THE EFFECTIVENESS OF NEUROMUSCULAR REHABILITATION ON UPPER EXTREMITY FUNCTION IN POST-STROKE PATIENTS AT THE COMPREHENSIVE PHYSICAL REHABILITATION CENTER

Ilona ILINCA[1]*, Eugenia ROȘULESCU[1], Radu ROȘULESCU[1]

[1] *University of Craiova, Faculty of Physical Education and Sport, Craiova, Romania*
Corresponding author: ilona.ilinca@yahoo.com

https://doi.org/10.52846/46.2025.1.16

Abstract: Introduction. In stroke survivors, the incidence of upper limb motor disability remains high, many of them having persistent neurological deficits that restrict activities and limit social participation. Although in many cases it is not possible to fully return to pre-stroke functional status, to treat the stroke survivors sustained and complex rehabilitation is essential. The study aim was to analyse the impact of neuromuscular rehabilitation based on mirror therapy in addition to a conventional upper limb rehabilitation program on upper limb functions and motor skills in patients with chronic stroke at a comprehensive physical rehabilitation Center.
Methods: this observational study was conducted on a group of 30 post-stroke patients who met the inclusion criteria and signed informed consent, between February and May 2025, in the city of Craiova, at the Day Center for Adults with Disabilities. Participants were allocated into 2 groups, group A-MT and group B-CT according to the therapy they received. Both groups participated in a stroke rehabilitation program and group A was given mirror therapy in addition. The rehabilitation program was performed 3 days per week for 12 weeks. The motor functioning of the upper limb and functional independence were assessed before the intervention (T0), 3 months after starting the rehabilitation program T1, between the two groups and within groups, and at the 3 months follow-up, T2.
Results: an improvement in all parameters evaluated was observed in both groups, but the postintervention scores were significantly higher in the mirror therapy group. We found significant differences between the mirror therapy group A and rehabilitation group B when compared UL abilities at the end of 12 weeks therapy: A 40.1 ± 6.26, B 36.1 ± 6.34, p=0.046.
Conclusions: Mirror treatment used in addition to conventional stroke rehabilitation therapy seems to be an effective method to increase functional and motor skills of the upper extremity in elderly patients' post-stroke compared to conventional therapy.
Keywords: stroke; rehabilitation; mirror therapy; spastic upper limb

Introduction

Stroke (CVA) is a neurological condition that occurs when there is a total or partial reduction of cerebral blood supply for a certain period, caused by the blockage or rupture of a cerebral artery, causing dysfunction of the cerebral tissue, followed by a temporary or permanent deficit in the functioning of one or more areas of the brain (Bargiela, 2017). CVA is classified into ischemic and hemorrhagic, with 80 to 85% being ischemic, compared to hemorrhagic strokes, which account for only 10-15% (Feigin et al., 2025). Stroke affects both motor and cognitive functions, resulting in high degrees of disability, functional dependence, and a decrease/alteration in the patient's quality of life. The sequelae of stroke are multiple, depending on several factors such as the severity and type of stroke, but also on the affected area of the brain, the patient's age, and the time elapsed since the onset of the event, as well as the presence of other comorbidities. The most common motor sequela post-stroke is hemiparesis characterized by spasticity, muscle weakness, abnormal synergistic movement, and exaggeration of reflexes, and impaired coordination of movements both in terms of fine and gross motor control, therefore, a long rehabilitation process is required (Park et al., 2015). The upper limbs play an important role in daily activities and personal care, as they are associated with fine motor skills, especially at the level of the fingers (Dewie & Has, 2017). Alteration of sensory and motor function in the upper limbs after a stroke affects performance in activities of daily living and leads to the experience of self-care deficit or dependence on others, restriction of social participation, requiring continuous medical assistance (Vergara et al., 2014).

More than half of individuals with upper limb impairment post-stroke continue to experience problems months to years after the stroke. Patient rehabilitation is fundamental to minimizing the

possibility of these effects becoming permanent (Suppiah et al., 2023).

Recovery of post-stroke patients continues to be a challenge, as strokes are considered one of the leading causes of mortality and morbidity worldwide. Despite an interdisciplinary intervention, many patients exhibit persistent neurological deficits that limit activities and restrict social participation (Alessandro et al., 2020).

In recent years, evidence regarding the recovery of neurological conditions, including stroke, shows that an individual approach based on treatment with conventional methods and techniques is not recommended, but rather the establishment of a combined recovery strategy based on intensity, task specificity, and the principles of neuroplasticity (Kleynen et al., 2020).

