

Original Article

Impact of Sensory Re-education Paradigm on Quality of Life, Tactile Sensation, and Proprioceptive Acuity in Patients with Post-COVID-19 Polyneuropathy: A Randomized Controlled Trial

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Abstract

Objectives: This study evaluated the effect of sensory re-education on quality of life and sensation in patients with post-COVID-19 polyneuropathy. **Methods:** Forty patients with post-COVID-19 polyneuropathy were randomly assigned to a study group (Group A) or a control group (Group B), each with 20 participants. Group A received a sensory re-education protocol plus the traditional physiotherapy, including proprioceptive neuromuscular facilitation (PNF) and strengthening exercises for wrist extensors, hand grip, and thumb opposition. Group B received the traditional physiotherapy alone. Both groups were treated for one hour, three times weekly, for six weeks. Quality of life was assessed using the Arabic WHOQOL-BREF. Tactile sensation was assessed using the Semmes-Weinstein Monofilament (SWM) test, and proprioception via the laser-pointer angle reproduction test (LP-ART). Assessments were performed pre- and post-intervention. **Results:** Both groups showed significant pre- to post-treatment improvements in quality of life, proprioception, and tactile sensation ($p \leq 0.05$). Group A demonstrated significantly greater gains in quality of life and proprioception compared to Group B ($p \leq 0.05$), but no statistically significant difference between groups in tactile sensation ($p > 0.05$). **Conclusion:** Sensory re-education, when integrated into traditional physiotherapy, significantly improves quality of life and proprioception in post-COVID-19 polyneuropathy but does not significantly affect tactile sensation. These findings support incorporating sensory re-education into rehabilitation protocols to enhance functional outcomes in this population. **ClinicalTrials.gov ID:** NCT05911113.

Keywords: Deep Sensation, Post-COVID-19 Polyneuropathy, Quality of Life, Sensory Rehabilitation, Tactile Sensation

The authors have no conflict of interest.

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Introduction

The pandemic of COVID-19 has affected millions of people all over the world. This disease presents with a wide array of symptoms, ranging from mild respiratory issues to acute respiratory distress syndrome (ARDS) and severe pneumonia, resulting in substantial illness and death¹. Although the initial phase of COVID-19 has been



extensively investigated, recent research has shed light on a considerable population of patients who continue to suffer from symptoms and complications long after recovering from the initial infection (including fatigue, dyspnea, neuropsychological disorders, as well as pain)². This condition is commonly known as post-COVID-19 syndrome. Recent research has reported many cases of neuropathy as a possible complication of the novel coronavirus. Polyneuropathy (a condition characterized by nerve damage) frequently manifests following a COVID-19 infection. The immune system's attack on nerve cells is responsible for the distinctive numbness and tingling sensations experienced in the extremities, often regarded as an initial symptom of polyneuropathy³.

The development of peripheral neuropathy in these cases can be attributed to immune processes or as a result of certain medications used to treat COVID-19 symptoms. Additionally, prolonged hospitalization may also contribute to the occurrence of entrapment neuropathy, which involves peripheral nerve compression⁴. Besides, another research has reported that a cytokine storm⁵. Polyneuropathy involves the impairment of the peripheral nerves that govern motor function, specifically those that control the muscles responsible for hand grip⁶. Furthermore, reduced tactile sensation in the feet and hands is a prevalent indication in individuals suffering from polyneuropathy⁷, and it can cause damage to deep sensation (proprioception)⁸.

COVID-19 can have a severe impact on different body systems. Patients with post-COVID-19 often experience persistent symptoms, which can greatly diminish their quality of life. Subjective symptoms like fatigue can affect various aspects of their well-being, including physical abilities, pain levels, energy levels, emotional well-being, and social interactions. In particular, patients with long COVID commonly report a significant decline in social functioning, suggesting a decreased attention in participating in normal daily activities due to the illness. Consequently, the social isolation measures imposed on these patients can significantly affect their overall quality of life⁹.

