

## Original Article

# Task-Oriented Mirror Therapy as an Effective Rehabilitation Strategy for Post-Stroke Upper Limb Dysfunction: A Randomized Controlled Trial

Rania Mamdouh<sup>1,2</sup>, Hoda M. Zakaria<sup>1</sup>, Ebtessam M. Fahmy<sup>3</sup>, Mostafa M. ElKholy<sup>4</sup>, Azza S.A. Khalil<sup>5</sup>, Marwa Mostafa<sup>1</sup>, Shreen Ibrahim Taha<sup>2,6</sup>

<sup>1</sup>Department of Physical Therapy for Neurology and Neurosurgery, College of Physical Therapy, Cairo University, Egypt;

<sup>2</sup>Department of Physical Therapy for Neuromuscular Disorders and its Surgery, Faculty of Physical Therapy, Beni-Suef University, Egypt;

<sup>3</sup>Department of Neurology, Faculty of Medicine, Cairo University, Egypt;

<sup>4</sup>Department of Clinical Neurophysiology, Faculty of Medicine, Beni-Suef University, Egypt;

<sup>5</sup>Department of Rehabilitation Sciences, College of Health and Rehabilitation Sciences, Princess Nourah bint Abdulrahman University, Saudi Arabia;

<sup>6</sup>Department of Physical Therapy for Neurology and Neurosurgery, Faculty of Physical Therapy, Badr University, Egypt

## Abstract

**Objectives:** Task-oriented mirror therapy (TOMT) may offer a viable treatment for impaired upper extremity functions after stroke. The purpose of our study was to evaluate the impact of TOMT on upper extremity motor performance and corticospinal excitability in chronic stroke patients. **Methods:** Forty chronic ischemic stroke patients, aged 45 to 60, with mild to moderate upper limb impairment, were randomly allocated into two equal groups; TOMT and Control groups. The TOMT group received 30 minutes of TOMT followed by 30 minutes of a physical therapy program, three times per week for 12 weeks. The Control group was treated by the same physical therapy program for 60 minutes, three times per week for 12 weeks. Fugl-Meyer Assessment of the Upper Extremity for assessing upper extremity motor function at 12 weeks of intervention was the primary outcome measure. Wolf Motor Function Test and corticospinal excitability (measured through resting motor thresholds and suprathreshold and maximal motor evoked potentials) at 12 weeks were the secondary endpoints. **Results:** Both groups revealed significant variations in all primary and secondary endpoints at 12 weeks, favoring the TOMT group. **Conclusion:** Our study shows that TOMT may improve upper extremity motor performance in chronic stroke patients. **Pan African Clinical Trial Registry ID:** PACTR202505804979619.

**Keywords:** Corticospinal Excitability, Randomized Control Trial, Stroke, Task-oriented Mirror Therapy, Upper Extremity Motor Performance

## Introduction

Stroke is one of the major causes of disability and mortality worldwide<sup>1</sup>. Stroke causes motor, sensory, cognitive, and gait impairment, decreasing quality of life

(QoL)<sup>2</sup>. Upper extremity dysfunction affects around 75% of stroke patients<sup>3</sup>. Corticospinal excitability (CSE) is defined as the response of the corticospinal tract, reflecting the ability of motor cortex to produce a voluntary effort<sup>4</sup>. It is considered as a main dynamic biomarker for corticospinal tract (CST) integrity<sup>5</sup>. The CSE is usually measured through transcranial magnetic stimulation (TMS). It has a major role in impacting motor recovery outcomes following stroke<sup>6</sup>. Specific rehabilitation treatments can stimulate corticospinal excitability, which can accelerate motor recovery after stroke<sup>7</sup>. Traditional physiotherapy programs may fail to fully utilize the potential for neuroplasticity, particularly in cases of severe upper limb disability. As a result, there is a developing interest in new techniques