Mirror therapy is a relatively new therapeutic approach, based on visual stimulation of the paretic upper limb through the reflection in a mirror of the unaffected limb. This therapy is important for optimizing muscle contraction, improving symmetry, and helping to synchronize the affected body side. The easiness of use of this technique and its low cost could represent an appropriate alternative.

Mirror therapy works on the principle of neuroplasticity, accentuated by visual cues and the activation of mirror neurons. The concept on which mirror therapy is based is that, by observing the movements of the non-paretic hand or limb, a reconfiguration of the brain can occur, leading to greater neural activity in the affected cerebral hemisphere. This will cause cortical reorganization and improve function on the affected side.

The clinical use of mirror therapy ranges from unilateral movements to task-centered bilateral movements. The presence of an object during mirror therapy induces greater stimulation of the affected cortical area. Therefore, performing a task during this therapy has a potential benefit for improving motor impairment of the upper limb.

The aim of this study is to analyze the impact of neuromuscular rehabilitation based on mirror therapy in addition to a conventional upper limb (UL) rehabilitation program on UL functions and motor skills in patients with chronic stroke at the comprehensive physical rehabilitation Center.

Materials and methods

This observational study was conducted and completed on a group of 30 post-stroke patients who met the inclusion criteria and signed informed consent, between February and May 2025, in the city of Craiova, Romania, at the Daily Rehabilitation Center for Adults with Disabilities.

A total of 53 participants (males and females) recruited in the study were included in the stroke rehabilitation program after they were diagnosed with stroke by a neurologist based on history, clinical examination, and neuroradiologic findings (computed tomography scans or magnetic resonance imaging).

Inclusion criteria: (1) adults (age ≥ 18 years) with hemiparesis due to a single stroke that occurred > 3 months before the before admission to the Rehabilitation Center and assessment; (2) complete outcomes measured at admission T0, the end of rehabilitation programme T1, and follow-up within 3 months T2; (3) absence of botulinum toxin injection in the evaluated muscles in the 3 months before the assessment; and (4) clinically stable condition.

Exclusion criteria were: (1) recurrent strokes or other neurological or orthopedic disorders affecting the evaluated muscles; (2) severe cognitive impairment (Mini-Mental Status test score < 23 or major receptive aphasia) interfering with the ability to assess the patient; (3) treatment with antispasticity medications that could produce synaptic depression, whether oral or intrathecal (baclofen, benzodiazepines, etc); (4) any other exclusion criteria for physical therapy.

In each patient evaluation chart, the first visit chronologically that met these criteria was selected for analysis – T0. All of the patients had also complete evaluations at the end of programme, T1. 23 patients no longer showed up for the follow-up evaluation at 3 months, T2 (Figure 1. Flowchart of the study).

Patients were evaluated clinically, cognitively, and functionally. At T0 - baseline for each patient were collected data on: age, gender, comorbidities (hypertension, diabetes, ischemic heart disease), time since stroke (in months), stroke subtype (ischemic or hemorrhagic, CT or MRI), spastic side of the body (right or left).

In all evaluation stages, were collected data on pain and functional upper limb status: upper limb pain (using visual analogue scale, VAS), passive range-of-motion (pROM) testing for upper limb joints (passive shoulder abduction, elbow and wrist joint extension deficits), upper limb active function (using the Modified Frenchay Scale for the upper limb, MFS). The Modified Frenchay Scale (MFS) consists in the assessment - quantification of ten activities of daily living (4

uni-manual activities using the paretic hand and 6 bimanual activities, in which the paretic hand assists the other hand) and rating each of them on a ten-point visual analog scale based on video review. Individual task rating on the MFS has excellent intra- and inter-reliability and the MFS has been validated against a subjective scale of perceived function (Disability Assessment Scale, DAS) as well as the Fugl–Meyer score, a classic measurement of motor impairment (Baude et al., 2016).

Participants were allocated into 2 groups according to the received therapy. The patients in both groups underwent a conventional physical therapy programme, 3 times a week for 12 weeks (36 sessions, around 3 months) under the supervision of a physiotherapist. Group A – the mirror therapy group MT, received 20 min of mirror therapy in addition to the 30 min of conventional rehabilitation therapy. Group B – the conventional therapy group CT, received 45 min of only physical therapy.

