Effect of compressive therapy on sensorimotor function of the more affected upper extremity in chronic stroke patients
A randomized clinical trial

Reem M. Alwhaibi, PhD², Noha F. Mahmoud, PhD², Hoda M. Zakaria, PhD², Walaa M. Ragab, PhD²,³, Nisreen N. Al Awaji, PhD², Hager R. Elserougy, PhD²,⁴, *

Abstract
Background: Common upper extremity (UE) physical impairments after stroke include paresis, abnormal muscle tone, and somatosensory affection. This study evaluated the effect of passive somatosensory stimulation using compressive therapy on sensorimotor function of the more affected UE in chronic stroke patients.

Methods: Forty chronic stroke patients were enrolled in this study. They were randomized into 2 groups: Gr1 and Gr2. Three patients dropped out leaving us with a total of 37 patients completing the study. Gr1 received UE motor program for the more affected UE along with sham electrical stimulation while Gr2 had the same UE motor program along with passive somatosensory stimulation. The session duration in both groups was 85 min. Gr1 and Gr2 received a total of 36 sessions for 6 successive weeks. UE function in Gr1 and Gr2 was examined, before and after treatment using Box and Block test (BBT) and Perdue Pegboard test (PPBT) as measures of motor of both the more affected and less affected UE while the Nottingham sensory assessment (NSA) scale was used as a measure of sensory function of the more affected UE.

Results: There were significant improvements in motor and sensory function of the more affected UE compared to the less affected UE in both groups, measured by the BBT, PPBT, and NSA scales post-treatment (P < .05). However, the comparison between both groups regarding improvement revealed no significant change (P > .05).

Conclusion: Upper extremity motor and passive somatosensory stimulation techniques are effective in improving sensorimotor function of the more affected UE, but none of them had the advantage over the other, in terms of improving motor and sensory function in chronic stroke patients.

Keywords: compressive therapy, passive somatosensory stimulation, stroke, stroke rehabilitation, upper extremity.

1. Introduction
Stroke results in massive impairment and functional disability in millions of people worldwide.[1,2] The Global Burden of Disease, Injuries, and Risk Factors Study reported that stroke is currently the second cause of death around the world.[3,4] A systematic review on stroke incidence worldwide showed a decreased incidence of stroke by 42% in high-income countries

This work was funded by the Deanship of Scientific Research at Princess Nourah bint Abdullah University through the Research Groups Program, grant no [RGP-1440-0012].

Informed consent was obtained from all subjects involved in the study.
The authors have no conflicts of interest to disclose.
The data presented in this study are available on request from the corresponding author.
The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the College of Physical Therapy at Cairo University, Egypt (P.T.REC/012/2012/00153).

* Correspondence: Hager R. Elserougy, Department of Neuromuscular Diseases and Its Surgery, College of Physical Therapy, Misr University for Science and Technology, Giza 77, Egypt (e-mail: hager.ellerougy@musty.edu.eg).

Copyright © 2022 the Author(s). Published by Wolters Kluwer Health, Inc. This is an open-access article distributed under the terms of the Creative Commons Attribution-Non Commercial License 4.0 (CCBY-NC), where it is permissible to download, share, remix, transform, and buildup the work provided it is properly cited. The work cannot be used commercially without permission from the journal.

How to cite this article: Alwhaibi RM, Mahmoud NF, Zakaria HM, Ragab WM, Al Awaji NN, Elserougy HR. Effect of compressive therapy on sensorimotor function of the more affected upper extremity in chronic stroke patients: a randomized clinical trial. Medicine 2022;101:38(e30657).

Received: 7 February 2022 / Received in final form: 18 August 2022 / Accepted: 19 August 2022
http://dx.doi.org/10.1097/MD.0000000000030657
and an increased incidence by more than 100% in low to middle-income countries. In Egypt, stroke incidence is high with no definitive statistics with an urgent need for more epidemiological studies.

Motor impairments are common after stroke. It is estimated that nearly 80% of the patients have some motor impairment with 20% regaining part of their motor functions in the months following injury and 50%–60% are left with a chronic motor disorder. Somatosensory deficits are reported in approximately 50% of stroke patients. Commonly reported upper extremity (UE) impairments after stroke include muscle weakness, changes in muscle tone, affection of the somatosensory system, and incoordination all resulting in motor control deficits.

