Home mirror therapy: a randomized controlled pilot study comparing unimanual and bimanual mirror therapy for improved arm and hand function post-stroke

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Home mirror therapy: a randomized controlled pilot study comparing unimanual and bimanual mirror therapy for improved arm and hand function post-stroke

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ABSTRACT
Purpose: To compare home-based unimanual mirror therapy (UMT) and bimanual mirror therapy (BMT) for upper limb recovery in subacute/chronic stroke individuals with moderate-to-severe arm impairment. Method: Twenty-two participants were randomized into 1 of 3 groups: UMT, BMT or traditional occupational therapy (TOT) home-based programs. The intervention was 6-weeks and consisted of OT 2 days a week, weekly sessions with the research OT, and 30-minutes of the home-based program 5 days a week, according to group allocation. The Action Research Arm Test (ARAT), ABILHAND, Fugl-Meyer Assessment (FMA), grip strength, and Stroke Impact Scale (SIS) were used for outcome measures. Results: All groups significantly improved over time on all outcome measures and adhered to the prescribed dosage regardless of group (p<0.05). While there were no between-group differences, effect size and 95% confidence interval data suggest a clinical significance in favor of UMT as compared to the other groups. Conclusions: All participants, regardless of home-based program, adhered to the prescribed dosage and significantly improved over time. Despite no between-group differences, effect size and 95% confidence interval data suggest that UMT may be more beneficial for individuals with moderate-to-severe arm impairment as compared to BMT or TOT. ClinicalTrials.gov: #NCT02780440

IMPLICATIONS FOR REHABILITATION
• Home-based unimanual mirror therapy (UMT), bimanual mirror therapy (BMT), and traditional occupational therapy (TOT), when administered in conjunction with outpatient OT, are helpful for improving upper limb recovery post-stroke.
• Home-based UMT may be more beneficial than BMT or TOT for improvement in upper limb motor function and activities of daily living of patients with moderate to severe arm impairment post-stroke.

Introduction
Stroke is the leading cause of adult disability in the United States with over 7 million survivors [1]. The majority of stroke survivors have persistent hemiparesis, with over 85% experiencing upper limb dysfunction, which is a significant barrier to function and life participation [2]. Thus, remediation of upper limb function is often the target of standard care in stroke rehabilitation programs [3–7]. However, despite various upper limb interventions, there continues to be challenges such as cost, labor intensity, required arm/hand movements for participation [4,8] and low practice dosage [9,10], which limits patients’ upper limb recovery and function post-stroke.

Mirror therapy (MT) was first described by Ramachandran & Rogers-Ramachandran [11] to relieve phantom pain after amputation and later introduced to treat hemiparesis post-stroke [12]. MT is an intervention in which a mirror box is placed in the mid-sagittal plane to the participant between the extremities. The affected hand is placed in the mirror box and the unaffected hand is placed outside of the box facing the mirror. During MT, the person moves the unaffected hand while watching the mirror reflection, giving the visual illusion that the affected limb is moving. MT not only has been shown to improve upper limb recovery post-stroke, but requires minimal supervision, no arm/hand requirements for participation, and low cost, thus can be used as an adjunct to standard stroke care to increase practice dosage [13–15]. Furthermore, MT has been shown to facilitate neuroplastic changes in the brain through 3 possible underlying mechanism: (a) perceptual motor process; (b) direct facilitation of the motor network; and (c) activation of the mirror neuron system [16]. 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.

Two different MT protocols have been used in stroke rehabilitation: unimanual mirror therapy (UMT) and bimanual mirror...
therapy (BMT). During both protocols, the affected hand is placed in the mirror box and the patient is instructed to view the mirror reflection of the unaffected hand. During UMT the affected hand is static, while during BMT, the affected hand moves in an attempt to duplicate the unaffected hand.