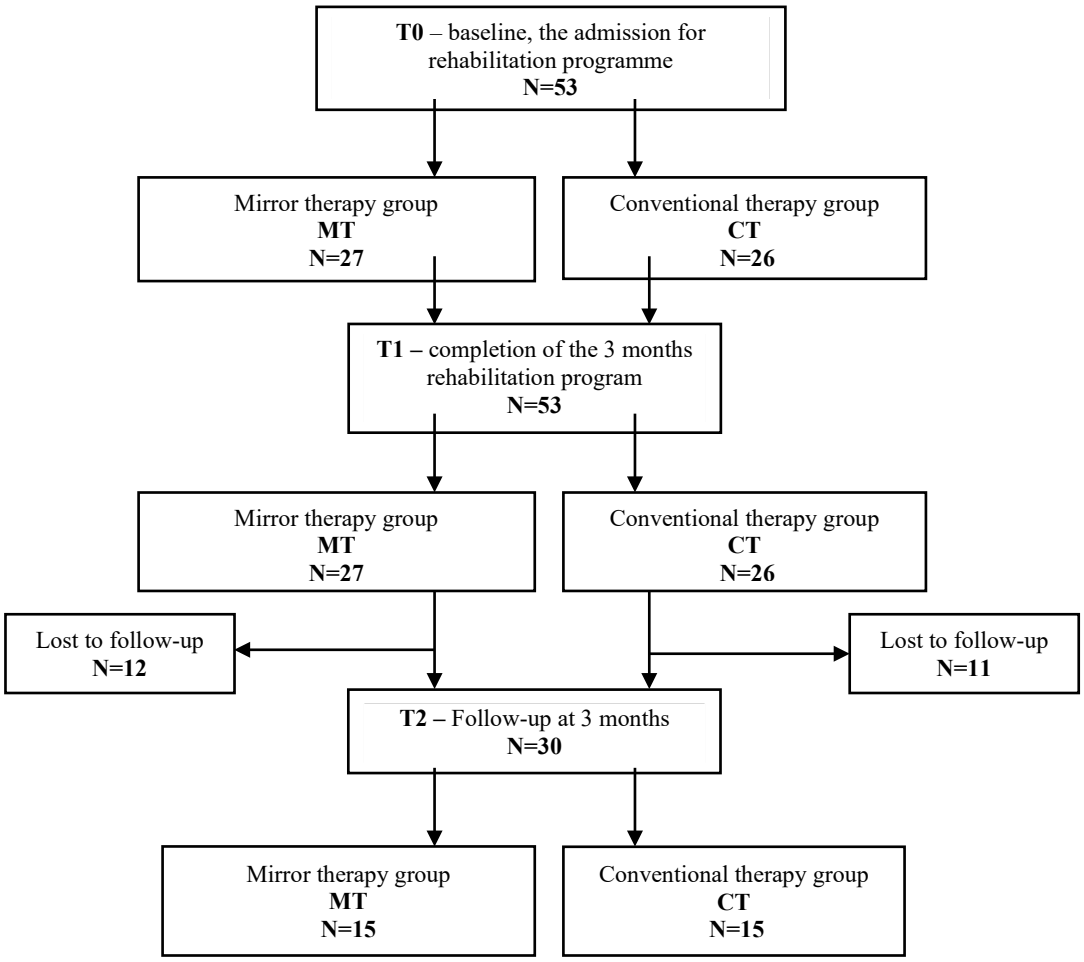

Figure 1. Flowchart of the study.

This conventional rehabilitation programme was organized depending on the particularities of each patient and consisted of proprioceptive neuromuscular facilitation techniques, passive muscle stretching and joint movement in the upper extremities, strengthening exercises, and task-oriented training lasting 30 min, conducted by a physical therapist. The traditional physical therapy program aimed for inhibition of spasticity, facilitation of muscle action, and improving the motor functions of the involved upper limb.

The mirror therapy based on simple elbow, fist, and hand movements and appropriate functional tasks based on the function of the affected upper limb. During the mirror therapy, patients were seated close to a table on which a mirror (30.5 × 30.5cm) was placed vertically. Non-paretic limb was placed in front of the reflecting surface of the mirror and asked to perform forearm pronation and supination, flexion and extension of the wrist and finger, numbering, opposition and movements for task while the patients looked into the mirror and observed the reflection of these movements in

the mirror. The affected upper limb positioned behind the mirror in a safe and comfortable position.
The functional tasks involved reaching, grasping and releasing objects (cylinders, balls, bottles, etc) manipulation and dexterity exercises, using objects of different sizes and textures.
All exercises were performed slowly and repeated at least 10 times, adjusting the complexity according to the individual abilities and limitations of each patient. The exercises began with simple movements with objects, and finally including more complex movements with objects. The progression was individually adapted to the patient's recovery, initially focusing on assisted execution, and finally to unassisted execution. Short rest periods were interspersed, and the difficulty of the task was progressively increased to improve performance.
Collected data were analysed using MS Excel 2013 spreadsheet. Descriptive statistics, namely percentage, mean, standard deviation, 95% confidence interval (CI) and median values were used for quantitative variables. Paired t-test was used to compare the pre and post therapy scores. P < 0.05 was considered statistically significant in the two-tailed analysis.