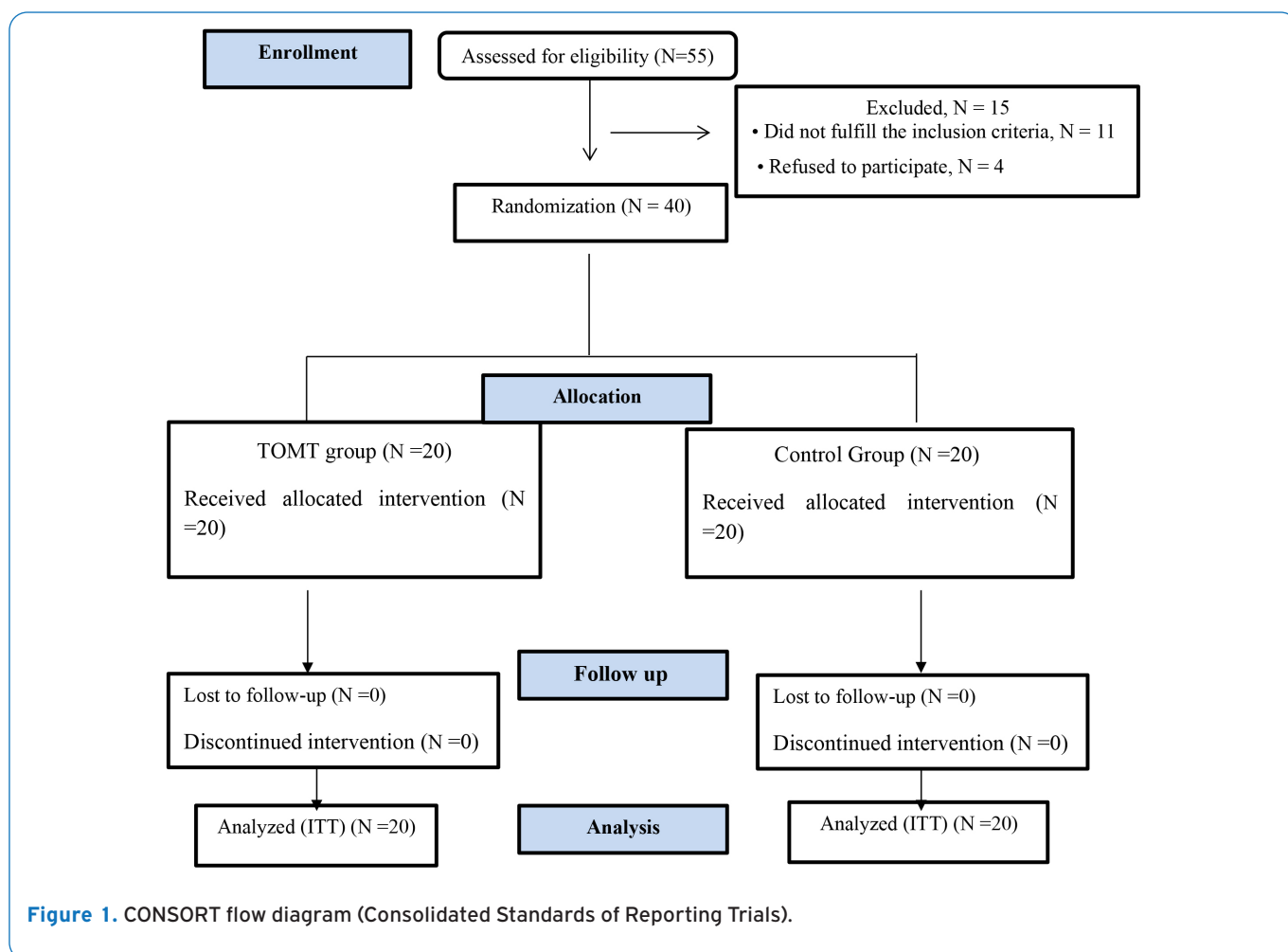
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Corresponding author: Marwa Mostafa, Department of Physical Therapy for Neurology and Neurosurgery, College of Physical Therapy, Cairo University, Giza, Egypt  
E-mail: marwamostafa506@gmail.com • marwa.mostafa@cu.edu.eg

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like task-oriented mirror therapy (TOMT) for enhancing corticospinal excitability and improving motor recovery and function of upper extremity in stroke patients.

Task-oriented mirror therapy (TOMT) is a novel rehabilitation technique that combines task-oriented training (TOT) with mirror therapy (MT). It depends on both visual feedback and motor learning. There is strong evidence that both task-oriented training (TOT) and mirror therapy (MT) can effectively improve upper limb motor function in stroke patients<sup>8,9</sup>. However, there is still little evidence for the effect of task-oriented mirror therapy (TOMT) on motor function of upper limb in chronic stroke patients. A previous pilot study revealed that TOMT can improve hand and wrist motor function in stroke patients without improving arm or upper limb function<sup>10</sup>. However, this study had a small-size sample with short intervention period. Another previous study revealed that both movement-based mirror therapy (MMT) and TOMT can enhance upper extremity function of subacute stroke patients in superiority to MMT<sup>11</sup>. The study of Paik et al.

(2014)<sup>12</sup> found that patients received TOMT showed more increase in their upper limb motor function than patients received simple mirror therapy. All these previous studies lack objective assessment of any neurophysiological changes for exploring underlying mechanisms of improvement in upper extremity function.

The TOMT is a non-surgical and low-cost treatment modality that can be easily implemented in post-stroke rehabilitation settings. It includes a structured, task-oriented program that allows for individualized progression. This makes the TOMT suitable for both in-clinic and home-based rehabilitation programs to improve motivation and progress. Our study aimed to investigate the impact of task-oriented mirror therapy on motor recovery and functional outcomes of upper extremity following chronic stroke. Findings of the current study may provide evidence for TOMT effect on improving activities of daily living (ADL) and quality of life (QoL) for chronic stroke patients.

**Table.1.** Task-oriented mirror therapy (TOMT) for TOMT group (n=20).

Phase	Exercise	Progression and Notes
Week 1-2	Wrist Flexion/Extension	Patient flexed and extended the wrist while observing the unaffected hand in the mirror, creating the illusion of movement in the affected wrist.
	Finger Flexion/Extension	Passive flexion and extension in the first week then active-assisted as the patient gained confidence.
	Thumb Opposition	Patient moved the non-affected thumb to touch the tips of each finger.
	Grasp and Release of small objects	Patient grasped the object (sponge or soft ball) with the unaffected hand while observing the mirror reflection.
Week 3-4	Forearm Pronation/Supination	Patient rotated the forearm smoothly with full range while keeping the wrist stable.
	Object Placement (Task-Oriented)	The patient placed small objects, like cubes or bottle caps, in specific positions on the table, practicing task-oriented exercises with visual feedback from the mirror.
	Bilateral Task: Lifting a Light Object	The patient was asked to use both hands to simulate lifting a light object. The unaffected hand lifted the real object while the mirror reflection gave the illusion of the affected hand participating.
Week 5-6	Complex Grasping Task	The patient tried to grasp and lift larger or heavier objects (e.g., water bottles) while focusing on coordination and precision in both hands.
	Simulated Functional Task (Cutlery Use)	The patient simulated using cutlery (knife, fork, spoon) to perform movements like scooping or cutting, while observing in the mirror.
Week 7-8	Multi-Object Task	The patient tried to organize objects (e.g., sorting cards, stacking blocks) while using both hands, encouraging complex bilateral coordination.
	Writing Simulation with Mirror	Patient was asked to write by holding a pen in the unaffected hand while observing the reflection in the mirror.
Week 9-10	Bilateral Reach and Grasp with Spatial Variation	Patient reached to grasp objects placed at different distances, heights, and orientations (e.g., shelves, tables) while focusing on motor planning, spatial awareness, and timing.
	Functional Manipulation Tasks	Many manipulation tasks (e.g., turning knobs, opening jars, or flipping cards) were introduced to the patient. Visual feedback from the mirror can enhance hand-eye coordination and precision in the affected hand.
	Sequential Object Transfer	Patient transferred objects from one location to another in a planned sequence (e.g., cups from left to right in a set order). This emphasized task sequencing, bilateral coordination, and functional relevance.
Week 11-12	Dynamic Fine Motor Task Circuit	Patient performed a series of small-object tasks (e.g., picking up coins, buttons, beads) in rapid succession. Speed and accuracy were progressively increased while observing the mirror.
	ADL Simulation with Bilateral Integration	Many daily activities such as folding clothes, pouring liquids, or utensil use were stimulated while focusing on bilateral coordination, task sequencing, and functional independence.
	Mirror-Assisted Functional Challenge	Many functional tasks were combined into a continuous, goal-directed circuit (reach-grasp-manipulate-release).
<i>Repetitions: 3 sets x 10 reps for all exercises, Frequency: 3 times per week for 12 weeks.</i>		

