participants either moved their unaffected limb while looking directly at this limb (unimanual no mirror condition) or with the use of a mirror, viewing the mirror image (UMT) while in the scanner. The second experiment was exactly the same as the unimanual trial; however, participants were asked to move both hands with the mirror (BMT) and without a mirror (bimanual no mirror condition). Results showed increased activity at the precuneus and posterior cingulate cortex, areas associated with spatial attention and awareness, with the participants in the BMT condition, but not the UMT condition. The researchers proposed that this occurred because the mismatch between the movement of the affected hand and the superimposed mirror image, which occurs during BMT, causes greater attention and awareness to the affected limb rather than the mirror image alone, which occurs in UMT. However, this appears to contradict Selles et al. (2014), who compared UMT to BMT in a single-session motor learning study. The results showed that the UMT group improved significantly more than the BMT group in movement time during the simple reaching task. The researchers suggested that the mismatch between movement of the affected arm and the visual illusion as a result of BMT was detrimental, causing a decrease in the positive effects of the mirror image and thus less improvement.

Regarding the second hypothesis, Deconinck et al. (2014) suggested that MT decreases the motor threshold by way of reduction in interhemispheric and/or intracortical inhibition, thereby enhancing the corticospinal output of the ipsilesional primary motor cortex in stroke patients; thus, MT directly affects the motor network. One study in the review examined cortical reorganization after MT in chronic stroke patients (Michielsen et al., 2011a), which supports this hypothesis. Forty participants were randomized to the BMT group or the control, while only nine experimental and seven control group participants underwent both baseline and post fMRI testing. All participants underwent a 6-week home-based program according to group allocation. Results showed a shift in activation within the primary motor cortex toward the affected hemisphere, thus balancing the two hemispheres, only in the mirror groups. Another study in the review investigated the fMRI changes in 20 chronic stroke patients after 8 weeks of computer-based bimanual MT, compared to 10 healthy controls (Bhasin, Srivastava, Kumaran, Bhatia, & Mohanty, 2012). The authors reported significant changes in the FMA (impairment level domain) and Barthel index (activity level domain) following BMT, but also an increase in the laterality index of the ipsilesional primary and premotor cortex, thus supporting the second hypothesis.

The third hypothesis relates to activation of the "mirror neurons system" (MNS), which is divided into the parietal and frontal MNS. The frontal MNS consists of the pars opercularis of the inferior frontal gyrus and ventral premotor cortex, while the parietal MNS consists of the inferior parietal lobule of the brain (Liew, Garrison, Werner, & Aziz-Zadeh, 2012). The MNS is associated with both execution and observation of movement, which are supported by neurophysiological, behavioral, and brain imaging studies (di Pellengrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Rizzolatti & Craighero, 2004; Small, Buccino, & Solodkin, 2012). For instance, "mirror neurons" vigorously fire when either an object is manipulated by an individual or when the individual observes an object being manipulated (action observation). Thus, MT provides the visual illusion of the affected limb moving, a form of action observation, which activates parts of the motor system and has been hypothesized to induce motor learning and skill acquisition (Buccino, Solodkin, & Small, 2006). However, according to Deconinck et al. (2014), the MNS plays a minimal role in MT as it only activates the superior temporal gyrus and the premotor cortex and no other part of the MNS.

Since the review, Rossiter, Borrelli, Borchert, Bradbury, and Ward (2014) examined the mechanism of MT with the use of magnetoencephalography (MEG) to measure cortical activity, more specifically movement-related Beta desynchronization (MRBD), during mirror training post-stroke. Stroke and healthy subjects' MBRD were measured during bimanual movements in both mirror and no mirror conditions. The results showed that in controls, MRBD was the same in both hemispheres and unchanged by the mirror; however, for stroke patients, the imbalance in MRBD between the hemispheres in the no mirror condition was made more symmetrical with the mirror. Thus, the presence of the mirror was balancing the primary motor cortex activity in ipsilesional and contralesional hemispheres, thus supporting the second hypothesis as proposed by Deconinck et al. (2014).

Summary

In summary, both UMT and BMT have been shown to be effective in upper limb recovery post-stroke (Thieme et al., 2012). However, there are inconsistencies in both UMT and BMT literature as to the areas of improvement, with some studies showing improvement only at the impairments level (Colomer et al., 2016; Gurbuz et al., 2016;

Wu et al., 2013) and others showing improvement at both impairment and activity levels (Invernizzi et al., 2013; Khandare et al., 2013; Kim et al., 2016; Lim et al., 2016; Park et al., 2015; Rajappan et al., 2016; Samuelkamlaeshkumar et al., 2014). One motor learning study suggested that UMT may be more beneficial than BMT; however, this was not an intervention study for the purpose of MT application (Selles et al., 2014). The researchers proposed that the mismatch of information of the affected hand and the visual image during BMT decreased the positive effects of the mirror illusion; thus, there was less benefit of BMT compared to UMT for upper limb movement post-stroke.

Home-based MT programs using both protocols as well as a combination of both protocols have been shown to be feasible and effective for upper limb recovery post-stroke (Amasyali & Yaliman, 2016; Hajializade et al., 2017; Michielsen et al., 2011a). These studies supported the notion that home-based MT programs can be self-directed and adhered to with minimal supervision and structured supports, such as home pamphlets and instructions.

Research has shown that after a stroke, the affected hemisphere has the ability to reorganize itself structurally or functionally as a result of repetition and practice of sensory-motor tasks and exercises (Liepert et al., 2000; Veldema et al., 2017). More specifically, it has been shown that the activation balance between the two hemispheres is an important element for better recovery post-stroke (Calautti et al., 2006; Zhang et al., 2016). While there is evidence that MT has an effect on cortical reorganization post-stroke, there is still no clear consensus on the underlying mechanism. According to Deconinck et al. (2014), there are three possible hypotheses: (a) MT activates attention and spatial areas in the brain; (b) MT has direct facilitation of the motor network; and

(c) MT activates the mirror neuron system, which is associated not only with movement but also with action observation (Deconinck et al., 2014).

While there is evidence of the effectiveness of both MT protocols in the clinic (Thieme et al., 2012) and in the home (Amasyali & Yaliman, 2016; Hajializade et al., 2017; Michielsen et al., 2011a), no intervention research studies have compared the two protocols for MT application. Therefore, it is imperative to compare the two home-based mirror therapy protocols as an intervention study to determine if one is more beneficial than the other for upper limb recovery in chronic stroke patients. This information could be used to guide clinical decision making about the use of mirror therapy for patients with stroke.

Research Aims and Hypotheses

The American Occupational Therapy Association's (2007) centennial vision states, "We envision that occupational therapy is a powerful, widely recognized, science-driven, and evidence-based profession…meeting society's occupational needs." The OT profession has focused on the importance of science-driven, evidence-based research to meet the needs of clients to provide them with the most beneficial treatments that can improve their daily living skills and overall quality of life. Since mirror therapy was introduced as an intervention to improve upper limb recovery post-stroke, research has shown the benefits of mirror therapy; however, information on the optimal mode of delivery is limited. Thus, in accordance with the AOTA centennial vision, it is essential to determine the optimal mode of mirror therapy delivery for stroke recovery best practice. This study was designed to address the following research aims:

Aim 1. To determine whether one home-based MT protocol (i.e., UMT and BMT) is more efficacious than the other for upper limb recovery post-stroke.

It is hypothesized that:

a. The UMT group would demonstrate better performance on the primary outcome measure (ARAT) as compared to the BMT group.
b. The UMT group would demonstrate better performance on the secondary outcome measures (FMA, ABILHAND, grip strength, and SIS) as compared to the BMT group.

Aim 2. To determine whether home-based MT programs (UMT or BMT) are more efficacious for upper limb recovery post-stroke, as compared to the control group receiving a traditional home-based occupational therapy program.

It is hypothesized that:

a. Both MT groups would demonstrate better performance on the primary outcome measure (ARAT) as compared to the control group.
b. Both MT groups would demonstrate better performance on the secondary outcome measures (FMA, ABILHAND, grip strength, and SIS), as compared to the control group.

II - METHODS

Participants

Participants were recruited from the outpatient occupational therapy department at New York University (NYU) Langone Medical Center.

Inclusion Criteria

The following inclusion criteria were used to determine participant selection:

1. age 19-85;
2. first unilateral stroke at least 3 months prior to recruitment;
3. ability to follow directions and consent to participate in the study;
4. Fugl-Meyer Assessment (FMA) score between 10-50, indicating moderate to severe upper limb impairment (Woodbury, Velozo, Richards, & Duncan, 2013); and
5. ability to grasp and release a small washcloth with any grasp.

Exclusion Criteria

The following exclusion criteria were used to determine participant selection:

1. complex medical problems, history of pre-existing neurological or psychiatric diseases, orthopedic conditions of the upper limb, or peripheral nerve injuries;
2. hearing and/or visual impairments that may impede participation in the home program;

3. perceptual deficits such as apraxia, neglect, or agnosias as per clinical evaluation;
4. botox injection in affected arm/hand within 3 months; and
5. global aphasia that may interfere with understanding instructions for testing or home exercise program.

All patients with a diagnosis of cerebral vascular accident (CVA) or stroke were prescreened by non-study occupational therapists within the first three OT outpatient sessions. The prescreening consisted of the following inclusion criteria: age 19 to 85, first unilateral stroke at least 3 months prior to recruitment, ability to follow commands, and ability to pick up and release a washcloth with any grasp. In addition, a prescreen FMA was performed on potential participants, and those who were at most 3 points below the minimum (FMA score of 7) or 3 points above the maximum (FMA score of 53) were referred to the research team and provided with informed consent prior to formal screening for the study. Participants were consented by the research OT and provided with a copy of the consent form. This was followed by screening of all of the inclusion and exclusion criteria, except for the FMA. If the participants met these criteria, they were scheduled for the baseline assessments with one of two senior OTs, who were the research assessors and trained on all outcome measures. During the baseline assessment, the senior OT administered the FMA prior to the other assessments as the final inclusion criteria screening. Thus, those who met the FMA inclusion criteria completed the baseline assessment, and those who did not were dropped from the study and continued with their regularly scheduled OT. Eligible participants were randomized into one of three home program groups: UMT, BMT, or Traditional OT (TOT). A non-research study OT performed randomization by a sealed envelope method.

Sample Size Calculation

To calculate the sample size, G*power, an online tool (available at https://www.macupdate.com/app/mac/24037/g-power) was used with the statistical test ANOVA: with repeated measures, between factor. The power analysis was computed given α set at 0.05, power ($1-\beta$) set at 0.80, effect size set at 0.5, for 3 groups, 2 measurements times, and 5 outcome measures. The sample calculation was $N = 27$.

Study Design

This was a single-blinded, randomized controlled design. One of two senior OTs in the study, blind to group allocation, administered the pretest and posttest outcome measures. The baseline measures were administered during the first OT outpatient session after the participants provided consent. The post-assessments, administered by the same senior OT (except for one instance), was completed after the 12th OT session in the clinic. The primary therapist (one of five therapists) who provided the conventional OT twice a week in the clinic were also blind to the participants' group allocation.

Data Collection

All outcome measures were obtained by the senior OT and recorded on standardized case report forms. Dynamometer grip strength was collected from the primary therapist's evaluation and follow-up re-evaluations for the pilot study to decrease the burden on the senior OT. However, the primary therapists did not consistently take grip strength measures on the re-evaluation, therefore, the post-assessment grip strength data were not consistently assessed at the 6-week mark. Hence, the dynamometer grip strength assessment was assigned to the senior OT after the pilot study for consistency. Demographic data were collected from participants' health records by the research OT. All data were entered by the research OT into the Research Electronic Data Capture (RED Cap), an online database management tool. The logs were collected at the end of the intervention by the research OT and data were entered into Excel for analysis.

Outcome Measures

The outcome measures were chosen to assess the participants' recovery across the full spectrum of disability, including impairment, activity and participation level domains. Outcome measures were performed by one of two senior occupational therapists, blind to group allocation, at baseline and post-intervention, and recorded on standardized report forms. Except for one occasion, due to logistical issues, the same senior OT performed the baseline and post-intervention assessment for each participant. Both assessors were trained on all of the outcome measures by means of lectures and videos, followed by administration of the FMA on two stroke patients with supervision and feedback. Outcome measures were completed (total time approximately 45 minutes) in the following order: Fugl-Meyer Assessment (secondary measure), Action Research Arm Test (primary measure), Stroke Impact Scale (secondary measure), and then ABILHAND (secondary measure) and grip strength (secondary measure). On the post-assessment, a Likert scale questionnaire, which evaluated the acceptability of the home program, was administered to the participants after completing the primary and secondary outcome measures.