Both MT protocols have been shown to improve upper limb recovery post-stroke [13–15]; however, results have been inconsistent across the impairment and activity domains of the International Classification of Functioning, Disability and Health (ICF) [17]. In recent randomized controlled UMT and BMT studies in subacute/chronic individuals, the results showed either improvements only at the impairment level [18–23], or improvement at both domain levels [24–30]. Furthermore, while two studies compared the MT protocols, neither were able to provide definitive conclusion regarding clinical application of MT. Selles et al. [31], compared five different upper limb interventions, including UMT and BMT, during a 1-session reaching task with chronic stroke patients. Movement time results showed no significant differences between UMT and paretic limb training without a mirror, while BMT showed significantly less improvement, suggesting UMT may be more beneficial than BMT. However, the focus of the study was upper limb motor learning after 1 session, not clinical application. In the second study, a MT meta-analysis of 32 randomized controlled studies, showed UMT to have a greater effect on motor function and motor impairment as compared to BMT, as per SMD and 95% CI data. However, since there were no statistically significant group differences, the researchers suggested further research is needed regarding optimal

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**Figure 1. CONSORT flow diagram.**
application of MT post-stroke [32]. Hence, there continues to be lack of clarity regarding which MT protocol would most benefit upper limb recovery post-stroke.

The aim of this pilot study was to compare the efficacy of home-based UMT, BMT, and traditional OT (TOT), as an adjunct to outpatient occupational therapy (OT) services, for upper limb recovery post-stroke. To our knowledge this is the first randomized controlled intervention study to compare UMT to BMT. It was hypothesized that: (1) UMT would be more beneficial than BMT; (2) both MT groups would be more beneficial than TOT for upper limb recovery in subacute/chronic stroke patients who have moderate-to-severe hemiparesis.

Material and methods

Participants

Participants were recruited from an outpatient OT department in the New York metropolitan area. The inclusion criteria were: (1) aged 19 to 85 with a first-time stroke >3 months; (2) Fugl-Meyer Assessment (FMA) score of 10–50 indicating moderate-to-severe arm impairment [33]; (3) following directions; (4) ability to grasp and release a washcloth with the affected hand. Exclusion criteria were (1) complex medical problems and pre-existing neurological or psychiatric disease; (2) hearing and/or visual impairments; (3) perceptual deficits, such as apraxia, neglect, and visual agnosia; (4) botulinum toxin injection in the affected limb <3 months prior to study inclusion; and (5) aphasia. Institutional review board approval was obtained in the academic hospital and all participants provided written informed consent.

Study design

This was a single-blinded, randomized controlled study and was registered at ClinicalTrials.gov ID: NCT02780440. The participants were pre-screened using the OTs initial assessment for age, time post-stroke, multiple strokes, following directions, and hand function (severe spasticity). This was followed by formal screening by 1 of 2 trained OT assessors. Qualified participants were randomized into 1 of 3 groups: UMT, BMT, or TOT (Figure 1). A non-research study OT performed randomization by a sealed envelope method. The same trained OT assessor, blind to group allocation, administered the pretest and posttest in the outpatient OT program in the rehabilitation department. In addition, non-research OTs providing the conventional therapy twice a week were blind to group allocation.

Intervention

Following the pre-test, the research OT educated the participants for 1 h on the home program, which was modeled after 2 studies [15,34], according to group allocation. All participants were provided with an instructional binder that included written instructions, pictures of the exercises and tasks, a log to document time spent per exercise, and home program tools (e.g., cup, paper clips etc.). Education included review of the binder though verbal instruction, demonstration, and participant return demonstration. Mirror group participants were provided with a mirror box and educated on the MT treatment protocol. UMT participants were instructed to keep the affected hand static in the mirror box (Figure 2(A)), while BMT participants were instructed to duplicate the unaffected hand as best as possible (Figure 2(B)). The TOT participants were instructed to perform all tasks with the affected limb with no mirror. All participants were instructed to perform the home-based program 30-min a day and 5 days a week. Each session was divided into three 10-min categories: (1) moving the arm/hand, (2) functional task with objects, and (3) object manipulation [34] as per group allocation (Table 1). Furthermore, participants were educated on the log, created by the primary research OT, to track time (minutes) performing the home program and for adherence purposes. The 6-week intervention consisted of two 45-min standard OT sessions in the clinic, one weekly 30-min session with the primary research OT, and the home-based program. The weekly meeting with the research OT included home program progression and review of the log. Weekly phone calls were also made for adherence purposes.