## Materials and Methods

### Setting

The study was implemented between February 2025 and September 2025 at El Zahir Physiotherapy Center, Egypt. Before baseline evaluation, all patients received a detailed explanation of aims and procedures of our study. All participants filled out a written consent prior to the study. Our protocol followed CONSORT reporting (Figure 1).

### Study Design

Assessor –blinded randomized controlled trial.

### Participants

Fifty-five patients with chronic ischemic stroke were initially assessed for eligibility by the treating therapist. Eleven participants failed to fulfill the inclusion criteria, while four patients refused participation in the study. The remaining forty patients were randomly allocated into two

equal groups (Figure 1). A neurologist provided a clinical diagnosis and referral for all participants. All patients were recruited from El Zahir Physiotherapy Center, Egypt. Inclusion criteria were single unilateral chronic ischemic stroke for at least six months, age from 45 to 60 years old, both sexes, mild to moderate upper limb motor dysfunction (assessed by the Fugl-Meyer Assessment of the Upper Extremity (FMA-UE)), sufficient cognitive ability (score >24 on the Mini-Mental State Examination (MMSE)), and a stable medical condition. Patients with any musculoskeletal or neurological conditions other than stroke that may affect upper extremity function, history of recurrent strokes, or any contraindications for magnetic brain stimulation (e.g. certain metallic implants or a history of seizures) were excluded.

#### *Sample size calculation*

A preliminary power analysis was carried out by G\*POWER software (version 3.1.9.2; Franz Faul, MÜN KIEL, Germany) to determine the required sample size. A similar previous research work was used to estimate effect sizes<sup>10</sup>. The minimum sample size was found to be 40 participants with an alpha of 0.05, power of 95%, and effect size of 0.95.

#### *Randomization and Blinding*

Eligible patients were randomly allocated (1:1 allocation ratio) to TOMT and Control groups by an independent assistant using a computer-generated, block randomization sequence, ensuring balanced groups. Then, sequentially numbered, opaque, sealed envelopes (SNOSE) were used to conceal the allocation sequence. These envelopes were opened by a therapist assistant after the initial assessments were finished by a blinded assessor. The outcome assessor responsible for collecting all primary and secondary variables was blinded to group allocation during the study to minimize assessment bias. All patients were instructed not to reveal their treatment during assessment sessions. Data analyst was also blinded to group allocation. The data was analyzed using coding (Group A and Group B), and the allocation key was cleared only after completing the data analysis.

#### *Interventions*

Participants in the TOMT group received 30 minutes of task-oriented mirror therapy followed by 30 minutes of a conventional physical therapy program, three times a week for twelve weeks. The Control group was treated by 60 minutes of the same conventional physical therapy program as the TOMT group. Both TOMT and the conventional physical therapy program were applied according to a standardized intervention manual to ensure fidelity across all patients in both groups. The treatment methods (TOMT and the physical therapy program) were

applied by a single well-trained treating therapist who has trained both intervention methods for one month before beginning the study. Sessions attendance was recorded and all participants attended all sessions. Patients in both groups didn't receive any additional home exercises or co-interventions. The intervention dose for both groups was 36 sessions and all participants completed all the sessions.

#### *Task-oriented mirror therapy (TOMT)*

Using a standard mirror box (its size is 35x40x20 cm), task-oriented mirror therapy (TOMT) was used to reflect the movement of the non-affected limb, giving the impression that the affected limb was moving symmetrically. The patients assumed upright sitting position with the mirror box placed on a table at the body level between both upper extremities. The affected limb was placed behind the mirror, and the unaffected limb was in front of it. Any accessories on the unaffected limb were removed before the TOMT session to facilitate the illusion. The functional tasks were progressively introduced to the patients through six progressive phases. Each phase was designed for two weeks (Table 1). Each exercise was performed for 10–15 repetitions for 3 sets, three times per week. The progression emphasized bilateral coordination, precision, and daily activities (Table 1).

#### *Conventional physical therapy program*

Both groups were treated by the same conventional physical therapy program, three times per week for twelve weeks. The conventional physical therapy program included passive and active-assisted range of motion exercises, resistance training, and functional reaching and grip training (Table 2). These exercises aimed to restore joint mobility, muscle strength, and coordination of all joints of the affected upper extremity. Each exercise was performed for 10–15 repetitions for 3 sets, three times per week with a 60-second rest between sets. Both the intensity and complexity of each exercise were progressively increased for all patients.