Results

Of the 53 patients with adult-onset spastic hemiparesis in whom the upper limb was rehabilitated and evaluated during the study period, 30 patients met the criteria for inclusion (complete clinical and functional evaluation at baseline T0, rehabilitation programme completed at T1, and follow-up evaluation within 3 months T2). 15 patients received 36 sessions of UL mirror therapy plus conventional therapy – the mirror therapy group MT. 15 patients have got 36 sessions of 45 minutes classical physiotherapy – the conventional therapy group CT.

1. Clinical study of mirror therapy on upper limb passive range-of-motion (pROM)

The measurement of the range of motion ROM - joint balance - in the patients affected by stroke spasticity, as a part of the examination of the passive tone of the muscles of the limbs, assessing it as a result of the motor functions and not as a muscle or joint analysis. Over time, many patients develop contractures and hypertonia, especially in shoulder flexors and internal rotators and wrist flexors. Many patients also develop shoulder pain, a condition strongly associated with restricted range of motion.

1.1. The effects on shoulder abduction range of motion

Between groups comparison showed that there were nonsignificant differences at the baseline measurements of shoulder abduction pROM (p=0.17), but has been found a statistically significant difference between the first and second evaluations measures for both groups (MT: T1 mean ± SD 111.7±16.5, T0 95±13.62, p=0.002; CT: T1 mean ± SD 114.67±17.5, T0 99.7±12.7, p=0.006), with no significant differences between groups also at T1 (p=0.32), what it proves the effectiveness of 36 sessions of both methods (mirror therapy and conventional physiotherapy) on shoulder abduction passive range of motion (Figure 2).
We found no significant differences between the MT group and CT rehabilitation group when compared shoulder abduction range of motion at baseline and the end of follow-up (three months after treatment phase), p=0.31.

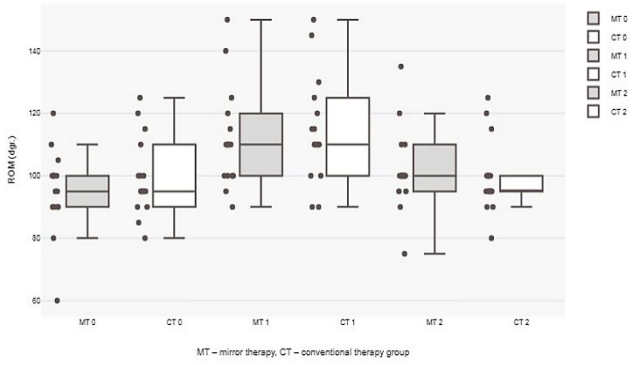

Figure 2. Shoulder abduction passive range of motion (pROM).

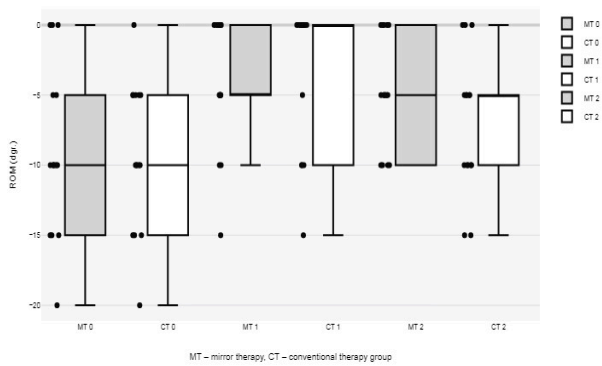

Figure 3. Passive range of motion (pROM) - elbow deficit of extension.

1.2. The effects on elbow extension range of motion

We considered this parameter significant due to the fact that the occurrence of elbow flexion (extension deficit) involves hypertonia/contracture/retraction of the flexor muscle tendons (biceps brachii) simultaneously with hypotonia of the antagonists of the spastic muscles: the elbow extensors (triceps brachii).