Primary Measure

The Action Research Arm Test (ARAT) is a standardized objective assessment used to evaluate arm and hand function at the activity level domain (Bushnell et al., 2015). This instrument contains 19 items and is divided into four subtests, including five-finger grasp, cylindrical grasp, pincer grip, and gross arm movements. All items are scored on a 4-point ordinal scale (0 to 3), with a maximum score of 57, with higher scores reflecting greater hand and arm recovery. Both interrater and intrarater reliability are excellent (ICC $> .93$) for the ARAT in chronic stroke subjects for all subscale scores and totals. The ARAT has been shown to have construct validity with the upper extremity FMA, ($r = .94$, $P < .01$), which is the gold standard for assessment of upper extremity motor function in individuals with hemiplegia (Yozbatran, Der-Yeghiaian, & Cramer, 2008). The minimal clinical important difference (MCID) was established to be 5.7 points for the ARAT in chronic stroke individuals (Van der Lee et al., 2001). The ARAT was chosen as the primary outcome because it measures activity performance, which was deemed more important than impairment level gains in stroke individuals (Duncan, Jorgensen, & Wade, 2000) and it has been used in previous MT studies (Invernizzi et al., 2013; Kandare et al., 2013; Kim et al., 2016).

Secondary Measures

The Fugl-Meyer Assessment (FMA) measures recovery in patients with hemiplegia post-stroke and has been the gold standard for measuring impairment level changes in stroke research (Fugl-Meyer, Jääskö, Leyman, Olsson, & Steglind, 1975). The upper extremity motor function section of the FMA measures performance at the impairment/body function domain (Bushnell et al., 2015) and is divided into four sections, including upper extremity, wrist, hand, and coordination. All items are scored on a 3-point ordinal scale (0 to 2) with a maximum score of 66, with higher scores indicating greater level of motor function recovery. The FMA has excellent test-retest reliability (ICC = 0.97) and interrater reliability (ICC = 0.99) for the motor score (Platz et al., 2005). The MCID was established to be 5.25 points for the upper extremity FMA in chronic stroke individuals (Page, Fulk, & Boyne, 2012).

Grip strength, an impairment level measurement, was evaluated with a dynamometer, which entails a standard method consisting of the participant seated with the shoulder at 0 degrees, elbow at 90 degrees, forearm neutral. The final score was taken from the average of three measurements, with higher scores indicating greater grip strength. Dynamometer grip strength demonstrates good reliability in both chronic stroke and healthy subjects (ICC > 0.86), and is significantly correlated ($p < 0 .01$) with four upper extremity tests, including the FMA (Boissy, Bourbonnais, Carlotti, Gravel, & Arsenault, 1999).

ABILHAND, an activity level measurement, is a valid and reliable interview-based tool, which measures participants' perceived difficulty with the use of their arms and hands with 23 bimanual hand activities, such as filing one's nails, taking the cap off a bottle, and opening mail. For each item, participants were asked to rate their perceived ability to perform the task by checking one of the following boxes: impossible, difficult, or easy. Participants who had not performed the task within the past 3 months were asked to check the question mark box, which was included in the analysis. The ABILHAND was first developed to measure patients' perceived ability to perform both bimanual and unimanual tasks; however, it was later calibrated for chronic stroke patients, resulting in a decline of the original 56 items to only 23 tasks, which were only bimanual tasks, as per Rasch analysis. For chronic stroke patients, the maximum logit score on the ABILHAND is 6.0 with higher scores indicating higher level of perceived manual ability during bilateral upper extremity tasks (Penta, Tesio, Arnould, Zancan, & Thonnard, 2001). Simone, Rota, Tesio, and Perucca (2011) examined the reliability and validity of the ABILHAND in 83 chronic stroke patients. The results demonstrated high reliability (item reliability index = 0.94; Cronbach's $\alpha = 0.99$) and moderate correlations with grip strength, box and blocks test, and the Purdue pegboard. The MCID of the ABILHAND was established to be 0.26 to 0.35 logits in chronic stroke individuals (Wang et al., 2011).

The Stroke Impact Scale (SIS), version 3.0, is a subjective standardized 59-item eight-domain questionnaire assessing health status post-stroke. The following domains of the SIS were used to measure changes in impairment, activity, and participation levels: strength domain, activities of daily living and hand use domains, and participation domain, respectively (Bushnell et al., 2015). Each item is rated on a 5-point Likert scale (1 to 5) regarding one's perceived difficulty (Duncan et al., 2005), with higher scores indicating less difficulty. Vellone et al. (2015) examined the psychometric properties of the SIS, version 3.0, in 392 acute/subacute stroke individuals. Results showed internal consistency and test-retest reliability between 0.79 and 0.98. The participation domain of the SIS was the only measure assessing participation in this study. The questions in this domain focus on the individual's ability to integrate into the community and revolve around work, social and spiritual activities, recreation, roles, the ability to control one's life and to help others. For this domain, Cronbach's α was 0.87, thus showing that this domain is sensitive and useful in assessing participation (Vellone et al., 2015).

Usability Questionnaire

The Likert Scale Questionnaire (Appendix B) was created by the research OT to evaluate acceptability of the home program, which was divided into three themes: usability, perceived improvement of the affected limb, and continuation of the program. Usability, a quality attribute of the ease of using a tool such as the home program, was assessed with seven questions, such as requiring assistance to perform the program or ease of set-up. Perceived improvement of the affected limb was assessed with five questions, such as perceived benefits during the MT protocol and perceived benefits after the 6-week intervention. The final question was the likelihood of continuing the home program after the research study was completed. There were a total of 13 questions with a rating of 1 to 5 for each question (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree). The questions were created such that the higher scores indicated increased usability and perceived improvement and more likelihood of continuing the home program.

Log Data

A log data sheet (Appendix C) was created by the research OT in order to track the frequency of MT performance during the week and time spent during each of the different tasks in the home program in minutes. If the participant adhered to the home program, the frequency would be 5 days a week for a total of 900 minutes over the 6-

week period. It was also used to increase adherence of the home program. The log sheet was divided into the three sections that corresponded to the categories of the home program.

Intervention Procedures

After completion of the baseline assessment, the research OT educated the participants for 1 hour on their home program, according to group allocation. The MT home program was modeled after two studies (Michielsen et al., 2011a; Nilsen & DiRusso, 2014) and the education entailed providing the subjects with a mirror box, if in one of the mirror groups, and all equipment needed to complete the home program. This included a binder with written instructions and pictures of the set-up of the mirror box, the home exercise program (Appendix D), and a log to record time spent per activity. All participants were educated, through verbal instruction, demonstration, and reading, on the set-up of the mirror box, if applicable, and how to perform the home exercise program. Participants in both mirror groups were instructed to view the mirror reflection of their unaffected hand rather than view the unaffected hand or the affected hand in the box. Participants in the unimanual group were instructed to keep the affected hand static in the mirror box, while the bimanual MT participants were instructed to move the affected hand as best as possible to match the unaffected hand during all of the exercises. The TOT group participants were instructed to perform all of the exercises with the affected limb with no mirror.

Following the education, all participants received 6 weeks of conventional occupational therapy in the clinic, twice a week for 45 minutes, which may have included neurodevelopment treatment, functional e-stimulation, motor learning, Neura-INFRAH strategies, repetitive task training, and adaptive compensatory training. In addition, all participants received a 30-minute session one time a week with the research OT for treatment progression, questions, and adherence to the home program. Adherence methods consisted of reviewing the log during the weekly meeting and 1-2 calls or emails a week, based on the subjects' preferred method of contact, by the research OT as a reminder to perform the training.

As seen in Appendix D, all participants received a home-based exercise program, which included three components: (a) moving the arm/hand, (b) functional task with objects, and (c) object manipulation. These three components were modeled after the protocol from the case study of Nilsen and DiRusso (2014). The first 10 minutes of the home program were the warm-up session. This included moving the arm/hand and, more specifically, movements of the shoulder, elbow, and wrist flexion and extension; forearm supination and pronation; opening and closing the hand; opposing the thumb to the fingers; finger individuation; and finger abduction and adduction. The traditional OT group participants were provided with two additional warm-up exercises, which included weight bearing and passive range of motion of the affected arm. These additional exercises were provided because these are widely used traditional OT exercises for patients who have minimal arm/hand movement. In other words, participants in the traditional group who had minimal arm/hand movement were prescribed these two additional exercises as preparatory means for the other exercises and tasks in the home program. Participants with more arm/hand movement were not prescribed these additional exercises because they were not as useful and challenging for this subgroup. The remaining categories of the home program were identical for the three groups.

The next portion of the home program included performing functional tasks with an object (10 minutes total), which included washing the table, holding a cup and moving it in different directions, pointing to different objects, using a mallet to drum, and shaking an egg shaker. This was followed by 10 minutes of object manipulation such as grasping different-sized objects, flipping cards, transporting items, and manipulating a ball. Rest breaks were recommended as per participant abilities and need for rest.

After the 6 weeks, the OT assessor administered the same outcome measures, including the Likert scale questionnaire evaluating their acceptability of the home program. In addition, all of the log entries were collected by the research OT for data entry. After completion of the study, all control group subjects were provided with education on the home mirror therapy program for a 1-time session. In this session, participants were educated on the mirror therapy set-up and both MT protocols. The participants were not provided with a mirror box, but were provided with a website to purchase a mirror box if interested in pursuing MT.

Intervention Progression

During the weekly OT research meetings after the initial home program education, all subjects' home exercise programs were reassessed and progressed, if warranted, to meet the specific needs of each participant. The criteria for progression of treatment were determined if the subject could perform the task 10 times with minimal compensation or was able to perform the task repetitively with isolated movements within 1 minute without rest breaks. Progression of functional tasks with objects

(Appendix E) and object manipulation tasks (Appendix F) entailed one of the following: (a) increasing the distance of reach, (b) increasing the height of reach, (c) increasing the weight of the object, (d) increasing the complexity of the movement, or (e) increasing the number of repetitions. Progression entailed changing only one parameter at a time as per the subject's movement deficits, unless the subject was higher level and required a more fitting challenge of two or three parameter changes at one time.

Data Analysis

The data were examined using descriptive and interferential statistical analyses. Data were analyzed using IBM SPSS statistics software (Version 23, IBM Corp., Armonk, NY). Demographic, log, acceptability, and baseline outcome measure data were analyzed using univariate analysis of variance for continuous variables and Fisher's exact test for categorical variables. Normal distribution of the data were verified with visual inspection of histograms and plots and the Shapiro-Wilks test. In regard to the Shapiro-Wilks test, the data were normally distributed if the p-value was greater than 0.05 and not normally distributed if less than 0.05. However, if the absolute z-scores for either skewness or kurtosis were less than 1.96, then it was deemed a normal distribution (Ghasemi & Zahediasl, 2012; Kim, 2013).

For data that were normally distributed, a repeated measure analysis of variance (ANOVA) was performed between group factor of three levels (3 groups) and within-subject factor for the two time points. If demographic data and/or baseline data were significantly different, a repeated measure analysis of covariance (ANCOVA) was performed. For data that were not normally distributed, the Kruskal-Wallis test was performed to determine statistical significance between the groups and the Wilcoxon Signed Rank Test was performed to determine the main effect of time. If warranted, post hoc analysis was completed using Tukey's HSD to identify where the significance occurred. Significance levels were set at 0.05. In addition, Cohen's *d* (effect size) was calculated for each outcome measure as well as group mean differences and 95% confidence intervals (CI).