#### *Outcome Measures*

All outcomes were measured by a single, blinded assessor at baseline, 6 weeks and 12 weeks (end of treatment). The primary outcome was Fugl-Meyer Assessment of the Upper Extremity (FMA-UE) at 12 weeks (end of treatment). Secondary outcomes included Wolf Motor Function Test (WMFT) and corticospinal excitability variables of the affected side (resting motor threshold (rMT), maximal motor evoked potentials (mMEPs) and suprathreshold motor evoked potentials (sMEPs)) at 12 weeks (the end of treatment). Both primary and secondary outcomes assessed at 6 weeks after starting the treatment and corticospinal excitability variables of

**Table 2.** Selected physical therapy program for both TOMT and Control groups.

Phase	Exercise	Progression and Notes
Week 1-2	Passive Wrist Flexion/Extension	The therapist moved the patient's wrist gradually, aiming for pain-free movement.
	Passive Shoulder Flexion/Abduction	The therapist moved the patient's shoulder to reduce stiffness and improve range of motion.
	Active-Assisted Finger Flexion/Extension	Patient was asked to flex and extend fingers with therapist support.
Week 3-4	Active Wrist Flexion/Extension	Patient actively moved wrist through its range of motion, emphasizing control and compensatory shoulder movement were avoided.
	Resistance Band Exercises (Wrist, Elbow)	Thera Bands were used for wrist and elbow flexion/extension. The band resistance was progressively increased as the patient gained strength.
	Object Grasp and Release	Patient practiced grasping and releasing small objects like balls or blocks to improve hand dexterity and strength.
	Bilateral Task Practice	The patient performed bilateral tasks such as moving objects, using both hands to promote coordination.
Week 5-6	Dumbbell Wrist Curls	Light dumbbells (0.5-1 kg) were used for wrist flexion and extension. The weight was gradually increased as strength improved.
	Functional Reaching Exercises	Patient practiced reaching objects at different heights and distances, promoting arm and shoulder functional use.
Week 7-8	Simulated Functional Tasks (e.g., Holding a Cup)	Everyday tasks, like holding a cup or lifting small objects, were stimulated. The task complexity was increased as the patient gained control and strength.
	Pinching and Grip Strengthening	Grip devices were used to improve finger strength and dexterity through pinching and squeezing motions.
Week 9-10	Dynamic Reach and Object Placement	Patient performed reaching tasks to place objects at varied distances, heights, and orientations, emphasizing bilateral coordination, motor planning, and spatial awareness. Task complexity was progressively increased.
	Fine Motor Manipulation with Resistance	Small weighted objects were used for finger manipulation, pinching, and rotation tasks focusing on precision, strength, and dexterity. Resistance and complexity were progressively increased.
	Sequential Functional Task Training	Patients practice stepwise sequences of functional tasks (e.g., pick up a cup, place it on a shelf, retrieve an object). Enhances task sequencing, bilateral integration, and cognitive-motor planning.
Week 11-12	Advanced Bilateral Functional Reach	Patients perform multi-directional reaching tasks with both hands to simulate real-life activities (e.g., opening cabinets, picking objects from different planes). Emphasizes coordination, joint control, and range of motion.
	Complex Object Manipulation Circuit	Perform rapid succession of fine motor tasks (e.g., stacking coins, opening containers, buttoning). Focus on speed, accuracy, and endurance.
	Integrated ADL Simulation	Combine multiple functional exercises into a continuous activity circuit simulating daily tasks (pouring, lifting, gripping, and reaching). Promotes task integration, endurance, and functional carryover.

the non-affected side were considered as exploratory variables to investigate motor recovery progression and support insights for functional improvement.

#### *Fugl-Meyer Assessment of the Upper Extremity (FMA-UE)*

The motor section of the FMA-UE Scale was used to assess upper limb motor impairment. It evaluates movement, coordination and reflex through 33 items. Each item is rated on a 3-point scale (from 0 to 2), where

0 represents inability to perform, 1 represents partial performance and 2 means full performance. The total score of FMA-UE is 66<sup>13</sup>.

#### *Wolf Motor Function Test (WMFT)*

Upper limb functional performance was evaluated through the modified WMFT during 15 tasks. Performance of each task was rated on a 6- point scale (0-5) on the functional ability scale, where 0 representing inability

**Table 3.** Baseline characteristics of all patients in both groups.

	TOMT group	Control group	t- value	p-value
	$\bar{X}\pm SD$	$\bar{X}\pm SD$		
Age (years)	54.1±4.34	52.65±4.72	1.01	0.32
Weight (kg)	75.2±6	74.45±6.1	0.39	0.7
Height (cm)	166 ±3.52	166.15 ±4.6	-0.12	0.91
BMI (kg/m <sup>2</sup> )	27.33±2.51	27.04±2.77	0.35	0.73
Sex, N (%)				
Male	15 (75%)	13 (65%)	0.47	0.49
Female	5 (25%)	7 (35%)		
Affected side, N (%)				
Right	8 (40%)	10 (50%)	$\chi^2=0.4$	0.53
Left	12 (60%)	10 (50%)		

*SD, standard deviation; p-value, probability value;  $\chi^2$ , Chi squared value; N, number; BMI, body mass index.*

to use the tested upper limb and 5 representing normal function. The first six tasks of modified WMFT included joint-segment activities. The remaining nine tasks involved integrated functional activities. Then, the total score of modified WMFT (0-75) for each patient was divided by 15 to get the average modified WMFT score. Higher scores indicate better functional ability<sup>14</sup>.