We found no differences between the MT group and CT rehabilitation group at the baseline measurements of elbow deficit of extension pROM (p=0.44), but has been found a statistically significant difference between the first and second evaluations measures for both groups (MT: T1 mean ± SD -4±4.7, T0 -9±6, p=0.008; CT: T1 mean ± SD -3.33±5.23, T0 -9.33±5.3, p=0.002), with no significant differences between groups at T1 (p=0.36), what it proves the effectiveness of 36 sessions of both methods on reduction of elbow deficit of extension (Figure 3).

1.3. The effects on forearm supination

In the forearm, spastic pronation appears to be more common than supination, and pronation attitude impairs a patient's ability to orient the hand. We found no differences between the mirror therapy plus rehabilitation group (MT) and conventional physical therapy group (CT) when compared forearm supination range of motion after three months rehabilitation programme, T1 p=0.31, but there were significant differences between groups when compared the forearm supination range of motion at the end of follow-up (three months after treatment phase): MT: T2 mean ± SD 58±16.01; CT: T2 mean ± SD 49±12.56, p=0.048 (Figure 4). This finding probably suggests a better long-term effect of mirror therapy added to conventional physical therapy on poststroke spasticity and upper limb range of motion.

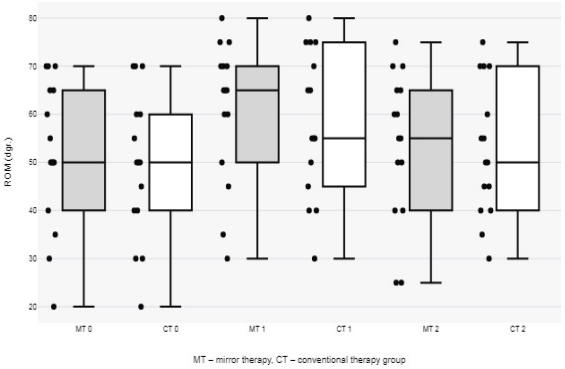

Figure 4. Forearm supination pROM.

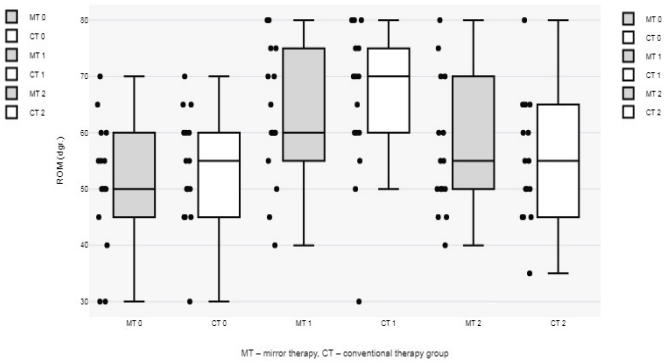

Figure 5. Wrist extension pROM.

1.4. The effects on wrist extension

Hemiparesis leads to deficiencies in active range of motion (ROM) and in static and dynamic muscle strength. This study presents the results of wrist extension and supination pROM which are directly related to the weakness of the agonist and prime mover muscles. Extension with fingers extended was measured in degrees. There were no differences between groups at the baseline measurements of wrist extension pROM (p=0.25), but has been found a statistically significant difference between the first and second evaluations measures for both groups (MT: T0 mean ± SD 51±11.37, T1 63±12.21, p=0.005; and CT: T0 mean ± SD 53.7±10.26, T1 65.3±13.6, p=0.006), with no significant differences between groups at T1 (p=0.31), what it proves the effectiveness of 36 sessions of both methods on wrist extension improvement (Figure 5).

We also found no significant differences between groups when compared the pROM wrist extension at the end of follow-up (three months after treatment phase): MT: T2 mean ± SD 57±11.9; CT: T2 mean ± SD 55±11.2, p=0.32.

2. The effects mirror therapy on upper limb pain in poststroke patients

Motor and sensory impairments and immobility are associated with an increased risk for stroke-related pain. Stiffness in the connective tissue of the immobilized limb may stimulate free nerve endings and proprioceptors, such as Pacini and Rufini corpuscles, in the tissue producing pain. Pain can lead to learned nonuse which may persist even after the pain has resolved.

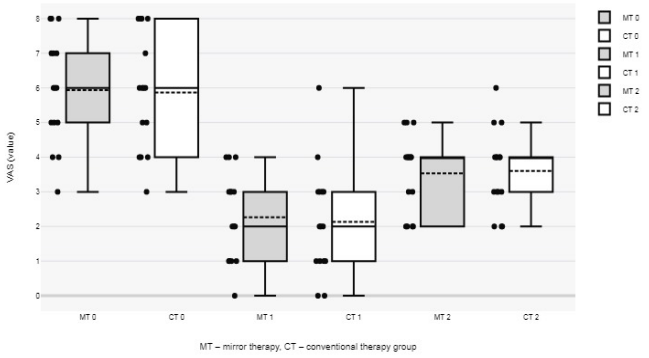

Figure 6. Mean and median VAS pain for the researched groups.