Sensory re-education, also known as sensory relearning, is a cognitive behavioral therapy method used to assist patients suffering from nerve injuries in effectively interpreting the modified neural impulses reaching their conscious level following stimulation of the affected sensory area¹⁰, and it has a significant impact on the central neural representation of the affected skin areas. It modifies the reaction of individual cortical cells involved in somatosensory processing when exposed to tactile stimulation. It also enhances synapse-to-neuron ratios and results in improved behavioral function following induced nerve damage, surpassing the effects of simple repetitive exercise^{11,12}. According to the results of neuroimaging studies, those who have sensory denervation and then receive sensory training experience comparable changes¹³.

The majority of physical therapy research had a greater emphasis on improving motor skills rather than sensory abilities, despite evidence suggesting that enhancing the

sensory system can have a significant impact on motor function. While motor skills are typically prioritized, it is important to recognize that improving sensory function may play a crucial role in enhancing overall motor performance¹⁴. Furthermore, there is insufficient evidence supporting the efficiency of sensory re-education to treat post-COVID-19 polyneuropathy; therefore, randomized trials are needed to evaluate its effectiveness in improving functional outcomes in patients with post-COVID-19 polyneuropathy. Currently, there is not enough research addressing the efficacy of the paradigm of sensory re-education on quality of life as well as sensation in patients suffering from post-COVID-19 polyneuropathy.

This study is part of a registered randomized controlled trial (ClinicalTrials.gov Identifier: NCT05911113) investigating the effects of a sensory re-education paradigm in patients with post-COVID-19 polyneuropathy. According to the original trial registration, health-related quality of life was defined as the primary outcome, while tactile sensation, proprioception, and hand-grip strength were prospectively specified as secondary outcomes. The results related to hand-grip strength have been reported previously¹⁵. The present manuscript reports the remaining pre-specified outcomes: quality of life, tactile sensation, and proprioception, which were defined a priori in the trial protocol but not addressed in the earlier publication. By focusing on sensory and patient-reported outcomes, this study provides complementary evidence on the multidimensional effects of sensory re-education in post-COVID-19 polyneuropathy. This study reports outcomes that were prospectively defined in the trial registry but were not included in our previously published article¹⁵.

Materials and Methods

Study Design

A randomized controlled study aimed to examine the effectiveness of the sensory re-education paradigm on quality of life and sensation in patients suffering from post-COVID-19 polyneuropathy. The study was carried out from November 2022 to August 2023, and all patients signed an informed consent.

Sample size was calculated utilizing G power software, with an effect size of 0.910, power (0.80), two-tailed, as well as α of 0.05, and revealed that a sample size of forty individuals, with 20 in each group.

Participants

Forty post-COVID-19 polyneuropathy patients from both genders were recruited from the Neurology Department, Kasr Al-Ainy Hospital, Cairo University, where they were hospitalized as inpatients. Then the study was performed at the physical therapy faculty outpatient clinic, Cairo University. The diagnosis was confirmed by a previous COVID-19 infection, PCR TEST, and nerve conduction study (NCS), and the neurologist referred the patients. The