Cohen's effect size, which compares the magnitude of difference between groups, can be described in ranges, which include trivial effect (<0.2), small effect (0.2-0.5), moderate effect (0.5-0.8), and large effect (>0.8) (Page, 2014). Thus, the larger the effect size, the larger the difference between the two groups and therefore the greater the clinical significance. The confidence interval, from a clinical perspective, is the range that contains the true value of the effect of treatment in the population. With small sample sizes, Page (2014) indicated that CIs are more important than statistical significance, as the latter is affected by sample size. Furthermore, the relationship between the mean difference of the two groups (95% CI) and the value of 0 provides important information about the clinical significance. The value of 0 suggests there is no clear effect between the groups; thus, when the mean difference is further from 0, this indicates more effect or more difference between the two groups. If there is a positive effect (>0), this indicates favoring the experimental group, while if there is a negative effect (<0), this indicates favoring the control group. In addition, if the CI does not contain a value of 0, this indicates that the results are clinically significant. However, if the CI contains a 0 (clinically insignificant) but the CI remains specifically large in the positive range, this indicates that the intervention may be beneficial but larger sample sizes are required

(Page, 2014). Individual data was also analyzed to determine whether the participant met the minimal clinically important difference (MCID) with respect to select outcome measures. The MCID refers to the smallest change in an outcome measure that is considered important and relevant to the patient and/or practitioner (Page, 2014).

The log data for total exercise time in minutes were calculated by adding the number of minutes each participant performed the home program over the 6-week home program, followed by calculating the mean for each group. Data were analyzed using univariate analysis of variance to determine if there were differences in total exercise time between the groups. In addition, percentages were calculated to determine if participants adhered to the prescribed frequency of 5 days a week for 6 weeks.

The Likert scale questionnaire data were analyzed by calculating the average of the 13 questions per individual to examine the acceptability of the home program by group allocation. Additionally, the average was calculated for each individual as per the three themes of questionnaire that included usability, perceived upper limb improvement, and continuation of the home program, by group allocation. Group comparison data were analyzed using univariate analysis of variance to determine differences between the three groups.

Ethical Assurances

This study was approved by Teachers College, Columbia University Institutional Review Board (IRB) and the New York University Langone Medical Center IRB. All research participants signed a "Research Consent Form" and were provided a copy. The research OT or research staff explained the study in terms of the procedures, benefits, risks, and privacy. Participants did not receive compensation for taking part in the study.

Summary

This chapter explained the research design, recruitment procedures, participant inclusion and exclusion criteria, intervention procedures, sequence and protocol, outcome measurements used, data collection and analysis, and ethical assurances. The next chapter presents the results of the study.

III – RESULTS

As seen in Figure 3, 276 stroke patients were prescreened by non-study occupational therapists. The prescreening included the following inclusion criteria: age between 19-85, at least 3 months post first stroke, ability to grasp the washcloth and release with any grasp, the ability to follow directions, and FMA score between 7 and 53. Of the 276, 249 were not referred to the research OT because of prescreening failure. Twenty-seven of the patients met the prescreening criteria and were referred to the research OT for consent and formal screening and scheduled for the baseline assessments. Two of the 27 participants did not meet the FMA criteria (10-50) and were deemed screen failures and dropped from the study. The remaining 25 participants were randomized into one of three groups: 10 in the UMT group, seven in the BMT group, and eight in the TOT group. Three of the 10 participants in the UMT group dropped out of the study. Of the three, one dropped out prior to starting the treatment because of scheduling issues; one was discharged from OT due to medical issues; and one reported not having a suitable table in the home to perform the mirror therapy. The remaining 22 participants completed all aspects of the study and were included in the final analysis. Thus, the retention rates for both the BMT and TOT were 100% and 70% for the UMT group. Furthermore, the post-assessment session ranged from 0 to 7 days after the 6-week intervention (12th OT session) due to the participants' schedule in relation to weekends and holiday, or sickness and weather conditions. However, one participant in the BMT completed the study in 8 weeks, due to schedules and sickness. This participant was instructed to discontinue the home program during the two weeks when not attending OT in the clinic, which was confirmed by his home program log. Thus, while this participant received the same amount of conventional OT and home program, it was over an 8-week time period.

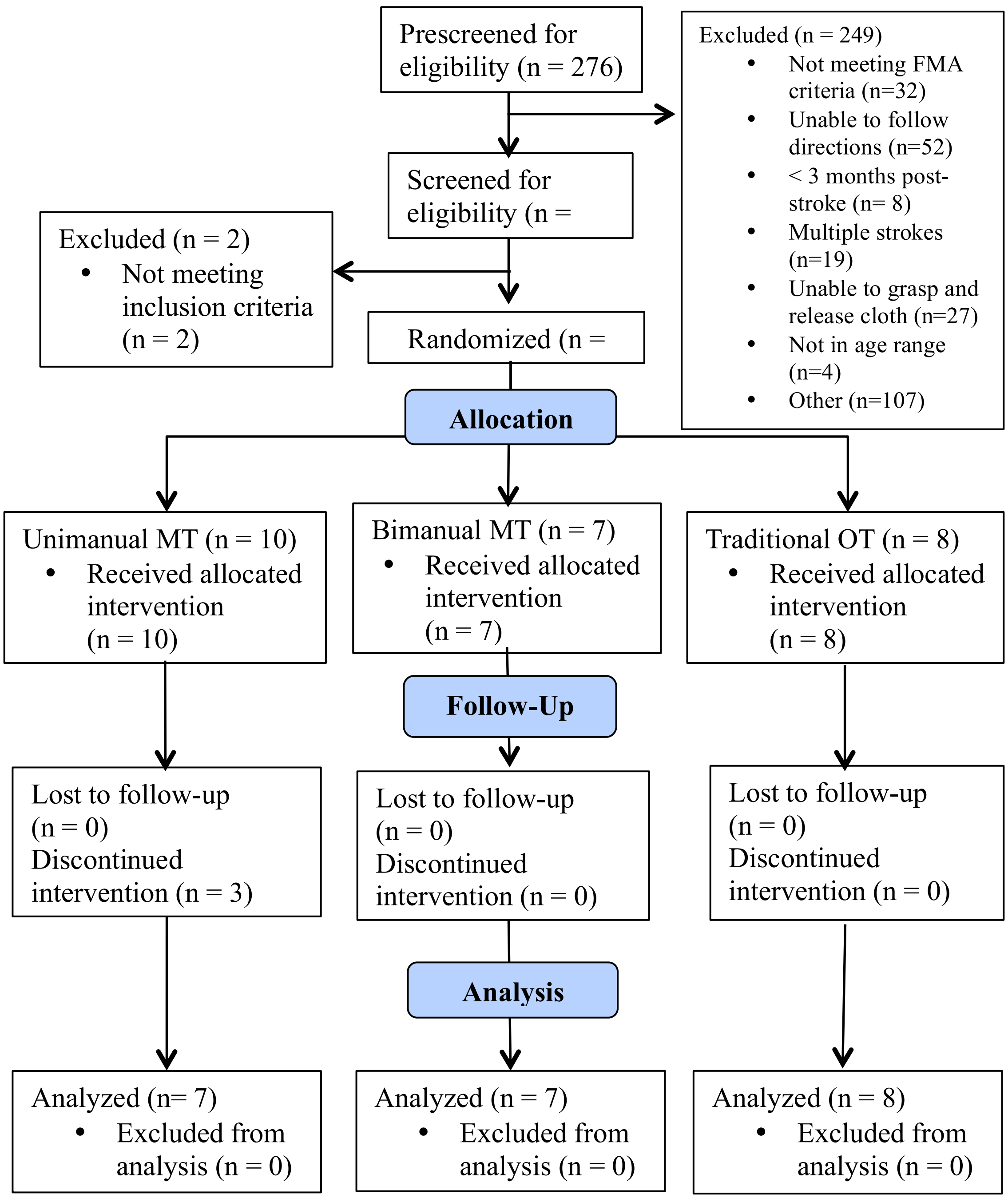

Figure 3. Consort diagram

Participant Characteristics

Twenty-two participants completed the study and their data were included in the final analysis (Table 2). All groups had participants from different ethnic backgrounds. Furthermore, the UMT group consisted of 7 participants with an age range of 35-73 and time post-stroke range from 3-94 months. Two of the participants were male; four were right-hand affected and seven were right-hand dominant. The BMT group consisted of seven participants with an age range of 34-77 and time post-stroke range from 3-56 months. Four of the participants were male; one was right-hand affected and seven were right-hand dominant. The TOT group consisted of eight participants with an age range of 38-83 and time post-stroke range of 3-280 month. Six of the participants were male; five were right-hand affected and five were right-hand dominant. The three groups were not significantly different with regard to demographic information or baseline outcome measures (all *p* values $>.05$), except for SIS-participation ($p = 0.046$). The SIS-participation baseline score for the UMT group was significantly lower than the BMT and TOT groups.

Home Program Compliance

As per the logs, mean total time of performing the home exercises per group in minutes were as follows: UMT group 878 (SD = 89.6), BMT group 904 (SD = 82.0), and TOT group 943 (SD = 98.9), and there were no significant differences between the groups ($p = 0.39$). However, in the BMT and UMT groups, 57% and 42% of the participants, respectively, performed less than the prescribed 900 minutes. In comparison,

Table 2

Characteristics of Participants and Clinical Baseline Data

	Unimanual Mirror Therapy (N = 7)	Bimanual Mirror Therapy (N = 7)	Traditional Occupational Therapy (N = 8)	*P* value
Age in years (SD)	57.6 (13.1)	57.3 (15.0)	65.3 (15.4)	0.494[a]
Race	2 Hispanic 2 Caucasian 2 African American 1 Other	1 Hispanic 1 Asian 4 Caucasian 1 African American	1 Asian 5 Caucasian 2 African American	NA
TPS in mo. (SD)	23.4 (32.9)	17.4 (22.9)	48.8 (94.5)	0.584[a]
Affected Side	4 Right 3 Left	1 Right 6 Left	5 Right 3 Left	0.176[b]
Hand Dominance	7 Right	7 Right	5 Right 3 Left	0.082[b]
Gender	5 Female 2 Male	3 Female 4 Male	2 Female 6 Male	0.239[b]
ARAT	15.3 (13.1)	22.7 (11.0)	17.8 (14.9)	0.570[a]
FMA	28.7 (11.0)	33.6 (9.40)	29.6 (9.61)	0.591[a]
ABILHAND	-.805 (1.26)	.280 (1.14)	-.112 (1.34)	0.283[a]
Grip Strength	10.9 (13.8)	16.6 (16.7)	18.6 (12.4)	0.576[a]
SIS-Strength	38.6 (9.45)	43.6 (11.1)	35.0 (10.0)	0.289[a]
SIS-ADL	42.3 (16.7)	50.3 (13.8)	45.8 (17.2)	0.651[a]
SIS-Hand Use	16.6 (21.3)	25.7 (24.9)	16.5 (22.4)	0.686[a]
SIS-Participation	22.9 (19.9)	48.2 (18.3)	40.3 (16.0)	0.046[a]

Note: Values are Mean (SD, Standard Deviation). The *p* value resulted from a given comparison test between the three groups, and the test was (a) One-way ANOVA, (b) Fisher's Exact Test
Abbreviations: ARAT, Action Research Arm Test; FMA, Fugl-Meyer Assessment; SIS, Stroke Impact Scale; ADL, activities of daily living; NS, not significant; mo., months; TPS, time post-stroke

only 25% of the participants in the TOT group performed less than the prescribed amount. In regard to frequency, 57% of the UMT participants adhered to the prescribed 5 days per week, while 42% and 0% of the BMT and TOT participants, respectively, adhered to the 5 days. However, although none of the TOT participants adhered to the 5 days, 42% exceeded the prescribed amount, as compared to 14% for both UMT and BMT groups.

Group Comparisons

Primary Outcome

The ARAT data were normally distributed; thus, the repeated measure 3x2 ANOVA was performed (Table 3). The ARAT results for all groups showed significant improvement over time (F = 18.0, $p = 0.00$); however, there were no significant differences between the groups (F = 0.61, $p = 0.55$). There was a moderate effect size ($d = 0.55$) between UMT and TOT, with a mean difference of 3.13 and a 95% confidence interval (CI) = -3.22 to 9.47, in favor of UMT. There was a trivial effect size between BMT and TOT ($d = 0.15$), with a mean difference of 0.70 and a 95% CI = -4.64 to 6.03, in favor of BMT. There was a small effect size ($d = 0.38$) between UMT and BMT, with a mean difference of 2.43 and a 95% CI = -5.10 to 9.96, in favor of UMT (Table 3).