Primary outcome measure

The Action Research Arm Test (ARAT) is a 19-item standardized objective assessment used to evaluate arm/hand function post-stroke at the activity level domain [35]. Scoring is based on a 4-point ordinal scale with a total score of 57, whereby higher scores reflect greater recovery. It has excellent interrater and intrarater reliability and construct validity with the FMA [36]. The minimal clinical important difference (MCID) was established to be 5.7 points for the ARAT in chronic stroke individuals [37].

Secondary outcome measures

The FMA upper-limb subscale is a 33-item standardized objective motor impairment measure for hemiplegia post-stroke patients [38]. Scoring is based on a 3-point ordinal scale with a maximum score of 66, with higher scores indicating greater motor recovery. Its psychometric properties have been well established [39].
an MCID of 5.25 points for the upper extremity FMA in chronic stroke individuals [40].

ABILHAND, an activity level measurement, is a valid and reliable interview-based tool, measuring participants’ perceived difficulty with 23 bimanual hand activities. It has high reliability and moderate correlation with grip strength, Box and Blocks Test, and the Purdue Pegboard [41]. The MCID of the ABILHAND was established to be 0.26 to 0.35 logits in chronic stroke individuals [42].

Grip strength, an impairment level measurement, was evaluated with a Jamar Dynamometer. Following standard clinical procedures, maximal grip strength was measured with the participant seated, feet flat on the floor and shoulder distance apart, arm position with shoulder at 0 degrees, elbow at 90 degrees, forearm and wrist in neutral. The final score was taken from the average of three measurements with higher scores indicating greater grip strength. Dynamometer grip strength has good reliability and has been correlated with four upper extremity tests [43] and performance improvement [44].

The Stroke Impact Scale (SIS), version 3.0, is a subjective standardized questionnaire assessing health related quality of life post-stroke. The global perception of stroke recovery, with moderate effect; and $d = 0.38$) and a moderate ($d = 0.55$) effect size in ARAT change scores, favoring UMT over both BMT and TOT, respectively. However, there was a trivial effect size ($d = 0.15$) in favor of BMT over TOT (Table 3). In addition, 43% of UMT and BMT group participants exceeded the MCID of 5.7, compared to only 25% of the TOT group participants.

**Secondary outcome measures**

As seen in Table 4, there was a significant main effect of time for the ABILHAND, $F (1,19) = 12.16, p = 0.002$; however, there was no significant main effect of group, $F (1,19) = 0.29, p = 0.60$ There also was no significant interaction between the groups and time, $F (1,19) = 0.69, p = 0.55$. Thus, indicating ABILHAND scores improved pre to post intervention within each group with no significant differences between the groups. The ABILHAND change scores showed a large effect size in favor of UMT over BMT ($d = 0.87$) and TOT ($d = 1.22$; MD 1.15; 95% CI 0.09 to 2.20), while only a small effect size of BMT over TOT ($d = 0.38$). In addition, 100% of the UMT participants exceeded the MCID, while only 43% and 63% of the BMT and TOT group participants, respectively, exceeded the MCID.

At the impairment level, there was a significant main effect of time on the FMA $F (1,19) = 18.14, p < 0.001$; however, there was no significant main effect of group, $F (1,19) = 0.69, p = 0.55$. There also was no significant interaction between the groups and time, $F (1,19) = 0.55, p = 0.70$. Thus, indicating FMA scores improved pre to post intervention within each group with no significant differences between the groups. The FMA change scores showed a large effect size in favor of UMT over BMT ($d = 0.87$) and TOT ($d = 1.22$; MD 1.15; 95% CI 0.09 to 2.20), while only a small effect size of BMT over TOT ($d = 0.38$). In addition, 100% of the UMT participants exceeded the MCID, while only 43% and 63% of the BMT and TOT group participants, respectively, exceeded the MCID.