Rehabilitation after stroke helps patients regain function, and to return to independent performance of activities of daily living (ADL). Various rehabilitative approaches improve recovery of motor function after stroke such as repetitive somatosensory stimulation and motor or task-specific training. Both approaches help promote cortical plasticity and brain reorganization and result in enhanced motor and functional recovery after stroke.

Physical therapy approaches that emphasize on sensory stimulation have gained increased recognition among modern rehabilitation strategies. Providing sensory information during active fine motor tasks improves functional movement of the hand, even though the sensory pathways after stroke remain affected. Active training is considered more efficient than passive training, but it can’t be applied to extremely impaired patients. Passive somatosensory stimulation techniques can be applied daily to stroke patients with complete paralysis.

Passive somatosensory stimulation includes modalities that passively stimulate sensory receptors such as neuromuscular electrical stimulation, transcutaneous electrical nerve stimulation (TENS), intermittent pneumatic compression, and thermal stimulation (TS).

Intermittent compression technique, a neurophysiological treatment involves stimulation of cutaneous and proprioceptive receptors by repeated movements. Previous randomized control trials showed its beneficial effects on sensory and motor functions in stroke patients in both acute and chronic phases. A significant improvement was observed in patients after 5-year follow-up. However, no further investigations have been conducted.

A study by Robichaud et al. reported the effectiveness of applying air-splint pressure on the soleus muscle in temporarily decreasing spasticity of the more affected lower extremity in stroke patients. A systematic review and meta-analysis by Serrada et al. reported a moderate positive effect of passive somatosensory stimulation on somatosensory function in stroke patients. Additionally, there was no evidence for the role of active somatosensory stimulation on somatosensory function due to the heterogeneity of the outcome measures used in these studies. Yet authors, still concluded that active somatosensory stimulation had a positive effect since there were positive changes in the outcome measures used.

Due to the complex process of stroke recovery and the methodological heterogeneity in various studies, it is difficult to determine which physical therapy program will result in better functional outcomes. There are no specific guidelines or recommendations concerning the timing, type, and intensity of different approaches used in stroke rehabilitation. That is why this study aimed to study the effect of passive somatosensory stimulation using compressive therapy on sensorimotor function of the more affected UE in chronic stroke patients.

2. Subjects and Methods

2.1. Study Design

This randomized clinical trial was approved by the College of Physical Therapy Ethical Committee, Cairo University, Egypt and issued the number (P.T. REC/012/002153). Forty-nine male and female patients (n = 49) were recruited from the outpatient clinic of the College of Physical Therapy, Cairo University along with several other facilities specializing in neurorehabilitation. Patients were examined for eligibility and 9 patients (n = 9) were excluded for not meeting the inclusion criteria while the remaining 40 patients (n = 40) were enrolled in this study. Three patients dropped out of the study and the remaining 37 completed the study. Inclusion criteria were: age ranged from 40–75 years, diagnosed with first-ever ischemic stroke resulting in hemiparesis confirmed by magnetic resonance imaging (MRI), stroke duration ranged between 6 to 18 months, reported medically stable by the treating neurologist, scored ≥24 on the mini-mental state examination (MMSE); he more affected UE score 1, 1+, or 2 on Modified Ashworth scale (MAS), and moderate to mild impairment measured on the Fugl Meyer scale-upper extremity (FMA-UE). Patients were excluded from the study if they had any cardiac arrhythmias, uncontrolled hypertension, obstructive pulmonary disease, and UE sensory deficit attributable to nonstroke pathology such as peripheral neuropathy. A proper explanation of the examination and treatment protocol was given. If agreed to participate in the study each patient was asked to sign a consent form. Each patient was instructed that if felt uncomfortable for any reason, at any moment they can withdraw from the study.

2.2. Randomization

A random number software (http://www.randomization.com) (accessed on 30th May 2020) was used to equally randomize patients into 2 equal groups (Gr1 and Gr2). Gr1 received UE motor program and sham electrical stimulation, while Gr2 received UE motor program and passive somatosensory stimulation.

2.3. Sample size

The sample size for the current study was calculated using G*POWER statistical software (version 3.1.9.2; Franz Faul, Universität Kiel, Germany), which indicated a required sample of 40 patients for the whole study (α = 0.05, β at 0.2, size effect 0.91 and allocation ratio N2/N1 = 1). The appropriate minimum sample size for this study was 40 patients (n = 20 patients in each group).