Table 3

Results of the Primary Outcome Measure (ARAT):
Mean Difference, 95% (CI), and Effect Size

Outcome by group		Mean (SD) Pre	Mean (SD) Post	Time Diff p-value	Group Diff p-value	Comparison	Mean Diff	95% (CI)	Effect Size
ARAT (Activity level)	UMT	15.3 (13.1)	22.3 (18.0)	0.00	0.55	UMT/TOT	3.13	-3.22, 9.47	0.55
	BMT	22.7 (11.0)	27.3 (13.6)			BMT/TOT	0.70	-4.64, 6.03	0.15
	TOT	17.8 (14.9)	21.6 (17.2)			UMT/BMT	2.43	-5.10, 9.96	0.38

Note: Values are mean (Standard Deviation). The *p* values from analysis of variance (ANOVA)
Abbreviations: ARAT, Action Research Arm Test (0 to 57); UMT, unimanual mirror therapy; BMT, bimanual mirror therapy; TOT, traditional occupational therapy; Diff, difference; CI, confidence interval

Secondary Outcome

The FMA data were normally distributed; thus, a repeated measure 3x2 ANOVA was performed (Table 4). The FMA results for all groups showed significant improvement over time (F = 32.0, p = 0.00); however, there were no significant differences between the groups (F = 1.58, p = 0.23). There was a large effect size (d = 0.84) between UMT and TOT, with a mean difference of 4.20 and a 95% CI = -1.37 to 9.76, as well as between UMT and BMT (d = 0.81), with a mean difference of 3.71 and a 95% CI = -1.66 to 9.08, both in favor of UMT. There was a trivial effect size between BMT and TOT (d = 0.09), with a mean difference of 0.49 and a 95% CI = -5.24 to 6.21, in favor of BMT (Table 4).

The ABILHAND data were normally distributed; thus, the repeated measure ANOVA 3x2 was performed (Table 4). The ABILHAND results showed significant improvement over time ($F = 12.2$, $p = 0.002$); however, there were no significant differences between the groups ($F = 2.66$, $p = 0.096$). There was a large effect size ($d = 1.22$) between UMT and TOT, with a mean difference of 1.15 and a 95% CI = 0.09 to 2.20, as well as between UMT and BMT ($d = 0.87$), with a mean difference of 0.73 and a 95% CI = -0.25 to 1.72, both in favor of UMT. There was a small effect size between BMT and TOT ($d = 0.38$), with a mean difference of 0.41 and a 95% CI = -0.81 to 1.63, in favor of BMT (Table 4).

The grip strength data were normally distributed. As seen in Table 4, grip strength results for the BMT and TOT groups showed significant improvement over time; however, in the UMT group, there was a small decline of 0.33 over time ($F = 4.49$, $p = 0.048$). In addition, there were no significant differences between the groups ($F = 1.34$, $p = 0.29$). There was a moderate effect size ($d = -0.59$) between UMT and TOT, with a mean difference of -5.19 and a 95% CI = -15.1 to 4.70, in favor of TOT. There was a trivial effect between BMT and TOT ($d = 0.11$), with a mean difference of 1.00 and a 95% CI = -9.12 to 11.1, in favor of BMT. There was a large effect size between UMT and BMT in favor of BMT ($d = -1.79$), with a mean difference of -6.19 and a 95% CI = -10.2 to -2.16 (Table 4).

Table 4

Results of the Secondary Outcome Measures: Mean Difference, 95% (CI), and Effect Size

Outcome by group		Mean (SD) Pre	Mean (SD) Post	Time Diff p-value	Group Diff p-value	Comparison	Mean Diff	95% (CI)	Effect Size
FMA (Impairment level)	UMT	28.7 (11.0)	37.3 (12.0)	0.00[a]	0.23[a]	UMT/TOT	4.20	-1.37, 9.76	0.84
	BMT	33.6 (9.40)	38.7 (9.96)			BMT/TOT	0.49	-5.24, 6.21	0.09
	TOT	29.6 (9.61)	34.0 (5.40)			UMT/BMT	3.71	-1.66, 9.08	0.81
Grip strength (Impairment level)	UMT	10.9 (13.8)	10.6 (13.7)	0.048[a]	0.29a	UMT/TOT	-5.19	-15.1, 4.70	-0.59
	BMT	16.6 (16.7)	22.4 (18.0)			BMT/TOT	1.00	-9.12, 11.1	0.11
	TOT	18.6 (12.4)	23.4 (9.91)			UMT/BMT	-6.19	-10.2, -2.16	-1.79
ABILHAND (Activity level)	UMI	-.805 (1.26)	.546 (1.24)	0.002[a]	.096[a]	UMT/TOT	1.15	0.09, 2.20	1.22
	BMT	.280 (1.14)	.897 (1.87)			BMT/TOT	0.41	-0.81, 1.63	0.38
	TOT	-.112 (1.34)	.091 (1.36)			UMT/BMT	0.73	-0.25, 1.72	0.87
SIS-Hand use	UMT	16.6 (21.3)	24.0 (27.0)	0.018[a]	0.37[a]	UMT/TOT	-13.1	-37.6, 11.4	-0.60
	BMT	25.7 (24.9)	32.6 (31.4)			BMT/TOT	-13.6	-38.2, 10.9	-0.62
	TOT	16.5 (22.4)	37.0 (20.5)			UMT/BMT	0.57	-2.12, 22.4	0.03
SIS-Part. (Part. level)	UMT	22.9 (19.9)	32.9 (20.0)	0.002[a]	0.78[a] 0.96[b]	UMT/TOT	1.56	-12.2, 15.3	0.13
	BMT	48.2 (18.3)	54.6 (19.0)			BMT/TOT	-2.01	-12.6, 8.55	-0.21
	TOT	40.3 (16.0)	48.8 (16.4)			UMT/BMT	3.57	-9.33, 16.5	0.32

Note. Values are mean (Standard Deviation). The *p* values from (a) analysis of variance (ANOVA), (b) analysis of covariance (ANCOVA).

Abbreviations: FMA, Fugl-Meyer Assessment (0 to 66); SIS, Stroke Impact Scale; UMT, unimanual mirror therapy; BMT< bimanual mirror therapy; TOT, traditional occupational therapy; Part. participation; Diff. difference; CI, confidence interval

The SIS-hand use data were normally distributed. As seen in Table 4, SIS-hand use results for all groups showed significant improvement over time (F = 6.71, p = 0.018); however, there were no significant differences between groups (F = 1.04, p = 0.37). There was a moderate effect size (d = -0.60) between UMT and TOT, with a mean difference of -13.1 and a 95% CI = -37.6 to 11.4, as well as between BMT and TOT (d = -0.62), with a mean difference of -13.6 and a 95% CI = -38.2 to 10.9, both in favor of TOT. The effect size was trivial (d = 0.03) between UMT and BMT, with a mean difference of 0.57 and a 95% CI = -21.2 and 22.4, in favor of UMT (Table 4).

The data for SIS-participation were normally distributed; thus, the repeated measure ANOVA 3x2 was performed. As seen in Table 4, the results showed significant improvement over time (F = 12.8, p = 0.002); however, there were no significant differences between the groups (F = 2.51, p = 0.78). In addition, the baseline group data were significantly different (p = 0.046); thus, the ANCOVA was performed using the baseline scores as a covariate, which again showed no significant differences between the groups (F = 0.037, p = 0.96). There was a trivial effect size (d = 0.13) between UMT and TOT, with a mean difference of 1.56 and a 95% CI = -12.2 to 15.3, in favor of UMT. There was a small effect size between BMT and TOT (d = -0.21), with a mean difference of -2.01 and a 95% CI = -12.6 to 8.55, in favor of TOT. There also was a small effect size between UMT and BMT (d = 0.32), with a mean difference of 3.57 and a 95% CI = -9.33 to 16.5, in favor of UMT (Table 4).

The SIS-strength data were not normally distributed. As seen in Table 5, there were no significant improvements over time for UMT (z = -1.80, p = 0.072), BMT (z = -0.136, p = 0.892), or TOT (z = -1.725, p = 0.084), as per the Wilcoxon Signed-Rank Test. The Kruskal-Wallis Test showed no statistical difference between the three groups, x^2 (2) = 0.557, p = 0.757 (Table 6). The SIS-ADL data were also not normally distributed. As seen in Table 5, there were no significant improvements over time for the BMT (z = -0.944, p = 0.345) or the TOT (z = -1.83, p = 0.068) group. For the UMT group, there was a decline in SIS-ADL; however, it did not reach significance (z = -1.95, p = 0.051). The Kruskal-Wallis Test showed no statistical difference between the three groups, x^2 (2) = 0.287, p = 0.866 (Table 6).

Table 5

Results of Wilcoxon Signed-Rank Test

Outcome by group		Pretest	Posttest	p-value
SIS-strength (Impairment level)	UMT	35 (9.45)	45 (15.1)	0.072
	BMT	40 (11.7)	40 (17.3)	0.892
	TOT	37.5 (10.0)	42.5 (14.9)	0.084
SIS-ADL (Activity level)	UMT	52 (16.7)	48 (17.5)	0.051
	BMT	50 (13.8)	52 (14.1)	0.345
	TOT	49 (17.2)	57 (15.0)	0.068

Note. Values are median (Standard Deviation)
Abbreviations: UMT, unimanual mirror therapy; BMT, bimanual mirror therapy; TOT, traditional occupational therapy; SIS, Stroke Impact Scale; ADL, activities of daily living

Table 6

Results of Kruskal-Wallis Test

Outcome by group		Kruskal-Wallis Test (Mean Rank)		Group Diff (pre)	Group Diff (post)
		Pretest	Posttest	p-value	p-value
SIS-strength (Impairment level)	UMT	11.3	13.0	0.457	0.757
	BMT	13.8	10.8		
	TOT	9.69	10.8		
SIS-ADL (Activity level)	UMT	10.4	10.9	0.743	0.866
	BMT	13.0	12.6		
	TOT	11.1	11.1		

Abbreviations: SIS, Stroke Impact Scale; UMT, unimanual mirror therapy; BMT, bimanual mirror therapy; TOT, traditional occupational therapy; Diff. difference; ADL, activities of daily living

Supplemental Analysis

Individual participant data were analyzed regarding the minimal clinical important difference (MCID) for specific outcome measures. The MCID were analyzed for the ARAT because it was the primary outcome measure; the FMA because it is the gold standard for motor function post-stroke; and the ABILHAND because of the significant findings regarding effect size and 95% CI data. For the ARAT, 43% of UMT and BMT group participants exceeded the MCID of 5.7, compared to only 25% of the TOT group participants. Furthermore, while no participants in the UMT group declined in the ARAT at post-assessment, two declined in the BMT group. For the FMA, 71% of the UMT group participants exceeded the MCID of 5.25, while for BMT and TOT, 57% and 38%, respectively, exceeded this number. Furthermore, while no participants in the

UMT group declined in the FMA at post-assessment, one declined in both the BMT and TOT groups. For the ABILHAND, 100% of the UMT participants exceeded the MCID, while 43% of the BMT and 63% of the TOT group participants exceeded the MCID of 0.26 to 0.35 for the ABILHAND. Furthermore, while no participants in the UMT group declined in the ABILHAND, two declined in the BMT group and three in the TOT group.

Acceptability

The acceptability of the Likert scale questionnaire was added after the pilot study (Appendix G); therefore, data were collected for 16 participants, five each from the UMT and BMT groups and six from the TOT group. It should be noted that there were five missing scores for one of the UMT participants. Three of the missing scores were from the perceived improvement subcomponent, one from the usability, and one from the continuation subcomponent. Regarding overall acceptability, the UMT mean (SD) was 3.96 (0.420) and TOT was 3.92 (0.850), indicating neutral to agreeable acceptability; for BMT it was 4.12 (0.559), indicating agreeable to strongly agreeable. However, there were no significant differences between the groups ($p = 0.87$).

With regard to the theme of usability, the mean (SD) results for usability for the UMT, BMT, and TOT were 3.96 (0.460), 3.97 (0.548), and 3.90 (0.775), respectively, with no significant difference between the groups ($p = .35$). This indicates that participants were neutral to agreeable with regard to usability for all groups. For perceived improvement of the affected limb, the results for the UMT and TOT were 3.86 (0.423) and 3.87 (1.05), respectively, indicating neutral to agreeable; for the BMT, it was 4.28 (0.539), indicating agreeable to strongly agreeable. However, there were no significant differences between the groups (*p* = 0.613). For continuation of the program, the results per group were UMT 4.25 (0.50); BMT 4.40 (0.548); and TOT 4.33 (0.516), with no significant group differences (*p* = .91), again indicating agreeable to strongly agreeable with continuation of the program for all groups.