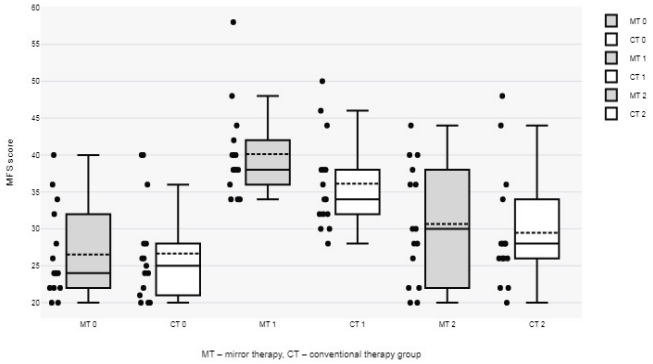

Figure 7. Mean and median upper limb MFS (Modified Frenchay Scale) values for the researched groups.

Our findings showed that there were not significant differences between groups regarding VAS pain at the T0, baseline measurements (p=0.46), nor at the second or third evaluations measures (T1 between groups p=0.4; T2 between groups p=0.44). Both rehabilitation therapies reduced the perceived level of pain at all stages of assessment (Figure 6).

The effects mirror therapy on upper limb functional abilities

For the upper limb, the active function was measured using the Modified Frenchay Scale (MFS), and consisted in the assessment - quantification of ten activities of daily living (4 uni-manual activities using the paretic hand and 6 bimanual activities, in which the paretic hand assists the other hand).

We found important differences in favour of mirror therapy plus conventional rehabilitation group (MT) after the 36 sessions of therapy, at the end of programme T1, regarding UL motor abilities: for the MT group the average MFS score was 40.13 ± 6.25, comparing with CT group – 36.13±6.35, p=0.046 (Figure 7). Much significant, the same differences were also present at the end of the follow-up period, 3 months after the end of rehabilitation programme, T2: MT group maintained an average MFS score of 34.4±7.22, comparing with CT group 29.5±7.9, p=0.042. This finding strongly suggests a better long-term effect of mirror therapy added to conventional physical therapy on poststroke spasticity and upper limb functional abilities.

Discussion

Although the existing pharmacological and surgical or orthopaedic treatments, along with many others physical therapeutic modalities that proved their efficacy, we hypothesized in the present study that mirror therapy added to a conventional physical therapy programme, may be an interesting alternative in the treatment of stroke affected UL by spasticity, in terms of mobility, pain and fine motor abilities.

Therefore, the aim of our study was to evaluate and compare the effects 36 sessions of MT plus CT, either CT, on spastic upper limbs in patients with spastic hemiparesis due to stroke.

Obtained clinical results were encouraging, by achieving a significant improvement after 12 weeks in both groups of patients.

The follow-up evaluation (at 3 months) showed that MT combined with conventional therapy produced greater and significant improvement in forearm supination pROM, suggesting a better long-term effect of MT on poststroke spasticity and upper limb range of motion.

These findings are in accordance with other studies despite differences in study design. (Sathian et al., 2000; Yavuzer et al 2008; Kim & Shim, 2015; Shaker et al., 2020). The previous studies suggest that there was a significant increase ROM in the upper limb joints (especially wrist extension and forearm supination) in the study group that received a selected physical therapy program in addition to the mirror therapy compared to the control group (Shaker et al., 2020). The difference between our study and previous studies is that the results obtained were maintained 3 months after the completion of Mirror treatment.

Neurorehabilitation may be defined as “facilitation of adaptive learning” (Carey et al., 2019), and neural plastic changes are associated with development and learning. They occur throughout the lifespan and may be enhanced following injury. They are influenced by

experience and the context in which that experience occurs. Neuroplasticity is key to rehabilitation from stroke. Brain plasticity allows the nervous system to remember or learn new skills, activating compensatory processes when functional neurological diseases occur, such as stroke (Choudhury & Wannyn, 2022). Mirror therapy focuses on the repetition of controlled, specific movements that can promote neuroplasticity. It is believed that this can help restore motor function, improve coordination, and reduce chronic pain associated with the affected limb; and a beneficial outcome for functional recovery after stroke (Thieme et al., 2018; Imaizumi et al., 2017; Zeng et al., 2018).