#### Corticospinal Excitability

Motor evoked potentials (MEPs) were used to evaluate corticospinal excitability through Transcranial Magnetic Stimulation (TMS). The Magstim standard rapid<sup>2</sup> stimulator (Magstim Company, Whiteland, Wales, UK) and circular coil (diameter 70 mm) were used to produce TMS. The motor-evoked potentials (MEPs) generated by TMS can assess corticospinal tract excitability. The Magstim was connected to Electromyography machine (Nihon Kohden, Neuropack X1, EMG/EP MEB-2300, Japan) to synchronize the TMS triggers to the recorded MEPs from first dorsal interosseous muscle of the affected and normal hands through surface electrodes. Initially, the circular coil was positioned with its central hole over Cz and moved in few centimeters to define the motor hotspot using 10 single TMS pulses. Resting motor threshold was determined as the lowest stimulus intensity (% of maximal stimulator output, MSO) that is required to induce a MEP ( $\geq 50 \mu V$  peak-to-peak amplitude) in 5 out of 10 trials. The MEPs were evaluated at suprathreshold (120% of rMT) and maximal (150% of rMT) intensities. The average peak to peak amplitudes were achieved after collecting 25 MEPs to evaluate corticospinal excitability and cortical reorganization<sup>15</sup>. None of the patients reported any adverse effects immediately after TMS. All patients were observed for any adverse events after TMS assessment sessions for one week through daily phone call.

#### Adverse Events and Safety Monitoring

All patients were monitored for TMS-related adverse events or exercise-related fatigue. No adverse events were reported after TMS assessment sessions. Mild transient fatigue was reported by 3 patients after upper-limb training sessions in the control group. No discontinuations occurred in both groups.

#### Statistical Analysis

The SPSS software version 25 was used for all statistical tests (IBM SPSS, Armonk, NY, USA). The homogeneity and normal distribution of data were measured by Levene's and Shapiro-Wilk tests, respectively. Standard deviation and mean were used to summarize parametric quantitative data. While median and interquartile ranges (IQR) were used for summarizing non-parametric quantitative data. Prior to the analysis, all underlying assumptions were assessed, including normality, homogeneity of variance-covariance matrices, absence of multicollinearity, and sphericity. All assumptions were met; therefore, repeated measures MANOVA was deemed appropriate for the analysis. A  $2 \times 3$  mixed-design repeated measures MANOVA was performed to investigate the effects of group (TOMT vs. control) and time (three measurement points) on the dependent variables (FMA-UE, WMFT, rMT, mMEPs and sMEPs) after confirming that all statistical assumptions were satisfied. The FMA-UE score at 12 weeks (end of intervention) was set as the primary endpoint with a significance level of  $p < 0.05$ . The WMFT and corticospinal excitability variables of the affected sides (rMT, mMEPs and sMEPs) at 12 weeks (end of intervention) were stated as secondary measures. For the primary outcome (FMA-UE at 12 weeks), the MANOVA design was chosen in spite of a single primary outcome to maintain consistency with the multivariate

**Table 4.** Clinical characteristics of all patients in both groups.

Variable	TOMT group (N=20)	Control group (N=20)	MD (95% CI)	P-Value
FMA-UE	23.25±2.94	23.6±2.35	-0.35 (-2.05, 1.35)	0.68
WMFT	1.83±0.24	1.84±0.22	-0.01 (-0.16, 0.134)	0.86

**Table 5.** Between groups analysis at 0, 6 and 12 weeks (end of treatment).

Outcomes	Time	TOMT Group (N=20)	Control Group (N=20)	MD (95% CI)	P-Value
WMFT: Functional ability (score)	Baseline	1.83±0.24	1.84±0.22	-0.01 (-0.16, 0.13)	0.86
	At 6 weeks	2.87±0.17	2.13±0.2	0.74 (0.62, 0.86)	< 0.001*
	At 12 weeks	3.94±0.18	2.8±0.39	1.14 (0.95, 1.34)	< 0.001*
FMA-UE (score)	Baseline	23.25±2.94	23.6±2.35	-0.35 (-2.05, 1.35)	0.68
	At 6 weeks	38.25±4.88	31±5.11	7.25 (4.05, 10.45)	< 0.001*
	At 12 weeks	54.8±6.27	38.85±5.76	15.95 (12.1, 19.81)	< 0.001*
<b>Motor evoked potential at affected side</b>					
rMT (% MSO)	Baseline	68.7±8.44	70±7.08	-1.3 (-6.29, 3.69)	0.6
	At 6 weeks	61.95±6.48	66.7±6.49	-4.75 (-8.9, -0.6)	0.03*
	At 12 weeks	56.2±5.36	64.35±6.03	-8.15 (-11.8, -4.5)	< 0.001*
mMEPs (mv)	Baseline	0.47±0.18	0.45±0.14	0.02 (-0.08, 0.12)	0.73
	At 6 weeks	0.79±0.14	0.49±0.12	0.31 (0.22, 0.39)	< 0.001*
	At 12 weeks	1.43±0.27	0.66±0.11	0.77 (0.6, 0.94)	< 0.001*
sMEPs (mv)	Baseline	0.34±0.12	0.32±0.07	0.02 (-0.05, 0.08)	0.57
	At 6 weeks	0.52±0.14	0.34±0.07	0.18 (0.11, 0.25)	< 0.001*
	At 12 weeks	0.8±0.15	0.39±0.05	0.42 (0.34, 0.49)	< 0.001*
<b>Motor evoked potential at normal side</b>					
rMT (% MSO)	Baseline	49.15±6.18	48.4±5.57	0.75 (-3.02, 4.52)	0.69
	At 6 weeks	47.35±7.32	47.45±4.88	-0.1 (-4.08, 3.88)	0.96
	At 12 weeks	44.35±6.29	45.65±5.64	-1.3 (-5.12, 2.52)	0.5
mMEPs (mv)	Baseline	2.66±0.35	2.73±0.24	-0.07 (-0.26, 0.12)	0.47
	At 6 weeks	2.77±0.39	2.78±0.27	-0.02 (-0.24, 0.19)	0.84
	At 12 weeks	2.93±0.36	2.82±0.3	0.11 (-0.1, 0.32)	0.31
sMEPs (mv)	Baseline	1.23±0.2	1.29±0.2	-0.05 (-0.18, 0.08)	0.42
	At 6 weeks	1.29±0.15	1.3±0.2	-0.01 (-0.11, 0.11)	0.99
	At 12 weeks	1.43±0.23	1.32±0.2	0.11 (-0.03, 0.25)	0.13