2.4. Clinical evaluation

The Box and Block test (BBT), Perdue PegBoard test (PPBT), and Nottingham sensory assessment (NSA) were applied twice, week 0 (pretreatment) and week 7 (posttreatment) by a well-trained and experienced physical therapist.

2.4.1. Box and Block test

The BBT is a test of unilateral gross manual dexterity, where the pick-up and release actions are performed by fingers. BBT has a test-retest reliability > 0.9. In the current study, each patient was seated in a quiet room, in front of a table of adjustable height. A wooden box containing 150 wooden cubes of similar shapes was placed on the table. Patients were instructed to pick up 1 cube at a time with the tip of the index and middle finger of the more affected UE, move it over the separating partition of the box, and drop it into the opposite compartment, for 1 min. The same task was...
performed for the less affected UE. Before the test began, each patient was allowed to rehearse the pick-up and release movement of the cubes for approximately 15 s. A stopwatch was used for monitoring time. The higher the score, the better the gross manual dexterity.

2.4.2. Purdue PegBoard test. The PPBT measures fine motor dexterity of the fingers and hand. PPBT has excellent test-retest reliability.[41,42] The PPBT consists of a board that has 2 rows with 25 holes in each row. Pins (pegs) are found at the extreme top right and left cups of the board. Collars and washers are in the middle 2 cups. Four subtests are present but in the current study only the first 2 subtests were administered, which measure unilateral hand prehension.

In the current study, each patient was seated in a quiet room, in front of a table of adjustable height, with the PPBT placed in front of them. Patients were instructed to pick 1 pin at a time, starting with the more affected hand (not necessarily the right hand), and try and place it in the top hole. This was followed by the less affected hand (while testing the right hand, patients must insert as many pins as possible in the right row and vice versa for the left hand). The duration of each sub-test was 30 s. Before the test began, each patient was allowed to rehearse picking up the pins and placing them in the designated hole for approximately 15 s. A stopwatch was used for monitoring time. The higher the score, the better the fine motor dexterity.

2.4.3. The Nottingham Sensory Assessment scale. The NSA measures tactile sensations, kinesthetic sense, and stereognosis. Tactile sensations and stereognosis are measured on a numerical scale from (0–2 where 0=absent, 1=impaired, and 2=normal). For kinesthetic sensations, a scale of (0–3 is used, 0=absent, 1=appreciates the movement taking place, 2=appreciates the movement and able to mirror the direction, 3=mirrors the test movement to 10° of the new position). For sensations not examined, a score of 9 is given. Total tactile sensations score for each part of the body is calculated by adding the sum of all scores obtained, while eliminating those with score 9. Total kinesthetic sensations score is obtained by adding the sum scores for each joint examined, also excluding those with score 9.[43,44]

The examination was performed in a sitting position and both UE uncovered. The procedure was explained and demonstrated before the patient was blindfolded. During the examination, the blindfold was removed 3 times (after finishing each section of the scale) to prevent the patient from being disoriented. The examination was performed from distal to proximal for both UE. The examination started with the more affected UE followed by the less affected UE. Patients were asked to indicate if he/she feel the sensation being tested.[43–45] Sensations tested were tactile sensation, kinesthetic sense, and stereognosis. The test took an average of 15 min to administer.

Tactile sensation tested included (1) light touch using a cotton ball applied on the tested UE, (2) gentle pressure applied by the index finger of the examiner, (3) pain using a neuropit, (4) temperature using 2 test tubes, one containing hot water and the other containing cold water, (5) tactile localization using the index finger of the examiner coated with talcum powder to mark the area being touched, after which the patient was asked to point to the spot being touched. Areas tested were the ones that scored 2 in the pressure sense, and (6) bilateral simultaneous touch where 2 corresponding places on the tested UE were touched by the fingertip of the examiner, and the patient was asked to indicate if he/she felt one or both areas touched. The areas tested were the ones that scored 2 in the pressure sense.[43,44]

Kinesthetic sensations tested were appreciation of movement, the direction of movement, and joint position sense. Testing started with the patient sitting and blindfolded. The more affected UE was supported and moved by the examiner in various directions but one joint at a time. The patient was asked to do the same movement with the less affected UE. Before blindfolding, 3 trials were allowed. The same was done for less affected UE. For stereognosis testing, an object was placed in the patient’s hand for a maximum of 30 s. Identification was by naming, description, or pair-matching with an identical set.[43,44]

2.5. Treatment procedures

Patients in (Gr1) and (Gr2) received 6 sessions per week, for 6 consecutive weeks by a well-trained and experienced physical therapist. Session duration was 90 min. Patients in (Gr1) received UE motor program for 60 min. and sham electrical stimulation for 25 min. Patients in (Gr2) received the same UE motor program for 60 min. and passive somatosensory stimulation in the form of compressive therapy applied to the more affected UE for 25 min.