Summary

This chapter provided the participant characteristics, the consort diagram, and the analysis of the following: 1) home compliance data, 2) primary and secondary outcome measure data 3) supplemental data, and 4) acceptability data. The next chapter presents the discussion of the study.

IV – DISCUSSION

UMT versus BMT

The aim of this study was to determine if one MT protocol was more beneficial than the other in improving upper limb recovery in subacute/chronic individuals post-stroke after a 6-week home-based mirror therapy intervention. In comparing the two mirror protocols, the results of the primary outcome measure (the ARAT) and the secondary measures (the FMA, ABILHAND, grip strength, SIS-hand use and participation) showed significant improvement over time; however, no significant differences were found between the groups. Although there were no significant differences between the groups, it could be argued that there may be clinical significance in favor of the UMT group, as per the Cohen's effect size, 95% CI, and minimally clinically important difference (MCID) data analysis.

Primary Outcome Measure

Activity level. The effect size for the ARAT was small (d = 0.38) in favor of UMT over BMT and the mean difference was 2.43 with a 95% CI (-5.10 to 9.96), suggesting that UMT may be more beneficial than BMT. Furthermore, all UMT participants improved on the ARAT, while two BMT participants declined at post-assessment. In addition, previous UMT and BMT research studies that used the ARAT as an outcome measure showed significant improvement on the ARAT, as compared to the control for the UMT studies (Invernizzi et al., 2013; Kim et al., 2016; Park et al., 2015), but not for the BMT studies (Dohle et al., 2009; Michielsen et al., 2011a). Therefore, this data coupled with previous research suggested that UMT may possibly be more beneficial than BMT for activity level improvement; however, larger sample sizes are needed for more definitive conclusions.

Secondary Outcome Measures

Impairment level. The effect size was large for the FMA (*d* = 0.81) in favor of UMT over BMT. In addition, similar to the ARAT 95% CI data, the mean difference was 3.71 with a 95% CI of -1.66 to 9.08, suggesting UMT may be more beneficial that BMT; however, larger sample sizes are needed. Furthermore, the UMT group had a higher percentage of participants (71%) who exceeded the MCID of 5.25 on the FMA (Page, Fulk, & Boyne, 2012), as compared to 57% of the BMT group participants. This suggested that UMT may be more beneficial than BMT for arm/hand motor recovery (impairment level), which is consistent with Selles et al.'s (2014) finding that UMT was more beneficial during a reaching task (upper limb motor recovery), as compared to BMT during a motor learning study.

However, for grip strength, the effect size was large in favor of BMT (*d* = -1.79) over UMT, with a mean difference of -6.19 with a 95% CI= -10.2 to -2.16. The mean difference of -6.19 was partially due to the mean grip strength decline of the UMT group; however, it should be noted that this was due to one participant who declined, while five participants made no gains and one improved. Nonetheless, the grip strength data showed strong clinical significance in favor of BMT, which possibly occurred due to implicit difference in the UMT and BMT protocols. During BMT, the affected hand consistently moved and gripped, while during UMT, the affected hand was static. Therefore, BMT may be more clinically relevant for improvement in grip strength because of the repeated movement of the affected hand. However, the results of grip strength are inconsistent with Michielsen et al. (2011a), which showed no significant difference over time or between groups for grip strength with use of the BMT home-based protocol. Interestingly, although the UMT group declined in grip strength, they had the greatest mean difference with respect to perceived strength as per SIS-strength. This discrepancy may be because of the subjective nature of the SIS-strength. Also, although grip strength declined, the objective hand/arm assessments for the ARAT and FMA improved, therefore possibly leading to a greater perception of increased strength. An alternative explanation may be that the SIS-strength domain contains questions about arm and leg strength and therefore is not an accurate subjective measure of hand strength alone.

Activity and participation levels. The effect size was trivial for SIS-hand use ($d = 0.03$), small for the ARAT (as indicated above), and large for the ABILHAND ($d = 0.87$), all in favor of UMT. Furthermore, the same 95% CI argument can be applied to these data because the mean difference for the ABILHAND was 0.73 with a 95% CI of -0.25 to 1.72, suggesting that UMT may be more beneficial but larger sample sizes are needed. In addition, 100% of the UMT group participants exceeded the MCID of 0.26 to 0.35 logits (Wang et al., 2011) for the ABILHAND, as compared to 71% of the BMT group participants. However, the SIS-ADL data for UMT decreased pre- to post-assessment, and while not statistically significant ($p = 0.051$), were trending to significance. Nonetheless, these data suggested that UMT may be more beneficial for activity level gains, as compared to BMT.

This study also examined the effects of mirror therapy on the participation level domain, which has been scarcely examined. The results showed that both mirror groups significantly improved over time; however, there were no statistical differences between the two mirror groups. With regard to clinical significance, the mean difference was 3.57 with a 95% CI data of -9.33 to 16.47 and a small effect size ($d = 0.32$), suggesting that UMT may be slightly more beneficial than BMT for participation; however, larger samples are needed.

While no definitive conclusions can be drawn, the data suggested that UMT may possibly be more beneficial than BMT at the impairment level, except for grip strength, and the activity level with subacute/chronic stroke individuals. This may possibly occur due to the conflict between visual and proprioceptive information during BMT that decreases the positive effects of the visual illusion, ultimately degrading motor performance (Selles et al., 2014). The negative effects of the conflict between visual and proprioceptive information that occurs during BMT have been supported in studies with healthy adults. For example, Holmes et al. (2004) examined the impact of visual and proprioceptive conflict during a reaching task with a mirror. Participants were seated with a mirror placed mid-sagittal plane on the table, while their left hand was always placed 12 cm facing the mirror and their right hand behind the mirror. Therefore, the mirror provided the visual illusion of the perceived right hand to be 12 cm behind the mirror. During the reaching trials, the right hand was placed at four different positions behind the mirror. When placed at 12 cm (bilateral hands equidistant from the mirror), participants perceived the mirror reflection (visual feedback) as the same as the actual position of the right hand (proprioceptive feedback). When the right hand was placed at other distances from the mirror, the perceived mirror reflection was different than the actual position of the right hand—thus the visual/proprioceptive conflict. Results showed that reaching error was significantly greater when there was visual-proprioceptive conflict. Furthermore, when the right hand was placed farther away from the 12cm position (26 cm versus 19 cm), there was greater reaching error. In other words, the greater the visual-proprioceptive conflict, the greater the reaching error.

Lajoie et al. (1992) showed that during a mirror drawing task of a six-pointed star, another example of conflicting visual and proprioceptive information, healthy adults performed worse on the task as compared to a deafferented subject. In other words, when drawing the oblique movements of the star, the mirror created the inversion of the visual feedback with the movement (proprioception) of the hand. With practice, the healthy participants were able to learn to draw the star with the mirror; however, they required more time because of the need to recalibrate when the visual and proprioceptive feedback were in conflict. For the deafferented participant with no sensation or proprioception, recalibration was not required because this task was simply a visual tracking task. This study suggested decay in motor performance when visual and proprioceptive information were incongruent. Given these studies with healthy participants, UMT may be preferred to BMT because of the increased visuoproprioceptive conflict during the BMT protocol.

Cross-limb transfer or cross-education refers to the bilateral gains following unilateral motor training (Magill, 2011). The concept of cross-limb transfer could be applied to stroke rehabilitation, whereby the individual trains the unaffected limb with gains in both the unaffected and affected limb. Dragert and Zehr (2103) showed that with strength training of the unaffected lower extremity in post-stroke individuals, there were strength gains in the affected lower limb as well as gains in functional gait performance. This may be the reason for the positive benefits of UMT, as there may be a transfer of learning from the unaffected limb to the affected limb. However, while the affected lower limb improved in strength and gait performance in the Gragert & Zehr (2013) research study, the UMT group in this study declined in grip strength, however improved at the activity level. Possibly, during UMT there is a transfer of limb dynamic properties (kinematics) from the unaffected limb to the affected limb, thus the improvement at the activity level despite limited gains in grip strength. Research has shown that visual feedback can be used to update representations of limb dynamics for improved upper limb movements during reach (Sarlegna, Malfait, Bringoux, Bourdin, & Vercher, 2010). In a study conducted by Sarlegna et al. (2010), the researchers examined limb dynamic properties of reach in a deafferented patient with the absence of upper limb proprioception with full vision (visual feedback) compared to healthy controls. The patient and age-matched control participants performed a one session reaching task (90 trials) to marked targets on a rotating platform from a seated position. Pre and post testing consisted of the same reaching task (30 trials) with a static platform. All participants were instructed to move as quickly and accurately as possible. The results showed that the deafferented patient had difficulty with the baseline reaching task as compared to the controls, due to the absent proprioceptive feedback; however, the patient was able to adapt to the new condition within the same time frame as the controls. Furthermore, at post-assessment, the patient exhibited reaching movement time and adaptation similar to the control participants. This study provides evidence that visual feedback is important for motor adaptation and learning even without limb proprioception, thus possibly supporting the positive affects of visual feedback during UMT on upper limb recovery post-stroke.

Studies in healthy adults have also shown the positive effects of cross-education with and without MT regarding both behavioral and physiological outcomes. Nojima et al. (2012) examined the effect of mirror therapy on human motor neuroplasticity and motor behavior in right-handed healthy individuals with the use of transcranial magnetic stimulation (TMS). The researchers tested the change in motor ability of the left hand and the contralateral M1 function after training of the right hand with and without a mirror. The results showed significant improvement in motor behavior and M1 excitability in both groups; however, there was significantly greater improvement in the mirror group. Therefore, the significant improvement in the non-mirror group suggested that there are positive effects of cross-education. Furthermore, since the mirror group had greater improvement as compared to the control group, there may be an added benefit of MT to cross-limb transfer. Possibly, there is a compounded effect of cross-limb transfer and MT that caused the significantly greater improvement in the mirror group.

Unimanual MT may be more beneficial than BMT for subacute/chronic stroke individuals; nonetheless, there needs to be further comparative research for more definitive conclusions. In addition, one could further compare the effectiveness of the two protocols regarding recovery time period (acute, subacute, chronic) and also examine other variables such as underlying mechanisms, stroke severity, lesion location, and left versus right hemiparesis. For instance, MT may not be beneficial for stroke individuals whose lesions are located outside of the brain areas outlined by Deconinck et al. (2014), such as the basal ganglia. Possibly, one protocol may be more beneficial than the other depending on stroke location, as there may be different underlying mechanisms for the two protocols. It has been suggested that BMT may be a special case of bilateral training—thus similar underlying mechanisms (Deconinck et al., 2014) and possibly different than UMT. According to Hatem et al. (2016), the underlying mechanism of bilateral training includes recruitment of the ipsilateral corticospinal pathways, normalization of inhibitory mechanisms, and increased control of the contralesional hemisphere. In contrast, the UMT protocol presents as perceived bilateral movement, not physical bilateral movements; thus, the underlying mechanism may be more influenced by activation of the mirror neuron system (movement observation) rather than by corticospinal pathways. Therefore, lesion location may affect whether one MT protocol is more beneficial than the other.

Hemiparetic side (left or right) may play a role in the application of either UMT or BMT for upper limb recovery post-stroke. In other words, one mirror protocol may possibly be more beneficial than the other with regard to the side of hemiparesis. Sale, Ceravolo, and Franceschini (2014) performed a randomized control study examining the effectiveness of action observation (AO) in left and right hemiparetic subacute stroke patients. All participants received conventional inpatient rehabilitation. The experimental group received additional AO training consisting of watching videos containing daily activities, such as combing hair or reaching for a cup followed by action execution. The control group had sham AO training consisting of a sequence of static photos, such as trees and mountains, followed by action execution similar to the experimental group. The results showed that the AO group not only improved significantly more than the control group on the FMA and Box and Blocks Test, but there were also greater benefits for the left hemiparetic individuals. The researchers argued that since it has been shown that viewing a tool (e.g., comb) activates the mental representation of its use in the left hemisphere, it could be hypothesized that daily tasks are also heavily represented in the same hemisphere. Hence, the sparring of this area with the left hemiparetic participants may be the reason for the greater benefits of AO, as compared to the right hemiparetic participants.