CI: confidence interval; Data are mean  $\pm$  SD, \*P-Value < 0.05 indicates statistical significance, MD; mean difference, WMFT: wolf motor function test, FMA-UE: Fugle-Meyer Assessment Scale- Upper Extremity, % MSO: percent of maximal stimulator output, mv: millivolt, rMT: resting motor threshold, mMEPs: Maximal motor evoked potentials, sMEPs: Suprathreshold motor evoked potentials, Comparison of FMA-UE at 12 weeks was performed through estimated marginal means (EMMS). No multiplicity adjustment was performed and a value was set at 0.05. Pairwise comparisons for WMFT, rMT, mMEPs, and sMEPs at 12 weeks were performed through estimated marginal means (EMMS) and no multiplicity modification was performed to these variables as they were exploratory and interpreted cautiously.

analysis plan for the multiple secondary outcomes at multiple endpoints. Comparisons of FMA-UE at 12 weeks between both groups were performed through estimated marginal means (EMMS). No multiplicity adjustment was performed and a value was set at 0.05 due to the single predefined primary outcome. Mean differences, 95% confidence interval, and p-values were reported. For the secondary outcomes (WMFT, rMT, mMEPs, and sMEPs at 12 weeks), the MANOVA design was chosen to be consistent with these multiple outcomes measured at multiple endpoints. Pairwise comparisons were performed through estimated marginal means (EMMS) for these outcomes. The comparisons included both between-group differences at each time point and within-group differences over time. No multiplicity modification was performed to all secondary outcomes and they were exploratory and interpreted cautiously. Mean differences, 95% confidence interval, and non-adjusted p-values were reported. Data analysis was performed according to the intention-to-treat (ITT) principle. It included all patients in both groups. All randomized participants completed all assessments; therefore, the ITT and complete-case populations were identical (N=40).

## Results

### Baseline Characteristics

Table 3 shows the basic characteristics of all patients in both groups. There were no significant variations in the baseline data (age, height, body mass index, weight, affected side and sex) ( $p > 0.05$ ) between the two groups.

### Patients' clinical characteristics

Table 4 shows the basic clinical characteristics of all patients in both groups, including means values of FMA-UE and modified WMFT scores. There were no significant differences in baseline scores of FMA-UE and modified WMFT between both groups ( $p > 0.05$ ). Other baseline characteristics of stroke patients like lesion side and dominant hand were not collected in the current study.

### Effect of treatment on FMA-UE, WMFT and MEPs

The  $2 \times 3$  mixed-design repeated measures MANOVA for outcomes revealed a statistically significant treatment-time interaction (Wilk's A = 0.03,  $F_{(16, 23)} = 44.53$ ,  $p$ -value  $< 0.001$ ,  $\eta^2 = 0.97$ ). Also, both time main effect (Wilk's A = 0.01,  $F_{(16, 23)} = 182.63$ ,  $p$ -value  $< 0.001$ ,  $\eta^2 = 0.99$ ) and the treatment main effect (Wilk's A = 0.08,  $F_{(8, 31)} = 45.64$ ,  $P$ -value  $< 0.001$ , Partial Eta Squared  $\eta^2 = 0.92$ ) showed significance. The intervention dose for both groups was 36 sessions and all participants completed them. All patients were included in data analysis as there were no dropouts.

### Primary endpoint

FMA-UE at twelve weeks (end of intervention)

*Within-group comparison* revealed a significant increase in FMA-UE in both groups at twelve weeks (end of intervention) ( $p < 0.001$ ) with more significant increase in TOMT group than Control group as in Table 6.

*The pre-treatment between-group analysis* showed no significant differences between both groups at the baseline assessment in FMA-UE ( $P = 0.68$ ) as in Table 5.

*Post treatment between-groups analysis* revealed significant difference in FMA-UE between both groups at twelve weeks (end of intervention) ( $P < 0.001$ ) as in Table 5.

### Secondary endpoints

Modified WMFT at 12 weeks (end of intervention)

*Within-group comparison* showed that there was a significant increase in modified WMFT score in both groups at twelve weeks (end of intervention) ( $p = 0.001$ ) with more significant increase in TOMT group than Control group as in Table 6.

*Pre-treatment between-group analysis* showed no significant variation between both groups at the initial assessment in modified WMFT scores ( $P = 0.86$ ) as in Table 5.

*Post treatment between-groups analysis* of modified WMFT revealed a significant difference between both groups at twelve weeks (end of intervention) ( $P = 0.001$ ) as in Table 5.

rMT, mMEPs and sMEPs of the affected side at 12 weeks (end of intervention)

*Within-group comparison* at the affected side at twelve weeks (end of intervention) revealed that the two groups demonstrated significant decrease in rMT and significant increases in mMEPs and sMEPs, favoring TOMT group as in Table 6.

*Pre-treatment between-group analysis* showed no significant variations between both groups at the initial assessment in rMT, mMEPs and sMEPs at the affected side ( $P > 0.05$ ).

*While post treatment between-groups analysis* showed statistically significant differences in rMT, mMEPs and sMEPs at the affected side between the two groups at twelve weeks (end of intervention) ( $P < 0.05$ ) as in Table 5.

### Exploratory Variables

FMA-UE and modified WMFT at six weeks

*Within-group analysis* revealed a significant increase in FMA-UE and modified WMFT in both groups at six weeks with more significant increase in TOMT group than Control group ( $P < 0.05$ ) as in Table 6.

*Post treatment between-groups analysis* revealed that there was a significant variation in FMA-UE and modified WMFT scores between both groups at six weeks ( $P < 0.05$ ) as in Table 5.