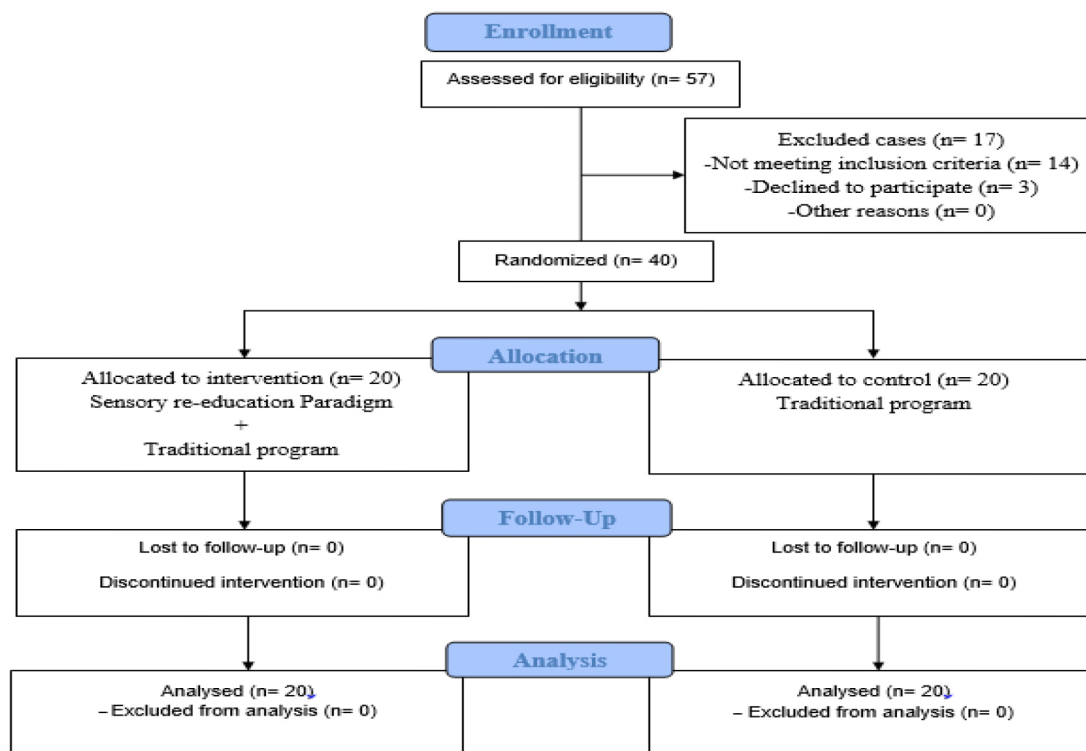


Figure 1. The flowchart of recruiting patients.

patient's age ranged from 30 to 40 years old. Participants predominantly presented with a distal symmetric, sensory-predominant polyneuropathy, characterized clinically by impaired tactile sensation and proprioception, with clinically evident motor weakness on neurological examination, which was considered and measured as hand grip strength in the previously published paper. Nerve conduction studies were used to confirm the diagnosis of polyneuropathy by the neurologist; however, detailed electrophysiological parameters were not uniformly taken from the neurologist and therefore not included in the analysis. Participants were required to live in Egypt during the pre-COVID and COVID-19 pandemic. Patients who met the guidelines of the World Health Organization (WHO) for long/post-COVID-19 syndromes were included. Diabetic patients, Rheumatology, Guillain-Barré syndrome, infection other than COVID-19 leading to sensory neuropathy, other neurological diseases of the central or the peripheral nervous system, and previous surgeries or medications leading to neuropathy were excluded.

The sequence was generated by an independent statistician using Block Randomization Software. To ensure proper allocation concealment, sealed opaque envelopes were used. The randomization process was conducted by the study coordinator, and the recruiters were blinded to group

allocation until after the participant was enrolled. Group (A) was given a designed sensory re-education paradigm as well as the traditional program of physiotherapy, which included proprioceptive neuromuscular facilitation (PNF) and strengthening exercises for wrist extensors, hand grip muscles, and the muscles of thumb opposition. Group (B) was given only the traditional program of physiotherapy. Treatment was carried out for one hour, three sessions per week for six successive weeks. Figure 1 is a flowchart showing the process of enrolling patients.