Since mirror therapy is a form of action observation, MT may be more beneficial for left hemiparetic individuals as compared to right hemiparetic individuals. Furthermore, action observation is more closely related to UMT, such that in both these interventions the affected limb is static, as compared to the BMT where both limbs are moving. Therefore, UMT may be more beneficial than BMT for left hemiparetic individuals at the activity level. Data from this study provides some support for this suggestion. In comparing left hemiparetic participants in the UMT and BMT groups, mean change scores were greater on the ARAT and ABILHAND, both activity outcome measures, for the UMT participants (9.33 and 1.42, respectively) as compared to the BMT participants (2.83 and 0.52, respectively). However, no definitive conclusion can be made due to the small number of subjects per group, which consisted of three in the UMT and six in the BMT group. For more definitive conclusions, research with a larger number of participants is needed.

Upper limb severity post-stroke may also play a role in the application of either UMT or BMT regarding best practice for upper limb recovery. One could argue that UMT may be more beneficial for stroke individuals with severe to moderate/severe hemiparesis, as this stroke population presents with minimal isolated and voluntary movements; therefore, positive visual feedback is imperative at this time of recovery. Augmented feedback, a motor learning principle, is a term to describe information external from the person that can be added to intrinsic feedback (sensory or motor) to facilitate learning or relearning a skill (Magill, 2011). Therefore, stroke individuals with severe to moderate hemiparesis may benefit from augmented feedback, such as the visual feedback produced by MT. This visual feedback may assist with the re-learning of limb dynamics resulting in improvement in movement skills. On the other hand, BMT may be more beneficial for stroke individuals with moderate to minimal hemiparesis because this population has increased isolated and voluntary movement of the affected limb and greater ability to duplicate the movements of the unaffected hand. With this greater ability, the proprioceptive and visual conflict decreases, thus possibly allowing for better recovery, or perhaps the error information generated by the conflict adds to the learning at this stage of recovery. It can further be argued that as the affected arm/hand continues to improve, MT may not be needed and other interventions may be more beneficial, such as repetitive task practice. Nonetheless, there needs to be more comparative mirror therapy research for best practice use.

Mirror Groups versus TOT

While many studies have shown the efficacy of mirror therapy for upper limb recovery, few have examined the efficacy of mirror therapy as a home program. Therefore, the second aim of this study was to determine if home-based mirror therapy using either approach is more beneficial for upper limb recovery post-stroke, compared to traditional home-based OT program. While the results of the study showed no significant differences between the mirror groups and the control group, the effect size and 95% CI data suggested that UMT may be more beneficial compared to TOT; however, in comparing BMT to TOT, it may be equally beneficial.

Primary Outcome Measure

Activity level. Participants in the UMT and BMT groups exhibited greater mean difference scores on the primary outcome measure, the ARAT, as compared to the TOT group, resulting in moderate to small effect sizes (d = 0.55, 0.15, respectively). In addition, the mean difference between UMT and TOT was 3.13 with a 95% CI of -3.22 to 9.47, suggesting possible clinical significance in favor of UMT. However, for BMT versus TOT, the mean difference was 0.70 with a 95% CI = -4.64 to 6.03, suggesting minimal if any advantage of BMT over TOT. Furthermore, 43% of UMT and BMT group participants exceeded the MCID of 5.7, compared to only 25% of the TOT group participants. These data suggested that UMT may be more beneficial at the activity level as compared to TOT, with minimal to no effect of BMT compared to TOT.

Secondary Outcome Measures

Impairment level. Participants in the UMT and BMT groups exhibited greater mean difference scores on the FMA as compared to the TOT group, resulting in large to trivial effect size (d = 0.84, 0.09, respectively) in favor of the mirror groups, thus suggesting that UMT may be more beneficial than TOT for improving motor function (impairment level), while BMT may have minimal benefits over TOT. This is consistent with several randomized controlled studies that reported improvement on the FMA with either UMT (Gurbuz et al., 2016; Khandare et al., 2013; Kim, et al., 2016) or BMT (Lim et al., 2016; Rajappan et al., 2015; Samuelkamaleshkumar et al., 2014; Wu et al., 2013) protocols compared to control groups.

It should be noted that when comparing both mirror groups to TOT, UMT appeared to be more beneficial as compared to BMT, as per the effect size data previously mentioned as well as the mean difference and 95% CI and MCID data. In comparing each mirror group with TOT, the mean difference between UMT and TOT was 4.20 with a 95% CI = -1.37 to 9.76, suggesting benefits in favor of UMT. On the other hand, in comparing BMT and TOT, the mean difference was 0.49 with a 95% CI of -5.24 to 6.21, suggesting minimal if any benefits in favor of BMT. Furthermore, 71% of the UMT group participants exceeded the FMA MCID of 5.25, while for BMT and TOT, 57% and 38%, respectively, exceeded this number.

The grip strength data, however, showed an increase in both BMT and TOT groups while there was a decline in the UMT group. The data suggested that TOT may be more clinically relevant compared to UMT for grip strength, as the effect size was moderate (d = -0.59) and the means difference was -5.19 with a 95% CI of -15.1 to 4.70 in favor of TOT. On the other hand, the effect size was trivial for BMT over TOT (d = 0.11) and the 95% CI data showed minimal to no clear advantage of BMT over TOT for grip strength (mean difference of 1.00 with a 95% CI of -9.12 to 11.1), thus indicating that both BMT and TOT may be equally beneficial for grip strength. These findings are not surprising as both BMT and TOT protocols have the participants consistently moving the affected hand, while in UMT the affected hand is static. It could be possible that BMT and TOT are clinically more relevant for improving grip strength due to the repetitive movement of the affected hand.

However, while BMT and TOT may be more clinically relevant for improved grip strength, this did not translate to greater improvement on the activity level measures as compared to the UMT group. The UMT group improved the most on the activity outcome measures, but declined in grip strength. It is possible that improved grip strength is not imperative for improvement in ADLs. However, research has conflicting results in regard to the relationship between grip strength and ADLs. Some studies have shown a positive correlation between grip strength and ADLs (Bae et al., 2015; Kim, 2016), while others have not (Ekstrad, Rylander, Lexell, & Brogårdh, 2016) Possibly, the relearning of limb dynamics is more relevant than increasing grip strength for improvement in ADLs in post-stroke individuals. However, further research is needed to make more definitive conclusions.

Activity and participation levels. The most significant finding was the ABILHAND in favor of the UMT group, compared to the TOT group, which strengthens the above argument that UMT may be more beneficial than TOT at the activity level. The effect size was not only large (d = 1.22), but the mean difference was 1.15 with a 95% CI= 0.09 to 2.20, suggesting strong clinical significance in favor of UMT over TOT. Furthermore, 100% of the UMT participants exceeded the ABILHAND MCID score as compared to 63% of the TOT group participants. However, the clinical significance of the BMT group did not meet these standards as the effect size was small (d = 0.38) and the mean difference was 0.41 with a 95% CI of -0.81 to 1.63. Overall, the ABILHAND and ARAT data suggested that UMT may be more beneficial than TOT at the activity level.

One possible reason for the significant clinical findings of the UMT group with respect to the ABILHAND may be because UMT participants improved the most on the objective measures of motor function (FMA) and activity (ARAT). These improvements may have positively impacted their perception of affected limb use during daily tasks. A second reason could be that during UMT there is a perception of bilateral movements, as participants move the unaffected hand while viewing the mirror image, while participants in the TOT group only move the affected hand (unilateral movement). Consequently, there is greater perceived ability with bilateral tasks on the ABILHAND for the UMT group, as compared to the TOT group. Regarding BMT, one can argue that although BMT provides the perception of bilateral movements, the visual and proprioceptive conflict degrades the visual illusion, thus decreasing the perception of bilateral movements.

The TOT group, however, appeared to perform better on the SIS-hand use as compared to both UMT and BMT groups (d = -0.60 and -0.62, respectively). It could be argued that the proprioceptive and visual conflict in BMT decreased the positive effects of the visual feedback, thus causing decreased perception of the ability to use the affected hand. However, the discrepancy for SIS-hand use could also be due to an outlier in the traditional group for this measure, as evidenced by box plot analysis. This participant improved from a score of 0, which represents the perception of no ability to perform the specific tasks with the affected hand, to a score of 72 (maximum score 80), which represents minimal to no difficulty with the same tasks. These data appeared to be inconsistent with the participant's FMA hand data, which assesses a patient's ability to perform voluntary hand movements (total score 14). The participant's baseline FMA hand score was 2 and improved to 3, suggesting minimal voluntary movement and improvement of the affected hand. Despite the small changes on the hand section of the FMA, the participant improved on the ARAT by 12 points. This clinically meaningful improvement at the activity level may have led to the increased perception of hand use as measured by the SIS. An alternative explanation may be that since the TOT group performed all of the exercises and tasks with their affected hand and observed the "real" movements, this created a perception of greater capacity of the arm/hand.

Interestingly, while the TOT group performed better on the SIS-hand use compared to the mirror groups, as just indicated, the TOT group fared worse on the subjective measure of hand use as per the ABILHAND. This may be explained because the ABILHAND assesses perceived difficulty with bilateral arm/hand tasks, while the SIS-hand use domain assesses perceived hand use for both bilateral and unilateral arm/hand tasks. Inherent in the UMT and BMT protocols, participants moved their affected limb while viewing the mirror illusion, thus creating bilateral sensory input and perceived or actual bilateral movements, respectively. Therefore, the MT groups performed better on the ABILHAND as compared to the SIS-hand use. On the other hand, the TOT group participants only moved the affected hand (unilateral input), hence higher perceived hand performance on the SIS-hand use, which assesses bilateral and unilateral tasks. The data from this study showed that 63% of the TOT participants improved on both unilateral hand task sub components of the SIS-hand use (turning a knob and picking up a dime) as compared to the UMT group (43% and 28%, respectively) and the BMT group (28% and 14%, respectively), thus supporting this argument.

With regard to participation, the results showed a main effect of time for all groups, but no statistical differences between the mirror groups and TOT. In addition, there was minimal to no clinical difference as per effect size and 95% CI data. For UMT versus TOT, there was a trivial effect size (*d* = 0.13) with mean difference of 1.56 with a 95% CI of -12.2 to 15.3 in favor of UMT. For BMT versus TOT, there was a small effect size (*d* = -0.21) in favor of TOT with a mean difference of -2.01 with a 95% CI of -12.6 to 8.55. This is consistent with Thieme et al. (2013), in which the research showed a main effect of time with no group difference on the SIS. In contrast, Michielsen et al. (2011a) also examined MT and participation with the EQ-5D and found no main effect of time or group differences. Interestingly, both of these studies used the BMT protocol. Thus, this study is the first to examine UMT and participation. While there were significant clinical findings in favor of the mirror groups compared to TOT at the level of impairment and activity, there was minimal to no effect in favor of the mirror groups on participation. These findings are not surprising given that participation is a complex construct consisting of multiple domains, making it challenging to measure (Chang & Coster, 2014).

According to the ICF, the three domains, including body structure, activity, and participation, all interact and influence one another (WHO, 2001). Mirror therapy is an intervention that targets training of the affected arm/hand, thus focusing on improvements at the impairment level, such as increased range of motion or strength, and at the activity level, such as ability to pick up items or reach for objects. Thus, while it has been shown that MT has positive effects on these two levels compared to controls (Thieme et al., 2012), it has not been shown at the participation level (Michielsen et al., 2011a; Thieme et al., 2013). For instance, one may increase hand strength and ability to pick up items or reach for objects; however, this may not translate to societal participation, such as going out to eat at a restaurant. This may be due to the complexity of participation that includes not only increased physical abilities, but also emotional and social considerations. Therefore, it is doubtful that one single form of intervention could be effective in changing all life situations and roles (Salter et al., 2005). However, improvements at the body function and activity level may possibly translate to changes in one's participation over a period of time. Possibly given the gains made with MT across the impairment and activity level domains, these could be built upon with other treatments, such as repetitive task training, and other disciplines, such as psychology and physical therapy, for increased participation later in recovery. Furthermore, it has also been suggested that participation should not be assessed sooner than 6 months post-stroke in order to provide time for the patient's social condition to stabilize (Duncan et al., 2000). Thus, since 50% of the participants in this study were 6 months or less post-stroke, assessing participation changes at this time would not be optimal.