2.5.1. Motor upper extremity program. Exercises for each patient progressed in parallel with improvement in motor performance. Rest periods between exercises were given when necessary. Progression included increasing the number of repetitions, increasing range of motion (ROM), altering movement speed, and decreasing rest time between each exercise and resistance. Some of the exercises used were based on motor learning concepts. Repetitive practice of meaningful tasks with increasing difficulty, practicing tasks that motivated patients and provide enhanced feedback, was stressed. Eccentric, isometric, or concentric, muscle contractions of different movements for the more affected UE (e.g., reaching, grasp, and release in addition to manipulation)[46] were practiced.

A home program was given for each patient and consisted of exercises performed during the sessions. The patient was instructed to practice these exercises as much as possible at home. Exercise selection, varied from one patient to another, depending on the status of the more affected UE. Exercises performed during the session were as follows[46]:

1. Passive stretching at the beginning of the session to decrease soft tissue contractures and muscle tone.
2. Mobilization of the scapula to facilitate movement in the glenohumeral joint.
3. Different varieties of strengthening exercises with a maximum repetition of up to 10 times practiced in 3 sets.
4. Enhancing functional performance of both UE using different weight-bearing positions such as prone on elbows, and quadruped. Once the patient could weight bear (support the body) on the more affected UE, the less affected UE was used for the performance of activities of daily living (ADL).
5. Simple active exercises during the session and as part of the home program including wrist extension, forearm supination, shoulder joint muscles, shoulder shrug, and reaching.
6. Reaching and balance training with the following progressions:

Each patient sat on a stool or plinth and tried to reach forward, sideways, or backwards to pick up an object, transport it to another place (e.g., the floor), pick it up again, and reach as far in one direction as possible then put it down.

Bimanual reaching (both UE) to pick up large objects. Pointing to different parts of a target.

While standing, each patient reached down to pick up and place objects on stool or floor. The distance of object placement varied depending on the patient’s ability.

While sitting or standing, each patient reached up to pick an object or place an object on the wall. Height of reaching varied depending on the patient’s ability.
(7) Manipulation and dexterity training to increase speed and movement precision. During the application of the following movements, each patient was instructed to use the pads of the thumbs and fingers for grasping and not the lateral surfaces. In addition, the wrist joint was kept in extension and all opposition movements were performed by the carpometacarpal joint of the thumb:
- Tapping tasks.
- Picking different objects between thumb and fingers and placing them on various targets.
- Picking up larger objects from one side of the table and placing to the other side: vary weight, and distance to be moved.
(8) Bimanual practice is when the patient gained the ability to control simple movements. Exercises included push-ups against the wall, picking up and placing objects of different shapes, sizes, and weights, walking, walking up and down steps, and standing up.

2.5.2. Passive somatosensory stimulation. Passive somatosensory stimulation was applied after completing the motor UE program. Compressible therapy (POWER-Q1000 PLUS, Wonjin Mulsan Co., Ltd, Namchon-dong, Namdong-gu, Incheon, Korea; Model: WHF-324) (Fig. 1) was applied for 25 min\(^{[24]}\) as follows:
Each patient sat comfortably on a chair with back support with both UE positioned on the treatment table.
The more affected UE was positioned as follows: shoulder protraction and external rotation, the angle between the trunk and the UE was approximately 45°, radioulnar supination, and elbow, wrist, and fingers in extension.
A long inflatable pressure splint was applied to the more affected UE along with a pressure pad placed inside the pressure splint, under the dorsal aspect of the hand.
The splint was then, connected to the compressible therapy system. The machine timer was set for 25 min. and then turned on. The inflation peak was set to 70 mmHg.
Each patient was asked to look to the more affected UE during the stimulation period.