**Participants**

Twenty-five participants were enrolled and 22 completed the study and were included in the final analysis. There were 3 withdrawals from the UMT group: (1) participant being discharged for medical issues, (2) after participant was consented and prior to starting the first treatment, the participant indicated the home program would be too time consuming and decided not to participate in the trial (3) environmental factors (patient reported difficulty setting up equipment) (Figure 1). Baseline demographics, outcome measures, and dosage results are presented in Table 2. There were no statistically significant differences between the groups in all areas ($p > 0.05$). It should be noted that the stroke onset time was larger for the TOT as compared to the other groups; however, this was due to one participant who was 280 months post-stroke.

**Primary outcome measure**

For the ARAT, there was a significant main effect of time, $F (1,19) = 18.14, p < 0.001$; however, there was no significant main effect of group, $F (1,19) = 0.61, p = 0.69$. There also was no significant interaction between the groups and time, $F (1,19) = 0.61, p = 0.55$. Thus, indicating ARAT scores improved pre to post intervention within each group with no significant differences between the groups. The ARAT change scores showed a large effect size in favor of UMT over BMT ($d = 0.87$) and TOT ($d = 1.22$; MD 1.15; 95% CI 0.09 to 2.20), while only a small effect size of BMT over TOT ($d = 0.38$). In addition, 100% of the UMT participants exceeded the MCID, while only 43% and 63% of the BMT and TOT group participants, respectively, exceeded the MCID.

**Results**

**Participants**

Twenty-five participants were enrolled and 22 completed the study and were included in the final analysis. There were 3 withdrawals from the UMT group: (1) participant being discharged for medical issues, (2) after participant was consented and prior to starting the first treatment, the participant indicated the home program would be too time consuming and decided not to participate in the trial (3) environmental factors (patient reported difficulty setting up equipment) (Figure 1). Baseline demographics, outcome measures, and dosage results are presented in Table 2. There were no statistically significant differences between the groups in all areas ($p > 0.05$). It should be noted that the stroke onset time was larger for the TOT as compared to the other groups; however, this was due to one participant who was 280 months post-stroke.

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**Secondary outcome measures**

As seen in Table 4, there was a significant main effect of time for the ABILHAND, $F (1,19) = 12.16, p = 0.002$; however, there was no significant main effect of group, $F (1,19) = 0.29, p = 0.60$ There also was no significant interaction between the groups and time, $F (1,19) = 0.69, p = 0.55$. Thus, indicating ABILHAND scores improved pre to post intervention within each group with no significant differences between the groups. The ABILHAND change scores showed a large effect size in favor of UMT over BMT ($d = 0.87$) and TOT ($d = 1.22$; MD 1.15; 95% CI 0.09 to 2.20), while only a small effect size of BMT over TOT ($d = 0.38$). In addition, 100% of the UMT participants exceeded the MCID, while only 43% and 63% of the BMT and TOT group participants, respectively, exceeded the MCID.
also was no significant interaction between the groups and time, F (2,19) = 1.58, p = 0.23. Thus, indicating FMA scores improved pre to post intervention within each group with no significant differences between the groups. There was a large effect size for the FMA change scores in favor of UMT over both BMT and TOT (d = -0.81 and d = -0.84, respectively), however, a trivial effect size (d = 0.09) favoring BMT over TOT. In addition, 71% of the UMT group participants exceeded the MCID of 5.25, while for BMT and TOT, 57% and 38%, respectively, exceeded this number. For grip strength, there was a significant main effect of time, F (1,19) = 4.49, p = .048; however, there was no significant main effect of group, F (1,19) = 1.20, p = .32. There also was a no significant interaction between the groups and time, F (2,19) = 1.33, p = .29. Thus, indicating grip strength scores improved pre to post intervention within each group with no significant differences between the groups. For grip strength, there was a large and moderate effect size in favor of BMT over UMT (d = -1.79; MD -6.19; 95% CI, -10.2 to -2.16) and BMT over TOT (d = -0.59), respectively (Table 4).