While no definitive conclusions can be drawn, the data suggested that UMT may be more beneficial than TOT for improvements at the impairment level, except for grip strength, and at the activity level for subacute/chronic stroke individuals. In addition, BMT appears to have no greater benefit as compared to TOT, hence UMT may be more beneficial than both BMT and TOT at the impairment level, except for grip strength, and at the activity level. The reason that UMT is possibly more beneficial than TOT may be because the participants had moderate to severe upper limb impairments; therefore, there was a decrease in task-intrinsic feedback (sensory and perceptual information) of the upper limb, which is important for learning and performing a skill. Augmented feedback or external feedback assists with learning and performing a motor skill because it enhances or substitutes for task-intrinsic feedback (Magill, 2011). Therefore, since UMT participants received positive augmented feedback (mirror illusion), this may have enhanced or substituted for the lack of task-intrinsic feedback, resulting in greater improvement. In contrast, the TOT group had less positive augmented feedback (no mirror illusion) and had to rely on task-intrinsic feedback, which was decreased due to the impairment severity. In this study, the one UMT participant who had severe hemiparesis (FMA score of 14) had the largest change scores on the FMA, ABILHAND, and grip strength. In comparison, one TOT participant with a FMA score of 16 had lower change scores on the FMA, ARAT, ABILHAND, and grip strength, indicating that UMT may be more beneficial for severely impaired stroke individuals. Hence, it may be possible that for severe to moderately impaired stroke individuals, the mirror illusion (augmented feedback) is important for motor relearning and skill acquisition.

Home Program Compliance

Overall, all participants regardless of age, gender, or time post-stroke adhered to their respective home programs. More specifically, 60% of the participants adhered to at least 900 total minutes of home-based therapy, while 36% were in the range of 818 to 872 minutes. One participant performed 700 total minutes of home-based therapy. These results showed that all participants, regardless of their home-based program, had a high adherence rate, which is inconsistent with research addressing exercise adherence in stroke rehabilitation. Yao et al. (2017) examined the longitudinal pattern of rehabilitation exercise adherence of individuals who sustained a unilateral first-time stroke with hemiparesis and followed them from 1- to 24-weeks post-stroke. Results showed that adherence rates increased rapidly after 1-week post-stroke and reached its maximum level 6 weeks post-stroke. After 6 weeks, adherence steadily declined until 21 weeks where it stabilized. The researches argued that at the acute stage post-stroke, individuals have a strong will to survive and recover, observe improvements, and have support and guidance from the rehabilitation team, thus the increase of rehabilitation exercise adherence. After 6 weeks, most patients are discharged home, professional guidance decreases, and family members do not provide sufficient guidance and supervision. Consequently, the adherence levels start to decline at this stage.

In comparison, in this home-based MT study, rehabilitation exercise adherence rates were high for all individuals regardless of time post-stroke and home program designation. This possibly could have occurred because the individuals were receiving OT 2x/week and one session with the research OT, thus increased professional guidance and positive reinforcement. In addition, each individual was called 1-2 times a week for guidance and reminders, had an extensive home instruction manual with pictures, and had to log their time spent with their home program, therefore more structure and feedback. In addition, the structured home program for this study was modeled after the Michielsen et al. (2011a) study which had high adherence rates of home-based mirror therapy for chronic stroke individuals. Therefore, it can be argued that rehabilitation exercise adherence can be increased with a structured home program and weekly guidance. Interestingly, although there were no statistical differences between the groups regarding total time of home-based therapy, the UMT group fell below the prescribed 900 minutes as compared to the BMT and TOT groups who were above the prescribed 900 minutes. Despite the UMT lower adherence to the prescribed time, this group improved the most at the impairment and activity level as per effect size and 95% CI analysis.

Acceptability

All three groups were not significantly different in regard to acceptability of the home program which indicated neutral to agreeable acceptability. Similarly, all groups were neutral to agreeable in regard to the subcomponents of the Likert scale which were usability, perceived improvement of the affected limb and continuation of the home program. This may have occurred because all groups improved on the majority of the outcome measures, both the objective and subjective—thus, similar perceived improvement of the affected limb and the overall acceptability of the home program. Curiously, the BMT and TOT groups not only adhered to the program, but also found it to be usable and would continue the home program to the same extent as the UMT group, despite that both BMT and TOT protocols may have been more challenging than the UMT protocol. For the UMT groups, the affected hand was static, while for BMT and TOT, the participants were instructed to move the affected limb—thus, the increased challenge. Nonetheless, all groups had similar adherence and acceptability outcomes. This may have occurred due to the structured home program, continued guidance of the OTs over the six weeks, and the phone call reminders. In addition, individuals who consent to participate in research are highly motivated; thus, even though the BMT and TOT protocols may have been more challenging, the participants continued with the home program. However, there was no follow-up data which would have increased our understanding of adherence, acceptability, and perceived improvements after the 6-week home-based program.

Clinical Implications

This study successfully demonstrated the efficacy of both home-based MT protocols as well as the traditional home-based program for improved upper limb recovery in subacute/chronic individuals post-stroke. In addition, all participants had high adherence rates as per the log and acceptability data. Although there were no statistical differences between the groups on all outcome measures across the spectrum of disability, there was clinical significance in favor of UMT at both the impairment and activity levels. Therefore, clinicians may opt for prescribing UMT as a home-based program for the subacute/chronic stroke population with moderate to severe hemiparesis over BMT and TOT as an adjunct to outpatient occupational therapy services.

Limitations

There were several limitations in this study. First, the sample size was small, which makes it difficult to generalize to the population. Additionally, the small sample may have created a type II error, which reflects a failure to detect group differences if present for the ARAT, FMA, and ABILHAND, as per the 95% CI data. Second, because there was no long-term follow-up, there was no understanding if improvements made post-intervention were maintained, improved, or declined over time. Third, while all of the evaluators were trained on the assessment through lecture, demonstration, and videos, there was no formal interrater reliability testing. Fourth, all of the participants received traditional occupational therapy; however, the treating OTs differed per participant due to logistics of the study and the facility. Due to variability of the OTs' experience and treating expertise, the participants may not have received the same care. However, all the OTs at the hospital are managed under one clinical supervisor, and thus receive similar assistance and feedback, attend the same department in-services, and attend similar continuing education classes. Fifth, the log data showed that all participants adhered to the home program; however, this was all subjective data, with no objective data to corroborate this information. Finally, grip data were not collected consistently for all the participants and this may have altered the final analysis.

Directions for Future Research

Although there were no statistically significant differences between the groups regarding upper limb recovery, the MCID, 95% CI, and effect size analysis suggested clinical significance in favor of UMT. Given these findings, continuation of this research is warranted to gain more information about best practice. However, modifications of the study would be needed to make a stronger and more robust study. First, since there already is a great deal of research on the efficacy of MT as compared to the controls, a comparative design (two groups) would be more suitable to examine the differences of the two protocols—thus, a larger number of participants per group. A power analysis of the ARAT, FMA, and ABILHAND data from this study showed that a future study with only two groups (UMT and BMT) would require 87, 39, and 30 participants, respectively, to show statistical significance. While it was challenging to recruit the appropriate patients for this study, a multi center clinical trial would help increase recruiting rates. In addition, a larger sample size would allow for subgroup analysis with regard to time post-stoke, left versus right hemiparesis, stroke lesion, and severity of stroke. Second, the intervention could either be changed to subjects only receiving the home-based mirror programs plus the one session per week with the research OT or maintaining the OT in the clinic twice a week, collecting treatment data from each therapist, and using the data as a covariate. Either method would eliminate the variability of the OT interventions in the clinic. In addition, adding weekly or biweekly Skype session with subjects in their home environment and/or adding a component of caregiver assist would provide more objective data on adherence and accuracy of performing the home program.

Third, a 3-month follow-up would help to determine the effectiveness of the treatment over time. Fourth, formally testing the interrater reliability of the assessors and not collecting outcome data from the chart would create more accurate and reliable data. Fifth, adding the Functional Upper Extremity Levels (FUEL), a valid and reliable assessment that measures paretic limb progression during ADLs in post-stroke individuals (Van Lew et al., 2015), would help measure real-time use of the affected arm during activities. In addition, adding kinematic outcome measures would help increase understanding of upper limb dynamics and learning in regard to MT and upper limb recovery in post-stoke individuals.

Conclusion

In summary, all groups appeared to adhere to their respective home-based programs and improved significantly over the 6-week period at the impairment, activity, and participation domains. Although there were no significant differences between the groups, the effect size, 95% CI, and MCID data suggested that the UMT may be more beneficial for chronic stroke patients with moderate to severe hemiparesis, as compared to BMT or TOT for motor function and activities. Regarding BMT, the conflict between the visual illusion and the proprioceptive feedback of the intact hand may have decreased the positive effects of the visual feedback, resulting in greater clinical significance of UMT over BMT. With regard to the TOT, the participants had moderate to severe hemiparesis and decreased task-intrinsic feedback, which may have resulted in the greater clinical significance of UMT over TOT. However, both BMT and TOT appeared to be more beneficial for grip strength, as compared to UMT, possibly because the BMT and TOT participants moved their affected hand throughout their home program, while UMT participants' hands were static. In conclusion, UMT may be the preferential home-based protocol for upper limb motor recovery and activity-level gains in moderate to severely impaired subacute/chronic stroke individuals, while BMT and TOT may be preferential for grip strength improvement. However, further research is needed for more definitive conclusions.

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Appendix A

Definitions of Terms

Mirror Therapy (MT): Mirror therapy is a non-invasive stroke rehabilitation strategy whereby the patient sits at a table in front of a mirror box placed in the mid-sagittal plane. The affected hand is placed in the mirror box, while the unaffected hand is placed outside of the box facing the mirror. The mirror is used to create a visual illusion that the affected limb is intact, and therefore recruiting or accessing dormant neural circuits and neuroplasticity of the affected hemisphere.

Bimanual Mirror Therapy (BMT): Bimanual mirror therapy is one of two protocols of mirror therapy that have been utilized in upper limb stroke rehabilitation. The set-up is as stated above for MT, with the affected hand in the mirror box, while the unaffected hand is placed outside the box facing the mirror. The patient is instructed to perform different exercises and tasks with the unaffected hand while moving the affected hand (the hand in the mirror box) as best as possible to duplicate the movements of the unaffected hand. Furthermore, the patient is instructed to view the mirror image instead of the unaffected hand or the affected hand in the mirror box.

Unimanual Mirror Therapy (UMT): Unimanual mirror therapy is the second mirror therapy protocol that has been utilized in upper limb stroke rehabilitation. The set-up is as stated above in MT and the protocol is similar to BMT; however, the patient is instructed to keep the affected hand in the mirror box static while the unaffected hand performs the exercises or functional tasks. Just as in BMT, the patient is instructed to view the mirror image instead of the unaffected hand or the affected hand in the mirror box.

Motor Learning: The permanent improvement of a motor skill as a result of practice, repetition, and experience (Magill, 2011).

Action Research Arm Test (ARAT): A standardized objective assessment used to evaluate arm and hand function at the activity level domain. This instrument contains 19 items and uses a 4-point ordinal scale to evaluate and measure activity level domain changes in five-finger grip, cylindrical grasp, pincer grip, and gross arm movements in post-stroke patients (Bushnell et al., 2015).

Fugl-Meyer Assessment (FMA): Measures recovery in patients with hemiplegia post-stroke and has been the gold standard in stroke research (Fugl-Meyer et al.,1975). The upper limb section of the FMA measures performance at the impairment/body function domain (Bushnell et al., 2015) and includes upper extremity motor function scored on a 3-point ordinal scale with a maximum score of 66.

Grip Strength: An objective measure of grip strength, tested with a dynamometer in the standard position and averaging three grip measures.

ABILHAND: An interview-based tool that measures a subject's perceived difficulty with use of his or her arms/hands during activities of daily living. The ABILHAND, a 56-item assessment, was first developed to measure patients' perceived ability to perform bimanual and unimanual; however, it was later calibrated for chronic stroke patients, resulting in a decline of the original 56 items to only 23 tasks, which were only bimanual tasks, as per Rasch analysis (Penta et al., 2001).

The Stroke Impact Scale (SIS), version 3.0: A subjective standardized 59-item, eight-domain questionnaire assessing health status post-stroke at the ICF activity and participation domains (Bushnell et al., 2015). Each item is rated on a 5-point ordinal scale in regard to one's perceived difficulty with an item, which can be repeated to track changes over time.