**Table 6.** Within-group Comparisons for all outcome measures at 6 and 12 weeks (end of intervention).

Outcomes	TOMT Group (N=20)		Control Group (N=20)	
	Pre-post change from baseline to 6 weeks		Pre-post change from baseline to 6 weeks	
	MD (95% CI)	P Value	MD (95% CI)	P Value
WMFT: Functional ability (score)	-1.04 (-1.18, -0.9)	< 0.001*	-0.29 (-0.43, -0.14)	< 0.001*
FMA-UE (score)	-15 (-18.3, -11.7)	< 0.001*	-7.4 (-10.7, -4.1)	< 0.001*
<b>Motor evoked potential at affected side</b>				
rMT (% MSO)	6.75 (4.77, 8.73)	< 0.001*	3.3 (1.32, 5.28)	< 0.001*
mMEPs (mv)	-0.33 (-0.38, -0.27)	< 0.001*	-0.04 (-0.09, 0.02)	0.35
sMEPs (mv)	-0.18 (-0.24, -0.12)	< 0.001*	-0.02 (-0.08, 0.04)	0.99
<b>Motor evoked potential at normal side</b>				
rMT (% MSO)	1.8 (-0.85, 4.45)	0.13	0.95 (-1.7, 3.6)	0.99
mMEPs (mv)	-0.11 (-0.25, 0.04)	0.2	-0.06 (-0.21, 0.08)	0.87
sMEPs (mv)	-0.06 (-0.13, -0.01)	0.051	-0.01 (-0.07, 0.05)	0.99
Pre-post change from baseline to 12 weeks		Pre-post change from baseline to 12 weeks		
WMFT: Functional ability (score)	-2.11 (-2.29, -1.93)	< 0.001*	-0.96 (-1.14, -0.78)	< 0.001*
FMA-UE (score)	-31.55 (-35.47, -27.63)	< 0.001*	-15.25 (-19.17, -11.33)	< 0.001*
<b>Motor evoked potential at affected side</b>				
rMT (% MSO)	12.5 (9.43, 15.57)	< 0.001*	5.65 (2.85, 8.72)	< 0.001*
mMEPs (mv)	-0.96 (-1.08, -0.84)	< 0.001*	-0.21 (-0.33, -0.09)	< 0.001*
sMEPs (mv)	-0.47 (-0.54, -0.4)	< 0.001*	-0.07 (-0.14, -0.01)	0.04*
<b>Motor evoked potential at normal side</b>				
rMT (% MSO)	4.8 (1.55, 8.05)	< 0.001*	2.75 (-0.5, 6)	0.12
mMEPs (mv)	-0.28 (-0.49, -0.06)	< 0.001*	-0.1 (-0.31, 0.12)	0.87
sMEPs (mv)	-0.2 (-0.3, -0.1)	< 0.001*	-0.04 (-0.14, 0.06)	0.99

*CI: confidence interval; Data are mean SD, \*P-Value < 0.05 indicates statistical significance; MD; mean difference; WMFT: wolf motor function test, FMA-UE: Fugle-Meyer Assessment Scale- Upper Extremity, % MSO: percent of maximal stimulator output, mv: millivolt, rMT: resting motor threshold, mMEPs: Maximal motor evoked potentials, sMEPs: Suprathreshold motor evoked potentials, Comparison of FMA-UE at 12 weeks was performed through estimated marginal means (EMMS). No multiplicity adjustment was performed and a value was set at 0.05. Pairwise comparisons for WMFT, rMT, mMEPs, and sMEPs at 12 weeks were performed through estimated marginal means (EMMS) and no multiplicity modification was performed to these variables as they were exploratory and interpreted cautiously.*

rMT, mMEPs and sMEPs of the affected side at 6 weeks

Within-group analysis of rMT, mMEPs, and sMEPs at the affected side at six weeks revealed that rMT was significantly changed in both TOMT and Control groups, while mMEPs and sMEPs were significantly increased in TOMT group only.

Post treatment between-groups analysis of rMT, mMEPs and sMEPs at the affected side at six weeks revealed a statistically significant difference in rMT ( $P=0.03$ ) with no significant change in sMEPs and mMEPs between both groups ( $P>0.05$ ) as in Table 5.

rMT, mMEPs and sMEPs of the non-affected side at 6 and 12 weeks (end of intervention)

Within group analysis at the non-affected side showed that there were no statistically significant variations in

rMT, mMEPs or sMEPs in both groups at six weeks. At twelve weeks (end of intervention), there were statistical significant differences in the three variables in the TOMT group only as in Table 6.

Post treatment between groups analysis at the non-affected side revealed no significant variations in rMT, mMEPs or sMEPs between the two groups at six or twelve weeks as in Table 5.

## Discussion

Our study aimed to assess the impact of task-oriented mirror therapy (TOMT) on motor recovery and function of upper limb following chronic stroke. The key finding of this study is that TOMT significantly improved upper limb motor function measured by FMA-UE at 12 weeks (end of

intervention).

Looking more in detail at the results, the FMA-UE score was significantly increased in the two groups at 12 weeks (end of intervention), favoring the TOMT group ( $P=0.001$ ). It was changed 31 points (from  $23.25\pm 2.94$  to  $54.8\pm 6.27$ ) in TOMT group and 15 points in Control group (from  $23.6\pm 2.35$  to  $38.85\pm 5.76$ ) at 12 weeks (end of treatment). This means that patients in the TOMT group had both more statistically and clinically significant improvements than the Control group. It was stated that the minimal clinically significant difference in the FMA-UE scale after chronic stroke was a change between four and seven points<sup>16</sup>.

These results partially agreed with two pilot previous studies<sup>11,12</sup>. The study of Bai et al<sup>11</sup> (2019) revealed that subacute stroke patients who received TOMT showed more statistical changes in FMA-UE score than those who received a standard rehabilitation program but less than patients who received a movement-based mirror therapy (MMT) program. The study of Paik et al<sup>12</sup> (2014) (included only four patients) showed that TOMT provided a more significant progression of the upper limb function of stroke patients when compared with simple mirror movement.