2.6. Statistical analysis
Statistical Package for Social Science (SPSS) Software (version 19) (IBM, Armonk, NY) for Windows was used for analysis. Descriptive statistics (e.g., mean, median, standard deviation) were calculated for all variables in the study. The independent sample t-test and chi-squared test were used to test the presence of significant differences between scores of demographic variables in (Gr1) and (Gr2). The Mann–Whitney test and the Wilcoxon test were used for comparison between scores of the BBT, PPBT, and NSA within and between both groups. All tests were set significant if the P value is <.05.

3. Results
Forty-nine stroke patients were screened for eligibility, 9 did not match the specified inclusion criteria of the study, and the remaining 40 patients were enrolled in the study, where 37 completed the study (Fig. 2).

3.1. Demographic data and clinical characteristics
No statistically significant pre-treatment difference (P > .05) was present between Gr1 and Gr2 in age, duration of stroke (months), and side of affection (Table 1).

3.2. Clinical scales
3.2.1. Box and Block test
There were significant changes between the more affected and less affected UE pre- and posttreatment in Gr1 and Gr2 (P < .05). Additionally, there were significant changes between the more affected UE pre-and posttreatment and the less affected UE pre- and posttreatment in both groups (P < .05) (Table 2). On the other hand, no significant change between Gr1 and Gr2, in the more affected UE, pre-and posttreatment was reported while in the less affected UE there was a significant change, posttreatment between Gr1 and Gr2 (Table 3).

3.2.2. Perdue Pegboard test
There was a significant change between the more affected and less affected UE pretreatment in Gr1 and Gr2 (P < .05) while there was no significant change posttreatment. Additionally, there were significant changes between the more affected UE pre-and posttreatment and the less affected UE pre- and posttreatment in both groups (P < .05) (Table 4). On the other hand, no significant change between Gr1 and Gr2 was reported in the more affected UE, pre-and posttreatment while in the less affected UE there was a significant change between pre- and posttreatment (Table 5).

3.2.3. Nottingham Sensory Assessment scale.
There were no significant changes between the more affected and less affected UE pretreatment in Gr1 and Gr2 (P < .05) except in pretreatment scores of tactile sensations of both groups with no significant changes reported post-treatment. Additionally, there was a significant change between pre- and posttreatment scores of the tactile sensation only in both groups (P < .05) (Table 6). On the other hand, significant changes between Gr1 and Gr2, in stereognosis, tactile sensations, and kinesthetic sense, pretreatment were reported in the more affected UE, (P < .05), while no significant changes were reported post-treatment and in the less affected UE (Table 7).

4. Discussion
The current study was designed to study the effect of passive somatosensory stimulation using compressive therapy on sensorimotor function of the more affected UE in chronic stroke patients. This was achieved using outcome measures that examined the motor and sensory function of the more affected and less affected UE. These included BBT as a measure of gross manual dexterity, PPBT as a measure of fine manual dexterity, and NSA scale as a measure of somatosensory function.
In this study, improvements were observed in gross manual dexterity, fine motor dexterity, and tactile sensation of the more affected UE compared to the less affected UE in both groups. This was consistent with expectations that applying UE motor
program in (Gr1) and adding passive somatosensory stimulation in the form of compressive therapy to the motor program in (Gr2) can improve the function of the more affected UE. Both treatment programs seemed to improve scores of BBT, PPBT, and NSA, indicating some sort of improved function of the more affected UE. Although the sample size was small, the effects of treatment were significant in both groups.

Results of the current study agree with that of Cambier et al. [24] who evaluated the effectiveness of using intermittent pneumatic compression on treating sensory affection of the more affected UE in stroke patients. 23 stroke patients were enrolled in the clinical trial and randomized to 2 groups. The experimental group (n = 11) received standard physical therapy along with intermittent pneumatic compression (10 cycles of 3 mins with a peak of 40 mmHg) for the more affected UE. The control group (n = 12) received the same standard physical therapy program along with a placebo treatment, which was short-wave therapy applied on the more affected UE. Clinical evaluation of sensation was performed 3 times over 4 weeks using the NSA scale. Results showed improvement in somatosensation in both groups, but the experimental group improved more than the control group (P = .036) or 81.1% improvement versus 30.9%. The authors concluded that the use of intermittent pneumatic compression in stroke rehabilitation may be