Appendix B

Likert Scale Questionnaire

Questions	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
I found the set up of the home program to be easy (setting up the exercises, setting up the mirror if you were in the mirror group).					
The instructions and pictures were helpful.					
Active range of motion (AROM) exercises.					
I found the AROM exercises the easiest to do.					
I found the AROM exercises the most helpful.					
I enjoyed doing the AROM exercises the most.					
Functional Tasks					
I found the functional tasks the easiest to do.					
I found the functional tasks the most helpful.					
I enjoyed doing the functional tasks the most.					
Other					
I required no help to do the home program.					
I noticed changes in my arm and hand while doing the home program.					
I noticed changes in my arm and hand while doing my every day tasks outside of the home program.					
I was able to use my arm and hand better after completing the 6 week home program.					
I will continue to do the home program.					
Total score					

Appendix C

Log Data Sheet

Daily Log for Mirror Therapy

Week   : Perform at least 5 sessions per week for 30 minutes.   **Start Date:** ________________**End Date:** __________________

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Time start of therapy							
Time end of therapy							
Moving the Arm/Hand (10 minutes total)							
Functional tasks with an object (10 minutes total)	Minutes	Minutes	Minutes	Minutes	Minutes	Minutes	Minutes
Wash table							
Place cup in hand and move							
Reach to touch switch							
Hold mallet and drum							
Play egg shakers							
Object Manipulation (10 minutes total)	Minutes	Minutes	Minutes	Minutes	Minutes	Minutes	Minutes
Grasp release of objects							
Flip Cards							
Transport items: side to side in tray							
Squeeze Ball							

Appendix D

Categories of Home Exercise Program

Categories of Activity	**Examples**	**General instructions**
Moving the Arm/Hand	• Reaching • Elbow flexion/extension • Forearm pronation/supination • Wrist flexion/extension • Hand grasp/release • Finger/Thumb opposition • Finger Tapping • Squeeze/Spread hand	Instructed to perform 10X each as warm up **OR** perform all within 10 minutes.
Functional Tasks with Objects	• "Washing" a table using forward-and-back and side-to-side motions • Place cup in hand and lift and move forward-and-back and side-to-side motions, and pouring motion • Reach to touch a switch • Hold mallet and play like drum • Hold egg shakers and shake forward-and-back and side-to-side motions	Pick 2 and perform both tasks within 10 minutes.
Object Manipulation	• Grasp and release of objects with different size, shapes, and textures • Flip cards • Transport items from one side of tray to the other • Squeeze a ball	Pick 2 and perform both tasks within 10 minutes.

Appendix E

Functional Tasks With Objects Progression
(Adapted from Shaping progression from CIMT)

Activity	Activity description	Progression
Washing a table	Subject is asked to use a washcloth to wipe the table with forward and backward motions	• **Distance**: Wash table farther away for increased shoulder flexion and elbow extension • **Complex movements:** Washing table with diagonals and circular motions to increase shoulder movements • **Weight:** Place a 1 # weight on washcloth and perform wiping motions • **Number:** Increase repetition for endurance

Cup in hand	Subject is asked to place cup in hand and slide on the table forward and backward	• **Distance**: Reach farther away to increase shoulder flexion and elbow extension
		• **Height:** Lift cup off of table and place forward to increase shoulder flexion
		• **Complex movements:**
		  o Diagonals and circular motions to increase shoulder movements
		  o Add pouring movement to increase forearm supination/pronation
		• **Weight:** Add water to cup for increased weight (¼, ½, ¾, full)
		• **Number:** Increase repetition for endurance

Reach to touch switch	Subject is asked to reach and touch a small sticker target with fisted hand	• **Distance**: Target moved farther away
		• **Complex movements:** Target moved to create diagonal movements
		• **Accuracy:**
		  o Reach and touch with specific location on hand
		  o Reach and touch with finger
		• **Number:** Increase repetition for endurance

Drumming with mallet	Subject is asked to hold a mallet and pretend to drum the table	• **Distance**: Reach farther away to drum table
		• **Complex movements:**
		  o Reach into diagonals to increase shoulder movements
		  o Increase wrist flexion and extension with elbow flexion/extension
		• **Height:** Reach higher and drum in the air for increased shoulder flexion
		• **Number:** Increase repetition for endurance

Egg shaker	Subject asked to grasp an egg shaker and shake back and forth	• **Distance**: Reach farther away and shake the egg
		• **Complex movements:**
		  o Reach into diagonals to increase shoulder movement
		  o Increased wrist flexion and extension
		• **Height:** Reach higher and shake the egg to increase shoulder flexion
		• **Number:** Increase repetition for endurance

Appendix F

Object Manipulation Progression
(Adapted from Shaping progression from CIMT)

Activity	Activity Description	Progression

Grasp and release small objects	Subject is asked to grasp and release objects	• **Size of object:** Use progressively smaller objects to increase fine motor coordination (fmc)
		• **Distance**: Reach for objects that are farther to increase elbow extension
		• **Height**: Place objects on box to increase shoulder flexion
		• **Complex movements:**
		    o Reach for objects in diagonals to increase shoulder movements
		    o Pick up one object then another object then release one at a time to increase hand fmc
		• **Number:** Increase repetition for endurance

Flip cards	Subject is asked to flip cards	• **Distance**: Reach farther away to increase shoulder flexion and elbow extension • **Height**: Place cards on a box to increase shoulder flexion • **Complex movements:** Reach for cards in diagonals to increase shoulder movements. • **Number:** Increase repetition for endurance

Transport items	Subject is asked to transport items from one side of tray to the other	• **Size of Object:** Use progressively small objects to increase fmc
		• **Distance**: Place tray farther away to increased shoulder flexion and elbow extension
		• **Height**: Place Tray on a box to increase shoulder flexion
		• **Complex movements:**
		    o Place tray to the side to create diagonal movements
		    o Pick up one object then another object then release one at a time into other side of tray to increase hand fmc
		• **Number:** Increase repetition for endurance

Squeeze a ball	Subject is asked to grasp a small soft ball and squeeze	• **Distance**: Reach farther away and squeeze ball
		• **Height**: Reach higher and squeeze the ball to increase shoulder flexion
		• **Complex movements:**
		    o Rotate the ball in the hand clockwise and counter clockwise
		    o Translate the ball from finger tips to palm and palm to finger tips
		    o Translate ball from palm to finger tips and then extend fingers
		• **Number:** Increase repetition for endurance

Appendix G

Pilot Feasibility Study

A pilot feasibility study was performed with the above-mentioned research design and intervention procedures. A total of eight subjects were consented for the study, while only seven were enrolled because of one screen failure. One subject voluntarily withdrew from the study, reporting he was unable to perform the home program consistently. There were a total of six subjects, two per group. In the unimanual MT (UMT) group, the mean age was 63 and mean time post-stroke was 52 months; there was one Asian female participant and one Caucasian male participant. In the bimanual MT (BMT) group, the mean age was 40 and mean time post-stroke was 30 months; there was one Hispanic participant and one Caucasian participant, both females. In the traditional OT (TOT) control group, the mean age was 55.5 and mean time post-stroke was 19.5 months; there was one Asian participant and one Caucasian participant, both males.

Results: The results of this pilot study are discussed in detail below.

Primary outcome measure. Mean change scores in the ARAT improved in all groups from pretest (Bimanual, *M* = 36, SEM = ±1.0; Unimanual *M* = 10.5, SEM = ±1.5; Traditional *M* = 25, SEM = ±10) to posttest (Bimanual, *M* = 43, SEM = ±9.0; Unimanual *M* = 19.5, SEM = ±9.5; Traditional *M* = 25, SEM = ±12). Mean change scores were greatest for the unimanual group, followed by the bimanual and traditional groups, respectively.

Secondary outcome measures. Mean change scores in the FMA improved in all groups from pretest (Bimanual, *M* = 39, SEM = ±3.0; Unimanual *M* = 26, SEM = ±0; Traditional *M* = 30.5, SEM = ±4.5) to posttest (Bimanual, *M* = 48, SEM = ±2.0; Unimanual *M* = 35.5, SEM = ±3.5; Traditional *M* = 38.5, SEM = ±10.5). Mean change scores were greatest for the unimanual group, followed by the bimanual and traditional groups, respectively. Grip strength mean scores pretest (Bimanual, *M* = 30, SEM = ±20.0; Unimanual *M* = 7.5, SEM = ±2.5; Traditional *M* = 15.5, SEM =±9.5) to posttest (Bimanual, *M* = 38.5, SEM = ±16.5; Unimanual *M* = 4.5, SEM = ±0.5; Traditional *M* = 29, SEM = ±4.0) improved for the bimanual and traditional groups, but declined in the unimanual group. Mean change scores were greatest for the traditional group, followed by the bimanual group, then the unimanual group, respectively. Mean scores in the ABILIHAND improved in all groups from pretest (Bimanual, *M* = 29.5, SEM = ±5.5; Unimanual *M* = 16.5, SEM = ±3.5; Traditional *M* = 19.5, SEM = ±6.5) to posttest (Bimanual, *M* = 29.5, SEM = ±1.5; Unimanual *M* = 24.5, SEM = ±1.5; Traditional *M* = 27.5, SEM = ±0.79). Change mean scores were greatest for the unimanual and traditional groups as well as equal, followed by the bimanual group, respectively. Mean scores in the SIS improved in all groups across all levels of disability. For SIS strength, pretest (Bimanual, *M* = 40, SEM = ±0; Unimanual *M* = 50, SEM = ±0; Traditional *M* = 37.5, SEM = ±7.5) to posttest (Bimanual, *M* = 45, SEM = ±5.0; Unimanual *M* = 60, SEM = ±10; Traditional *M* = 45, SEM = ±10), improved the most for the unimanual group, followed by the traditional group, then the bimanual group, respectively. For SIS activity, pretest (Bimanual, *M* = 52, SEM = ±18; Unimanual *M* = 22, SEM = ±16; Traditional *M* = 49, SEM = ±17) to posttest (Bimanual, *M* = 73, SEM = ±3.0; Unimanual *M* = 42, SEM = ±19; Traditional *M* = 49, SEM = ±5.0), improved the greatest for the bimanual group, followed by the unimanual group, then the traditional group, respectively. For SIS participation, pretest (Bimanual, *M* = 48.8, SEM = ±19; Unimanual *M* = 27.5, SEM = ±25; Traditional *M* = 43.7, SEM = ±6.3) to posttest (Bimanual, *M* = 55, SEM = ±15; Unimanual *M* = 31.3, SEM = ±29; Traditional *M* = 55, SEM = ±7.5), improved the most for the traditional group, followed by the bimanual group, then the unimanual group, respectively.

Discussion. No definitive conclusions can be made from this pilot study due to the small number of subjects in each group; however, the data did suggest that the mirror therapy home program positively affects the upper limb in both impairments and activity levels in post-subacute stroke patients. In addition, the data showed that unimanual MT produced better outcomes than the bimanual group. Participants in both mirror groups exhibited greater change scores on the primary outcome the ARAT, as compared to the control group. Additionally, both MT groups exhibited greater change scores on secondary outcome measures, the FMA and SIS-ADL. However, these improvements at the impairment and activity levels for the MT groups did not translate into greater change in participation. According to the SIS-participation outcome, the TOT group had the greatest mean change score. This finding was not surprising given that participation is a complex construct consisting of multiple domains, making it challenging to measure.

In comparing the two mirror groups, the UMT group had a greater mean change score on the ARAT, suggesting that adding UMT may improve UE function to a greater degree than BMT. Additionally, the UMT group had larger mean change score on the following secondary outcome measures, the FMA, ABILHAND, SIS-ADL and SIS-strength. Interestingly, hand strength declined in the UMT group, yet this group reported the greatest change on their perceived strength as per SIS-strength. This discrepancy may be because of the subjective nature of the SIS-strength and that arm and leg strength are both measured in this domain. An alternative explanation may be that the improved ability to use the arm and hand, as measured by the ARAT, led to the perception of increased strength. However, the improvements seen on the aforementioned secondary outcome measures further supported the notion that UMT may be the preferred MT protocol for improving UE impairment and function for this population. One important consideration is that the inclusion criteria were changed after the pilot study to include participants with a lower FMA score (10 instead of 20) and increase in age from 75 to 85.