Also, the MT added to conventional physical therapy seemed to be much more efficient in UL functional abilities rehabilitation after 12 weeks of programme when compared to CT, but even more, these effects lasted at least 3 months compared with classical rehabilitation.

There are numerous studies in the literature that have investigated the role of MT in the recovery of chronic stroke patients with mild, moderate or severe upper limb motor dysfunction.

In a systematic literature review, Chrastina & Svízelová (2021) concludes that MT can facilitate motor learning, with positive results in improving upper extremity function and ADL, even in patients with subacute or chronic stroke.

Task-oriented MT is based on the introduction of functional tasks to prevent loss of concentration on movement due to boredom.The results of this study reveal that mirror therapy based on simple upper arm movements and appropriate functional tasks paired with conventional rehabilitation programme significantly improves upper limb motor function and improves functional independence in post-stroke patients, surpassing the results obtained with conventional therapy alone.

Similar results were found by Medeiros et al (2014) reported that mirror therapy focused the performance of tasks, aimed at functional activities, are more effective in motor improvements, because they apply and reinforce the concepts of motor learning.

Other studies conducted by Arya et Pandian (2013); Lim et al. (2016); Paik et al. (2014); Rodrigues et al. (2016) have demonstrated significant improvements in functional motor outcomes following mirror protocols focused on real-life tasks associated with ADL.

These results support the premise that engagement in purposeful, goal-directed activities promoting cortical reorganization and reinforcing motor patterns associated with daily functionality.

Basic research and further large randomized controlled studies are necessary to support the results of this observational study.

Conclusions

Mirror treatment used in addition to conventional stroke rehabilitation therapy seems to be an effective method to increase functional and motor skills of the upper extremity in elderly patients' post-stroke compared to conventional therapy.

Author Contributions: All authors contributed equally to this manuscript. All authors have read and agreed to the published version of the manuscript.

References

Alessandro L, Olmos LE, Bonamico L, Muzio DM, Ahumada MH, Russo MJ, et al. (2020). Rehabilitación multidisciplinaria para pacientes adultos con accidente cerebrovascular. *Revista Medicina (Buenos Aires)*, no 1, vol.80, 54-68, *On-line* ISSN 1669-9106.

Arya KN, & Pandian S. (2013) Effect of task-based mirror therapy on motor recovery of the upper extremity in chronic stroke patients: A pilot study. *Top Stroke Rehabil*. Vol. 20, no.3, 210-217 https://doi.org/10.1310/tsr2003-210

Bargiela, C. (2017). Las enfermedades crónicas no transmisibles.
http://www.msal.gob.ar/ent/images/stories/programas/pdf/2015-11_protocolo-ACV_3Nov2015.pdf

Baude M, Mardale V, Loche CM, Hutin E, Gracies JM, Bayle N. Intra-and inter-rater reliability of the Modified Frenchay Scale to measureactive upper limb function in hemiparetic patients. *Ann Phys RehabilMed*, 2016;59s:e59–e60. https://doi.org/10.1016/j.rehab.2016.07.138

Carey L, Walsh A, Adikari A, Goodin P, Alahakoon D, De Silva D, Ong KL, Nilsson M, Boyd L. (2019). Finding the Intersection of Neuroplasticity, Stroke Recovery, and Learning: Scope and Contributions to Stroke Rehabilitation. Neural Plasticity, No.1, Vol. 2019.https://doi.org/10.1155/2019/5232374

Choudhury S, & Wannyn W. (2022). Politics of Plasticity: Implications of the New Science of the "Teen Brain" for Education. *Cult Med Psychiatry,* 46(1), 31–58. https://doi.org/10.1007/S11013-021-09731-8

Chrastina J., & Svízelová H., (2021). Mirror therapy in adult stroke patients: a review of possible applications and effectiveness with an emphasis on activities of daily living. *Cent Eur J Nurs Midw* 12(1),295–305 doi: 10.15452/cejnm.2020.11.0026

Dewie, N. S., & Has, E. M. M. (2017). Self-Care Needs in Patients with Physical Immobilization. *Jurnal Ners*, *12*(2), 286–295. https://doi.org/10.20473/jn.v12i2.6518

Feigin, V. L., Brainin, M., Norrving, B., Martins, S. O., Pandian, J., Lindsay, P., F Grupper, M., & Rautalin, I. (2025). World Stroke Organization: Global Stroke Fact Sheet 2025. *International journal of stroke : official journal of the International Stroke Society*, *20*(2), 132–144. https://doi.org/10.1177/17474930241308142