Instrumentation for assessment

Every patient was assessed at baseline and after treatment by the following:

1) The Arabic version of the World Health Organization Quality of Life Scale Brief Version (WHOQOL-BREF):

It is a self-administered quality of life scale¹⁶. Every participant was instructed to thoroughly read each category of the WHOQOL-BREF in Arabic and then rate their level of satisfaction on a 5-point Likert scale (1 being extremely dissatisfied/very poor to 5 being very satisfied/very good). A 26-item quiz called the WHOQOL-BREF includes domains and aspects (or sub-domains). The "Overall rating of QoL is also well, and subjective contentment with health was both

evaluated in the first two questions. The following 24 items assessed four distinct domains: physical health (7 questions), psychological health (6 items), social interactions (3 items), as well as the environment (8 items)¹⁷. The four domains' raw ratings were transformed into a 0-100 scale, with 100 being the best QOL and 0 the worst. The higher the score is, the higher the living quality¹⁸.

2) Semmes-Weinstein monofilament (SWM):

Five filaments from 0.07 to 300 g were used¹⁹. The evaluation was performed in a quiet environment. The patient was asked to close his eyes during testing. Initially, a monofilament was applied to the patient's forearm to assess understanding and perception of the test. Two locations on the hand (index fingertip and little finger) were tested, with subjects required to identify the exact location where the monofilament was detected. A sensory score of intact was assigned if subjects correctly identified the test location at least two out of three times²⁰. Start with the smaller monofilaments to the larger. The filament was applied and pressed on the skin at a 90° angle until it bent and was maintained for two seconds. The findings were recorded in a color that matches the color of the monofilament handle that was applied. The detection of touch threshold was recorded according to a 1 to 5-point scale, filament (magenta 300g) =1, filament (red 4g) =2, filament (violet 2.0g) =3, filament (blue 0.4g) = 4, and filament (green 0.07g) =5.

3) The laser-pointer assisted angle reproduction test (LP-ART): is a quantitative test used as a clinical procedure to measure an individual's ability to perceive joint position with their vision occluded with minimal external cues²¹. Before testing, the procedure was explained to the patient. The patient was seated on a chair with the forearm supported while the wrist remained free. The chair was positioned along a line drawn on the floor, parallel to and one meter away from the opposite wall. A laser pointer was fixed to the dorsum of the hand. At the beginning of the test, the wrist joint was positioned in neutral (0°), as determined using an inclinometer, and a reference marker was placed on the wall at the point indicated by the laser. Additional markers corresponding to 45° of wrist extension and flexion were then placed in the same manner. The patient was instructed to actively move the wrist from the neutral position and direct the laser pointer toward the 45° target. This procedure was repeated three times with eyes open to allow memorization of the target position. Subsequently, the patient repeated the task three times in a randomized order with eyes closed to eliminate visual feedback. Wrist joint angles were recorded using an inclinometer. The procedure was performed for both wrist extension and flexion. For each trial, the angle reproduction error was calculated as the absolute difference between the target angle (45°) and the reproduced wrist angle. The mean absolute error across the three trials was used for statistical analysis²².

Intervention Protocol

1) The study group (A): Patients received about 30 minutes for the designed paradigm of sensory re-education as well as 30 minutes for a selected program of physiotherapy (Progressed active as well as resisted strengthening exercises for wrist extension, hand grip muscles strengthening exercise, thumb opposition exercise, proprioceptive neuromuscular facilitation (PNF) diagonal 1 Extension in addition to PNF diagonal 2 flexion.), 3 sessions/week, for 6 successive weeks.

2) The control group (B): Patients were treated for one hour per session, only by the selected physical therapy program which included (Graduated active and resisted strengthening exercises for Wrist extension for 10 minutes per session, hand grip muscles strengthening exercise for 10 minutes per session, and Thumb opposition exercise for 10 minutes per session, and PNF diagonal 2 flexion 15 minutes per session and PNF diagonal 1 Extension 15 minutes each session), three times a week for successive 6 weeks.

The sensory reeducation paradigm

Step1. Texture discrimination training:

The patient's upper limb was placed on a stable surface, and subsequently, massage was applied over the palm and fingertips with the same pressure, direction, and speed. Then the light pressure to rub over sensitive areas by materials from cotton, velvet, terry cloth, as well as polyester to wool was used. This procedure was performed while the patients were opening eyes for 2 minutes and also with eyes closed for 2 minutes to inhibit visual control, for a total time of 8 minutes for both hands²³.