---

**Table 1**

Demographic and baseline clinical characteristics in both groups, pretreatment.

|                        | Gr1 (n=18) | Gr2 (n=19) | P value |
|------------------------|------------|------------|---------|
| Age (y)                | 58.8 ± 5.1 | 56.7 ± 2.6 | .222a   |
| Type of stroke (ischemic) | 18         | 19         | 1       |
| Duration of stroke (months) | 10 ± 0.2   | 10 ± 0     | .114b   |
| Gender (male/female)    | 14/4       | 13/6       | .495c   |
| Side of affection (right side/left side) | 10/8       | 13/6       | 1b      |
| Edinburgh handedness inventory for dominance (right-handed) | 18         | 19         | 1b      |
| Mini-mental state examination (MMSE) | 28.2 ± 2.5 | 28.7 ± 1   | .562a   |
| Modified Ashworth scale (MAS) | 1.1 ± 0.2  | 1.1 ± 0.3  | 1c      |
| Fugl-Meyer assessment of the upper extremity (FMA-UE) | 36 ± 21.5  | 38 ± 14.3  | .418a   |

---

**Table 2**

BBT scores of the more affected and less affected UE in (Gr1) and (Gr2), pre- and posttreatment.

|                        | More affected side | Less affected side | P value |
|------------------------|--------------------|--------------------|---------|
| BBT Gr1 Pretreatment   | 23 ± 21.9          | 40 ± 14.2          | .005*   |
| Posttreatment          | 38 ± 22.1          | 45 ± 13.4          | .005*   |
| P value                | .005*              | .011*              |         |
| Gr2 Pretreatment       | 14 ± 15.5          | 28 ± 8.1           | .002*   |
| Posttreatment          | 20 ± 12.3          | 32 ± 9.8           | .010*   |
| P value                | .002*              | .005*              |         |

---

*aMann–Whitney test, bWilcoxon test, cP < .05 = significant.
importance for the restoration of sensory function. Drawbacks of that study included small sample size and a short follow-up period. It is also worth mentioning that the only clinical trial evaluating the effect of using intermittent pneumatic compression on upper extremity function in stroke patients was that by [24].

Generally, the results of the current study match work by [13-15,33,34,47] who demonstrated the benefits of physical therapy on UE function in stroke patients, and work by [13,17,18,26,48-52] who proved the benefits of somatosensory stimulation on UE function in stroke patients.

As mentioned previously, improvement was observed in gross manual dexterity of the more affected and less affected UE in both groups which indicates that both physical therapy programs were effective in improving function. On the other hand, the comparison between both groups did not show the superiority of one treatment approach over another which did not agree with our assumption that somatosensory stimulation programs are equally effective in terms of improving sensorimotor function of both the more affected and less affected UE in chronic stroke patients.

4.1. Limitations

First, the sample size is considered quite small and leads to reduced power of the study. Second, the follow-up was only 6 weeks after therapy, which may be too short to find retention effects. Third, the duration of treatment also is considered too short, maybe a longer period of treatment was required. Fourth, more objective ways can be implemented to measure the changes in motor and sensory function in both UE such as functional magnetic resonance imaging (fMRI) or electroencephalogram (QEEG). 5. Conclusion

The purpose of this study was to investigate the effect of adding passive somatosensory stimulation to the rehabilitation program of stroke patients. The results obtained are promising but further investigations are required due to the complex and changing nature of stroke rehabilitation. Passive somatosensory stimulation is considered a nonexpensive modality and can help in improving both motor and sensory function of the UE in stroke patients when added to the treatment program.
Author contributions

Funding acquisition, the experimental design of the study, and the work: RMA, NNA, WMR, and HMZ; validation: NFM; writing—original draft, writing—review and editing: HRE. All authors have read and agreed to the published version of the manuscript.

Correction

Princess Nourah bint Abdulrahman University has been corrected in affiliation information from Princess Nourah bint Abdulrahman University.

References

[1] Meyer S, De Bruyn N, Krumlinde-Sundholm L, et al. Associations between sensorimotor impairments in the upper limb at 1 week and 6 months after stroke. J Neurol Phys Ther. 2016;40:186–95.

[2] Mozaffarian D, Benjamin EJ, Go AS, et al. American heart association statistics committee and stroke statistics subcommittee. Heart disease and stroke statistics—2015 update: a report from the American heart association. Circulation. 2015;131:e29–322.