Imaizumi, S., Asai, T., & Koyama, S. (2017). Agency over Phantom Limb Enhanced by Short-Term Mirror Therapy. *Frontiers in human neuroscience*, *11*, 483. https://doi.org/10.3389/fnhum.2017.00483

Kim, H., & Shim, J. (2015). Investigation of the effects of mirror therapy on the upper extremity functions of stroke patients using the manual function test. *Journal of physical therapy science*, *27*(1), 227–229. https://doi.org/10.1589/jpts.27.227

Kleynen, M., Beurskens, A., Olijve, H., Kamphuis, J., & Braun, S. (2020). Application of motor learning in neurorehabilitation: a framework for health-care professionals *Physiotherapy Theory and Practice*, *36*(1), 1-20. https://doi.org/10.1080/09593985.2018.1483987

Lim, K. B., Lee, H. J., Yoo, J., Yun, H. J., & Hwang, H. J. (2016). Efficacy of Mirror Therapy Containing Functional Tasks in Poststroke Patients. *Annals of rehabilitation medicine*, *40*(4), 629–636. https://doi.org/10.5535/arm.2016.40.4.629

Medeiros C.S.P, Fernandes S.G.G. , Lopes J.M., et al., (2014) Effects of mirror therapy through functional activites and motor standards in motor function of the upper limb after stroke. *Fisioter Pesq.* 21(3), 264-270 https://doi.org/10.590/1809-2950/87821032014

Paik, Y., Kim, S., Lee, J., & Jeon, B. (2014). Simple and Task-oriented Mirror Therapy for Upper Extremity Function in Stroke Patients: A Pilot Study. *Hong Kong Journal of Occupational Therapy,* *24*, 6–12. https://doi.org/10.1016/j.hkjot.2014.01.002

Park, Y., Chang, M., Kim, K. M., & An, D. H. (2015). The effects of mirror therapy with tasks on upper extremity function and self-care in stroke patients. *Journal of physical therapy science*, *27*(5), 1499–1501. https://doi.org/10.1589/jpts.27.1499

Rodrigues, L. C., Farias, N. C., Gomes, R. P., & Michaelsen, S. M. (2016). Feasibility and effectiveness of adding object-related bilateral symmetrical training to mirror therapy in chronic stroke: A randomized controlled pilot study. *Physiotherapy theory and practice*, *32*(2), 83–91. https://doi.org/10.3109/09593985.2015.1091872

Sathian K, Greenspan AI, Wolf SL. (2004). Doing it with mirrors: a case study of a novel approach to neurorehabilitation. *Neurorehabil Neural Repair*. 14(1),73–76.https://doi.org/10.1177/154596830001400109

Shaker H., Fahmy E.M, Honin A. A.N., Mohamed S.S. (2020). Effect of mirror therapy on hand functions in Egyptian chronic stroke patients. The Egyptian Journal of Neurology, Psychiatry and Neurosurgery 56, 1-6. https://doi.org/10.1186/s41983-020-00226-8

Suppiah R, Kim N, Abidi K, Sharma A. (2023). A comprehensive review of motor movement challenges and rehabilitative robotics. Smart Health. *29*, 100402. https://doi.org/10.1016/j.smhl.2023.100402

Thieme, H., Morkisch, N., Mehrholz, J., Pohl, M., Behrens, J., Borgetto, B., & Dohle, C. (2018). Mirror therapy for improving motor function after stroke. *The Cochrane database of systematic reviews*, *7*(7), CD008449. https://doi.org/10.1002/14651858.CD008449.pub3

Vergara, M., Sancho-Bru, J. L., Gracia-Ibáñez, V., & Pérez-González, A. (2014). An introductory study of common grasps used by adults during performance of activities of daily living. *Journal of hand therapy : official journal of the American Society of Hand Therapists*, *27*(3), 225–234. https://doi.org/10.1016/j.jht.2014.04.002

Yavuzer, G., Selles, R., Sezer, N., Sütbeyaz, S., Bussmann, J. B., Köseoğlu, F., Atay, M. B., & Stam, H. J. (2008). Mirror therapy improves hand function in subacute stroke: a randomized controlled trial. *Archives of physical medicine and rehabilitation*, *89*(3), 393–398. https://doi.org/10.1016/j.apmr.2007.08.162

Zeng, W., Guo, Y., Wu, G., Liu, X., & Fang, Q. (2018). Mirror therapy for motor function of the upper extremity in patients with stroke: A meta-analysis. *Journal of rehabilitation medicine*, *50*(1), 8–15. https://doi.org/10.2340/16501977-2287