Step2. Limb position sense:

A. Passive proprioceptive training: The patient's limb was placed on a stable surface, with the forearm initially in a prone position. Subsequently, passive positioning of the patient's wrist and finger joints was done, encompassing different degrees of extension. The patient was instructed to concentrate on these movements while keeping their eyes open for 4 minutes per session. Following this, the maneuver was repeated to perform flexion of the wrist and fingers, from forearm supination, and the patient's eyes should be open with concentration on the movement for 4 minutes per session²⁴. The total duration of the task was 8 minutes.

B. Joint repositioning training: The patient's limb was positioned on a stable surface, and the wrist joint and fingers were moved passively to reach the desired extension or flexion angle. Concurrently, the patient was instructed to concentrate on these movements while keeping their eyes open to memorize the specific angle. Following this, the wrist joint and fingers were returned to a neutral position, and the patient was instructed to close their eyes. Subsequently, the patient was instructed to reproduce the same angular movement with their eyes closed, without visual feedback.

Table 1. Comparison of subject characteristics between group A and B.

Physical Characteristics	Study group (A) Mean \pm SD	Control group (B) Mean \pm SD	Effect Size (Cohen's D)	t-value	p-value
Age (years)	35.60 \pm 2.82	34.75 \pm 3.02	0.29 (Small)	0.920	0.364
Weight (Kg)	73.25 \pm 6.74	74.40 \pm 5.62	0.19 (Negligible)	-0.586	0.561
Height (cm)	171.35 \pm 8.45	173.00 \pm 6.86	0.21 (Small)	-0.678	0.502
BMI	24.84 \pm 1.84	24.98 \pm 2.09	0.07 (Negligible)	-0.233	0.817
Sex, n (%)					
Female	10 (50%)	7 (35%)		$\chi^2=0.921$	0.337
Male	10 (50%)	13 (65%)			

SD, Standard deviation; t, unpaired t value; χ^2 , Chi-squared value; p value, Level of significance.

The total duration of the task was 8 minutes, with each hand receiving 4 minutes per session²⁵.

Step 3. Tactile object recognition:

The patient underwent specialized training to improve their ability to distinguish between different characteristics, such as shape, size, weight, and hardness, using a range of multidimensional objects. The training involved the patient resting their extremity on a stable surface and practicing catching and returning objects to a box with their eyes open. They were then challenged to identify the same object by touch alone while their eyes were closed. The task was performed for 8 minutes, with 4 minutes allocated to each hand. The objects used were graded from largest to smallest, heaviest to lightest, and most multidimensional to less multidimensional, to gradually enhance the patient's sensory perception and discrimination skills²⁶.

Statistical Analysis

The statistical analysis was performed using IBM SPSS Statistics version 25 for Windows (SPSS Inc., Chicago, IL). The mean as well as the standard deviation were used to represent normally distributed variables (Physical characteristics, and WHOQOL-BREF), while the median as well as the interquartile range were used to represent data that was not normally distributed (SWM scores and LP-ART). The gender ratio of the two groups was compared using the Chi-Square Test. Paired t-test: was utilized for the pairwise comparison of the means in the same group for different times of measurement (pre-and post-treatment) for the normally distributed variables. -An unpaired t-test was utilized to compare the means of the two groups for the normally distributed variables. The Wilcoxon Signed Rank Test was utilized for pairwise comparison of the mean ranks in the same group for different times of measurement (pre-and post-treatment) for the non-normally distributed variables. The Mann-Whitney U test was employed to

compare the mean ranks of the two groups for the non-normally distributed variables. The analysis was conducted using an intention-to-treat (ITT) approach, which included all participants who were originally assigned to the study. Since no data were missing, there was no need to apply any specific methods for handling missing data. A post-hoc power analysis was conducted for the primary outcome (quality of life) utilizing the G*Power 3.1 software (Heinrich Heine University Düsseldorf, located in Düsseldorf, Germany). No formal adjustment for multiple comparisons was applied; therefore, analyses of secondary sensory outcomes should be interpreted as exploratory. All statistical analyses were significant at $P \leq 0.05$.