[3] Katan M, Luft A. Global burden of stroke. Semin Neurol. 2018;38:208–11.

[4] GBD 2015 Neurological Disorders Collaborator Group. Global, regional, and national burden of neurological disorders during 1990-2015: a systematic analysis for the global burden of disease study 2015. Lancet Neurol. 2017;16:877–97.

[5] Boutayeb A, Derouich M, Boutayeb W, Lamlili M. Cerebrovascular diseases and associated risk factors in WHO Eastern Mediterranean countries. Cardiol Angiol. 2014;2:62–75.

[6] Abd-Allah F, Moustafa RR. Burden of stroke in Egypt: current status and opportunities. Int J Stroke. 2014;9:1105–8.

[7] de Vries S, Mulder T. Motor imagery and stroke rehabilitation: a critical discussion. J Rehabil Med. 2007;39:5–13.

[8] Hendricks HT, van Limbeek J, Geurts AC, Zwarts MJ. Motor recovery after stroke: a systematic review of the literature. Arch Phys Med Rehabil. 2002;83:1629–37.

[9] Song B, Chung S, Hwang B. The effects of somatosensory training focused on the hand on hand function, postural control and ADL of stroke patients with unilateral spatial neglect and sensorimotor deficits. J Phys Ther Sci. 2013;25:297–300.

[10] Hussain N, Alt Murphy M, Sunnerhagen KS. Upper limb kinematics in stroke and healthy controls using target-to-target task in virtual reality. Front Neurol. 2018;9:300.

[11] Kwakkel G, Lannin NA, Borschmann K, et al. Standardized measurement of sensorimotor recovery in stroke trials: consensus-based core recommendations from the stroke recovery and rehabilitation roundtable. Int J Stroke. 2017;12:451–61.

[12] Coupar F, Pollock A, Rowe P, Weir C, Langhorne P. Predictors of upper limb recovery after stroke: a systematic review and meta-analysis. Clin Rehabil. 2012;26:291–313.

[13] Chen JC, Shaw FZ. Progress in sensorimotor rehabilitative physical therapy programs for stroke patients. World J Clin Cases. 2014;2:316–26.

Table 6

| NSA | Stereognosis | Gr1 | Pretreatment | Posttreatment | P value | Gr2 | Pretreatment | Posttreatment | P value |
|-----|--------------|-----|--------------|---------------|---------|-----|--------------|---------------|---------|
|     |              |     | 22 ± 2.7     | 22 ± 0.0      | .063    |     |              |               |         |
|     | Tactile sensation |     | 22 ± 0.0     | 22 ± 0.0      | 1   |
|     | Kinesthetic sense |     | 16 ± 0.0     | 48 ± 0.0      | .002   |
| Stereognosis |     | 48 ± 8.4     | 48 ± 0.0      | .157   |
| Tactile sensation |     | 12 ± 0.0     | 12 ± 0.0      | 1   |
| Kinesthetic sense |     | 12 ± 0.0     | 12 ± 0.0      | 1   |

P value: Mann–Whitney test; *P < .05 = significant.

Table 7

| NSA | Stereognosis | Gr1 | Pretreatment | Posttreatment | P value | Gr2 | Pretreatment | Posttreatment | P value |
|-----|--------------|-----|--------------|---------------|---------|-----|--------------|---------------|---------|
|     |              |     | 22 ± 2.7     | 22 ± 0.0      | .019    |     |              |               |         |
|     | Tactile sensation |     | 22 ± 0.0     | 22 ± 0.0      | 1   |
|     | Kinesthetic sense |     | 16 ± 0.0     | 16 ± 15.8     | .049   |
| Stereognosis |     | 48 ± 0.0     | 48 ± 0.0      | 1   |
| Tactile sensation |     | 48 ± 0.0     | 48 ± 0.0      | 1   |
| Kinesthetic sense |     | 12 ± 0.0     | 12 ± 0.0      | 1   |

P value: Mann–Whitney test; *P < .05 = significant.
Alwhaibi et al. • Medicine (2022) 101:38

[14] Veerbeek JM, van Wegen E, van Peppen R, et al. What is the evidence for physical therapy poststroke? A systematic review and meta-analysis. PLoS One. 2014;9:e87987.