At the participation level, there was a significant main effect of time for total SIS, F (1,19) = 6.17, p = 0.023; however, there was no significant main effect of group, F (1,19) = 0.13, p = 0.88. There also was no significant interaction between the groups and time, F (2,19) = 0.22, p = 0.81. Thus, indicating total SIS scores improved pre to post intervention within each group with no significant differences between the groups. The effect size data was either small or trivial when comparing the 3 groups (Table 4).
Although the groups did not differ significantly on the ARAT and FMA baseline data, the BMT group was clearly higher functioning. For this reason, an analysis of covariance (ANCOVA) on the posttest scores using the pretest scores as a covariate was performed. The ANCOVA results for the ARAT and FMA showed no statistically significant between group differences ($p = 0.33$ and 0.23, respectively).

**Discussion**

To our knowledge, this is the first intervention study to compare home-based UMT and BMT in subacute/chronic stroke individuals with moderate to severe hemiparesis. This 6-week home-based program demonstrated excellent adherence regardless of group designation. Although Yao et al. [49], reported adherence in stroke rehabilitation to be low, this study was modeled after previous home-based MT studies that showed adherence success [15,34]. Possible explanations for the participant adherence could be due to the structured clinic sessions, weekly sessions with the research OT, log tracking and weekly reminders by phone call or email.

**UMT versus BMT**

It was hypothesized that UMT would be more beneficial for upper limb recovery as compared to BMT. While there were no between group differences, there were indications of clinical significance in favor of UMT at the activity level. The results showed a small to large effect size in favor of UMT, as per the ARAT and ABILHAND, respectively. Furthermore, the ABILHAND had an MD = 0.73; 95% CI, −0.25 to 1.72, suggesting that UMT may be more beneficial, but larger sample sizes are needed [48]. In addition, all UMT participants exceeded the MCID, while less than half met this in the BMT group. These results are consistent with Morkisch et al. [32] research, which showed that while both UMT and BMT groups improved, the UMT groups had considerably large changes on motor function and impairment as compared to BMT. In addition, previous randomized controlled MT studies showed significant improvement on the ARAT for the UMT studies [24–26], but not for the BMT studies [15,50].

At the impairment level, the FMA data suggested that UMT may be more clinically beneficial than BMT for motor recovery. This is consistent with data presented by Selles et al. [31] whereby movement time (impairment level) was not statistically different between UMT and arm training without a mirror, while BMT was statistically less effective. In addition, while data presented by Morkisch et al. [32] showed that both MT protocols reduced motor impairments, the UMT analysis showed more robust changes. On the other hand, our grip strength data suggested BMT as more clinically relevant as compared to UMT. This may have occurred due to the implicit difference between the mirror protocols, whereby in BMT the affected hand moves, while in UMT the hand remains static. Another explanation could be that since the sample size was small, the difference in the baseline data for grip strength for BMT and UMT may have partially led to the large effect size in favor of BMT. Although grip strength is correlated with improved UE function [43], our results suggest that UMT may be more clinically relevant for the activity level domain. Possibly, the visual feedback from the mirror, which has been shown to improve internal representation of limb dynamics [51], may positively influenced the activity level domains. Sarlegna et al. [51] examined the effect of visual feedback on a novel reaching task with a deafferented patient as compared to healthy matched controls. The results showed that the deafferented patient was able to adapt to the novel reaching condition, with the use of the visual feedback, similarly to the controls. In other words, the peak velocities (limb dynamics) were similar for the patient and the healthy controls, thus the similar reaching results. The researchers concluded that visual feedback may be able to update limb dynamics, thus improve reaching capability.