The WMFT was also significantly increased in both groups with more improvement in favor to TOMT group ( $P=0.001$ ). At 12 weeks (end of intervention), the WMFT score was changed about 2 points in TOMT group (from  $1.83\pm 0.24$  to  $3.94\pm 0.18$ ) and about only one point in Control group (from  $1.84\pm 0.22$  to  $2.8\pm 0.39$ ). These results disagree with Bai et al (2019)<sup>11</sup> which stated that TOMT didn't significantly improve the WMFT score. The differences in results may be due to the different sample (subacute stroke patients) and smaller sample size of the previous study (11-12 patients in each group). However, the WMFT was a secondary outcome in our study without multiplicity modification analysis. So, it was exploratory and should be interpreted cautiously.

Our findings confirm other studies' conclusions that FMA-UE is a more sensitive and reliable scale than WMFT for evaluating changes in motor function following stroke rehabilitation<sup>17</sup>. So, the FMA-UE was selected as the primary outcome in this study.

Therefore, the current study can state that TOMT can enhance the functional outcomes of upper extremity in chronic stroke patients, improving their ADL and quality of their life. This improvement may be due to integrated effect of task-oriented training (TOT) and mirror therapy (MT). During MT, the patient's attention is directed toward the movement of the non-affected upper extremity in the mirror. This gives positive visual feedback and enhances proprioceptive input, resulting in premotor cortex and neuronal activation<sup>18,19</sup>. Moreover, this immediate visual feedback of successful movement can improve confidence, motivation, and adherence to the therapy, addressing the emotional and psychological dimensions of recovery<sup>18</sup>. Previous neuroimaging studies have also demonstrated that MT can activate the mirror neuron system. This helps

to engage bilateral sensorimotor regions, improving inter-hemispheric balance and facilitating motor relearning<sup>19,20</sup>. Beside the effect of MT, TOT focuses on repetitive specific-oriented movements. This combination provides motor learning and can promote motor recovery<sup>21</sup>. As a result, we can assume that integrated effect of MT and TOT can improve motor function and recovery in stroke patients.

The present study revealed that resting motor threshold (rMT) and maximal and suprathreshold motor evoked potentials (mMEPs and sMEPs) of the affected side were more significantly changed at 12 weeks (end of intervention) in TOMT group than the Control group. The (rMT) was more significantly decreased in TOMT group than the Control group. While sMEPs and mMEPs showed a more significant increase in TOMT group than the Control group. These TMS-induced potentials (rMT, mMEPs and sMEPs) are considered as direct indicators of corticospinal excitability and integrity<sup>15</sup>. Therefore, these higher changes in the TOMT group than in the control group suggests enhanced activation of corticospinal pathways and improved interhemispheric communication. Our finding is in line with prior studies which showed that the mirror therapy can induce cortical reorganization measured by functional MRI in chronic stroke patients<sup>22,23</sup>. However, the rMT, mMEPs and sMEPs were secondary outcomes in our study without multiplicity modification analysis. So, they were just exploratory and should be interpreted cautiously.

#### *Clinical implications*

The present study included both valid clinical assessment scales (FMA-UE, WMFT) and objective neurophysiological measures. This provided a more comprehensive assessment of stroke patients than other trials that relied solely on clinical scales, which unable to capture the underlying neural mechanisms. So, we can conclude that TOMT is a comprehensive, low-cost and feasible treatment option that may improve motor recovery in chronic stroke patients. However, neurophysiological measures (rMT, mMEPs, and sMEPs) and modified WMFT were secondary outcomes without multiplicity modification analysis, which remains a limitation of our study.

#### *Limitations and future recommendations*

Some limitations of the current study should be considered. Stroke patients with a narrow age range (45–60) from single-center setting were only included in this study, limiting the generalizability of the study findings. Due to the nature of the treatment, blinding of both patients and the treating therapist was not feasible, which might introduce performance bias. However, both outcome assessor and analyst were blinded to group allocation, reducing this bias. Secondary findings should be interpreted with special caution to avoid possible selective reporting however; all measured variables were

reported. Our study also included multiple secondary endpoints, increasing the risk of multiplicity related- type I error. However; there was a single pre-specified primary endpoint. The study lacks cognitive and psychological assessment of the patients to be correlated with motor and neurophysiological findings. A further limitation is the absence of long-term follow-up to determine whether the observed neurophysiological and functional benefits persist after therapy cessation. Questionnaires of ADL and QoL were not used in this study. Further studies should include patients with wider inclusion criteria from multi-center settings to enhance generalizability of results. Future research work should also include objective assessment tools for ADL, QoL, cognition, and psychological aspects with a long-term follow-up for comprehensive understanding of recovery. Furthermore, the risk of type I error should be avoided in the future trials by statistical correction of multiplicity for multiple outcomes.

## Conclusion

Our findings suggest that TOMT can yield superior results when combined with conventional physical therapy. TOMT may improve motor and functional outcomes following chronic stroke which supported by changes in corticospinal excitability indices measured by TMS.

### Ethics Approval

The Ethics Committee for Clinical Research at Faculty of Physical Therapy, Cairo University approved our study (P.T.REC/012/005711, Date of Ethical Approval: 9 February 2025). The study was conducted in accordance with the ethical principles of the Declaration of Helsinki.

### Consent to Participate

Written informed consent was obtained from all subjects involved in the study.

### Authors' Contributions

Rania Mamdouh and Shreen Ibrahim Taha: Conceptualization and Methodology, Marwa Mostafa: writing and editing, Hoda M. Zakaria, Ebtessam M.Fahmy and Mostafa M. ElKholi: data analysis, Visualization and editing, Azza S.A. Khalil: help and advice. All authors read and confirmed the final manuscript.

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