[15] Dolbkin BH, Dorsch A. New evidence for therapies in stroke rehabilitation. Curr Atheroscler Rep. 2013;15:331.

[16] Schaechter JD, Perdue KL, Wang R. Structural damage to the cortico-spinal tract correlates with bilateral sensorimotor cortex reorganization in stroke patients. Neuroimage. 2008;39:1370–82.

[17] Sasaki I, Wu CW, Kaelin-Lang A, Cohen LG. Effects of somatosensory stimulation on use-dependent plasticity in chronic stroke. Stroke. 2006;37:2467–7.

[18] Celnik P, Hummel F, Harris-Love M, Wolk R, Cohen LG. Somatosensory stimulation enhances the effects of training functional hand tasks in patients with chronic stroke. Arch Phys Med Rehabil. 2007;88:1369–76.

[19] Kita K, Otaka Y, Takeda K, et al. A pilot study of sensory feedback by transcutaneous electrical nerve stimulation to improve manipulation deficit caused by severe sensory loss after stroke. J Neuroeng Rehabil. 2013;10:55.

[20] Seo NJ, Fischer HW, Bogey RA, Rymer WZ, Bogey RA, Rymer WZ, Kamper DG. Use of visual force feedback to improve grip force direction during pinch grip in persons with stroke: a pilot study. Arch Phys Med Rehabil. 2011;92:24–30.

[21] Quanney BM, He J, Timberlake G, Dold K, Carr C. Visuomotor training improves stroke-related ipsilesional upper extremity impairments. Neurorehabil Neural Repair. 2010;24:52–61.

[22] Kato H, Izumiyama M. Activation of Brain Sensorimotor Network by Transcranial Magnetic Stimulation in Patients with Hemiaparetic Stroke: A Functional MRI Study. 2013.

[23] Cuypers K, Levin O, Thijs H, Swinnen SP, Meesen RL. Long-term TENS treatment improves tactile sensitivity in MS patients. Neurorehabil Neural Repair. 2010;24:420–7.

[24] Cambier DC, De Corte E, Danneels LA, Witvrouw EE. Treating sensory impairments in the post-stroke upper limb with intermittent pneumatic compression. Results of a preliminary trial. Clin Rehabil. 2003;17:14–20.

[25] Wu HC, Lin YC, Hsu MJ, Liu SM, Hsieh CL. Effect of thermal intervention on upper extremity motor recovery 3 months after stroke. Stroke. 2010;41:2378–80.

[26] Chen JC, Liang CC, Shaw FZ. Facilitation of sensory and motor recovery by thermal intervention for the hemiplegic upper limb in acute stroke patients: a single-blind randomized clinical trial. Stroke. 2005;36:2665–9.

[27] Chen JC, Lin CH, Wei YC, Hsiao J, Liang CC. Facilitation of motor and balance recovery by thermal intervention for the paretic lower limb of acute stroke: a single-blind randomized clinical trial. Clin Rehabil. 2011;25:823–32.

[28] Feys HM, De Weerdt WJ, Selz BE, et al. Effect of a therapeutic intervention for the hemiplegic upper limb in the acute phase after stroke: a single-blind, randomized, controlled multicenter trial. Stroke. 1998;29:785–92.

[29] Feys H, De Weerdt W, Verbeke G, et al. Early and repetitive stimulation of the arm can substantially improve the long-term outcome after stroke: a 5-year follow-up study of a randomized trial. Stroke. 2004;35:924–9.

[30] Robichaud JA, Agostimucci J, Vander Linden DW. Effect of air-split application on soleus muscle motoneuron reflex excitability in nondisabled subjects and subjects with cerebrovascular accidents. Phys Ther. 1992;72:176–83; discussion 183.

[31] Serrada I, Hordacre B, Hillier SL. Does sensory retraining improve sensation and sensorimotor function following stroke: a systematic review and meta-analysis. Front Neurosci. 2019;13:402.

[32] De Bruyn N, Saenen L, Thijs L, et al. Sensorimotor vs. motor upper limb therapy for patients with motor and somatosensory deficits: a randomized controlled trial in the early rehabilitation phase after stroke. Front Neuroul. 2020;11:597666.

[33] Zorowitz R, Braim M. Advances in brain recovery and rehabilitation 2010. Stroke. 2011;42:294–7.