Previous studies have examined the effect of BMT on participation, but this is the first study to examine the effects of UMT on participation. Participation results showed a significant effect of time for all groups, but no between group differences. Similar to our results regarding BMT and participation, Thieme et al. [52] showed a main effect of time for participation as measured by the SIS total score. In contrast to our findings, Michielsen et al. [15] showed no effect of time on participation. This inconsistency may have occurred because the researchers used the EQ-5D instead of the SIS to measure participation. However, participation is a complex construct consisting of multiple layers, not only making it challenging to measure [53], but also doubtful that one intervention type could effectively change life participation [54].

While no definitive conclusions can be drawn, the data suggested that UMT may be preferential to BMT for impairment and activity gains. However, it should be noted that although there were no statistically significant baseline differences on the ARAT and FMA, it was clear that the BMT group had higher motor function, which may have impacted the results. One possible explanation for UMT being more clinically relevant than BMT may be that during BMT a visual/proprrioceptive conflict occurred (mirror visual image conflicting with proprioception of the moving affected hand), which caused a decline in the positive effects of the visual feedback [31]. This conflict has been shown to decrease motor performance in healthy adults [55–56]. Another explanation could be the concept of cross-limb transfer, whereby bilateral gains occur from unilateral motor training [57]. One stroke study showed significant gains in the affected lower limb, in both strength and gait after strength training of the unaffected lower limb [58]. Another study, in healthy adults, showed positive behavioral and physiological outcomes due to cross-limb transfer with and without MT [59].

**Mirror groups versus TOT**

It was hypothesized that both mirror groups would be more beneficial for upper limb recovery as compared to TOT. Although there were no between group differences, there were indications of clinical significance in favor of both mirror groups, especially for UMT. Regarding the activity level measures, both the ARAT and ABILHAND showed moderate to large effect sizes for UMT over TOT as compared to small effect size for BMT over TOT. Furthermore, the ABILHAND data (MD = 1.15; 95% CI, 0.09–2.2) suggested a strong clinical significance in favor of UMT over TOT. Thus, the activity level data showed a clinical significance in favor of UMT over TOT, however, minimal difference between BMT and TOT.

At the impairment level, the FMA data suggested that UMT may be more clinically beneficial than TOT. This is consistent with several randomized controlled studies that reported improvement on the hospital and FMA with UMT [18,20,25,26] compared to control groups. The grip strength data, however, showed an increase in both BMT and TOT groups and a decline in the UMT group. Possibly, BMT and TOT are clinically more relevant for improving grip strength due to the repetitive movement of the affected hand.
While no definitive conclusions can be drawn, UMT may be more beneficial and clinically relevant than TOT for improvements at the activity and impairment level, except for grip strength. In addition, BMT appeared to have minimal to no clinical advantage as compared to TOT. One possible explanation could be that since the participants had moderate/severe upper limb impairments (poor intrinsic feedback), augmented feedback (visual feedback) would be a beneficial strategy for motor recovery. Thus, MT (visual feedback) would benefit to a greater extent as compared to TOT participants who relied solely on intrinsic feedback [57]. While BMT also used augmented feedback, it could be argued that the visual/propioreceptive conflict may have degraded the positive effects of the visual feedback as compared to UMT [31]. Overall, data from this pilot study suggest a full scale randomized controlled trial is warranted. Thus, to determine sample size, a power analysis was performed using the ARAT effect size data comparing UMT to BMT. The sample calculation was computed with G*power, an online tool (available at https://www.macupdate.com/app/mac/24037/g-power), with the statistical test ANOVA: with repeated measures, between factor, a = 0.05, power (1-ß) set at 0.80, and effect size set at 0.38. The sample calculation was N = 54.

There were several limitations in this study. First, the sample size was small, which makes it difficult to generalize to the population and may have created a type II error, which reflects a failure to detect group differences if present. Furthermore, the differences in the baseline characteristic of the 3 groups may have affected the results given the small sample size. 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 the experience and treating expertise, the participants may not have received the same care. However, all the OTs 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. In a future randomized controlled study, video calls would increase the ability to monitor participants, corroborate adherence and help with therapy progression.

Disclosure of statement

No potential conflict of interest was reported by authors.

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