Results

Demographic characteristics of participants

Table 1 shows that there was no statistically significant difference in demographic data, including age, weight, height, BMI, or gender distribution among the groups.

Scores for WHOQOL-BREF

Table 2 shows the mean \pm SD values for WHOQOL-BREF in both groups.

The Paired t-test (for WHOQOL-BREF, pre-and post-treatment) revealed a significant difference ($P=0.001$, 0.001) in Group A and B, respectively. The effect sizes using Cohen's D formula indicated very large (substantiated) effect sizes of 4.43, 3.07 within Groups A and B, respectively.

When comparing groups A and B using the Unpaired t-test, we found no statistically significant difference in WHOQOL-BREF values before treatment ($P= 0.342$), but we did find a difference after treatment ($P= 0.001$). Between Group A and B (pre-treatment), there was a small-moderate effect size of 0.31. While (post-treatment), there was a very large (substantiated) effect size of 1.21, which confirms the potential effect of adding the sensory

Table 2. Comparison of WHOQOL-BREF mean values within and between both groups.

Scores of WHOQOL-BREF	Group A Mean (SD)	MD and 95%CI Group A	p-value Group A	Group B Mean (SD)	MD and 95%CI Group B	p-value Group B	MD {A vs. B}	p-value {A vs. B}
Pre-Treatment	36.75 (8.36)	-	-	34.24 (8.12)	-	-	2.51	0.342
Post-Treatment	75.77 (9.26)	39.02 (43.56-34.48)	0.001*	63.61 (10.84)	29.37 (33.15- 25.59)	0.001*	12.16	0.001*

*SD, Standard deviation; MD: Mean difference; CI: Confidence interval; *: Significant difference.*

Table 3. Comparison of SWM scores at the 2 points of the right and left hand.

SWM scores of Both hands	Group A Median (IQR)	Mean Rank Group A	p-value Group A	Group B Median (IQR)	Mean Rank Group B	p-value Group B	Effect Size (η^2)	p-value {A vs. B}
Rt Pre-Treatment point 1	3 (0)	19.55	-	3 (0)	21.45	-	0.02 (Small)	0.323
Rt Post-Treatment point 1	3.5 (1)	21.50	0.001*	3 (1)	19.50	0.005*	0.01 (Small)	0.530
Rt Pre-Treatment point 2	3 (1)	19.45	-	3 (0)	21.55	-	0.02 (Small)	0.414
Rt Post-Treatment point 2	4 (1)	19.20	0.001*	4 (1)	21.80	0.008*	0.04 (Small)	0.212
Lt Pre-Treatment point 1	3 (0)	19.55	-	3 (0)	21.45	-	0.02 (Small)	0.323
Lt Post-Treatment point 1	4 (1)	22.00	0.001*	3 (1)	19.00	0.005*	0.02 (Small)	0.348
Lt Pre-Treatment point 2	3 (0)	20.55	-	3 (0)	20.45	-	0.00 (Small)	0.971
Lt Post-Treatment point 2	4 (1)	22.18	0.001*	3.5 (1)	18.83	0.002*	0.03 (Small)	0.294

*Rt, Right; Lt: Left; IQR, Interquartile range; *: Significant difference; p value, Level of significance.*

re-education paradigm to the traditional physiotherapy program on the quality of life in patients with post-COVID-19 polyneuropathy. The post hoc power analysis using the very large effect size of 1.21, a two-tailed alpha level of 0.05, and a total sample size of 40 patients (20 for each group) indicated an achieved power of 96%. This very high achieved power means that there is only a 4% chance of a false negative (Type II error).

Scores for the 2 points of Semmes Weinstein Monofilament (SWM) in the right and left hands

- The Right-hand:

Table 3 shows the median and IQR values for the 2 points of SWM of the right hand in both groups. The Wilcoxon Signed Rank Test (pre-and post-treatment) revealed significant differences between scores of SWM for point 1

Table 4. Comparison of wrist angle reproduction error (LP-ART) at 45° extension and flexion in both hands.

LP-ART of Both Hands Wrist Extension/Flexion	Group A Median (IQR)	Mean Rank Group A	p-value Group A	Group B Median (IQR)	Mean Rank Group B	p-value Group B	Effect size (η^2)	p-value {A vs. B}
Rt LP-ART at 45° Wrist Extension Pre-Treatment	7.6 (10.7)	17.9	-	12.6 (5.4)	23.1	-	0.05 (Small)	0.174
Rt LP-ART at 45° Wrist Extension Post-Treatment	3.5 (10.5)	15.8	0.001*	9.5 (7.3)	25.2	0.001*	0.17 (Large)	0.010*
Lt LP-ART at 45° Wrist Extension Pre-Treatment	9.6 (5.1)	17.3	-	12.8 (4.3)	23.7	-	0.08 (Medium)	0.086
Lt LP-ART at 45° Wrist Extension Post-Treatment	3.6 (7.0)	16.2	0.001*	8.9 (7.9)	24.8	0.001*	0.14 (Large)	0.020*
Rt LP-ART at 45° Wrist Flexion Pre-Treatment	12.4 (5.7)	19.5	-	12.9 (4.4)	21.5	-	0.01 (Small)	0.598
Rt LP-ART at 45° Wrist Flexion Post-Treatment	3.7 (8.8)	15.5	0.001*	9.9 (6.5)	25.5	0.006*	0.19 (Large)	0.007*
Lt LP-ART at 45° Wrist Flexion Pre-Treatment	10.3 (10.1)	18.2	-	12.3 (6.7)	22.8	-	0.04 (Small)	0.213
Lt LP-ART at 45° Wrist Flexion Post-Treatment	3.7 (8.4)	16.8	0.001*	8.0 (6.1)	24.2	0.009*	0.10 (Medium)	0.047*

*Rt, Right; Lt, Left; IQR, Interquartile range; η^2 : eta squared for measured effect sizes of non-normally distributed variables; *: Significant difference; p value, Level of significance.*

and point 2 in Group A ($P=0.001$ and 0.001), respectively. Additionally, there were significant differences in scores of SWM for points 1 and 2 in group B ($P=0.005$ and 0.008 , respectively). Comparison between groups regarding the right hand revealed non-significant differences in Pre-Treatment point 1 ($P=0.323$), post-treatment point 1 ($P=0.530$), Pre-Treatment point 2 ($P=0.414$), and post-Treatment point 2 ($P=0.212$).

- The Left-hand:

Table 3 shows the median and IQR values for the 2 points of SWM in both groups. The Wilcoxon Signed Rank Test (for the left hand, pre-and post-treatment) revealed significant differences between scores of SWM for the 2 points ($P=0.001$ and 0.001), respectively, in group A. Also, there were significant differences among scores of SWM for the 2 points ($P=0.005$ and 0.002), respectively, in Group B. The Comparisons between groups for the left hand revealed non-significant differences in Pre-Treatment point 1 ($P=0.323$), post-treatment point 1 ($P=0.348$), Pre-Treatment point 2 ($P=0.971$), and post-Treatment point 2 ($P=0.294$).

Pre-treatment and post-treatment comparisons between Group A and Group B showed very small to small effect sizes across all variables ($\eta^2 \approx 0.00-0.04$). This confirms the non-significant effect of adding the sensory re-education paradigm to the traditional physiotherapy program on tactile sensation in patients with post-COVID-19 polyneuropathy.

(LP-ART) test for proprioception of wrist extension of the right and left hands

- Angle reproduction for wrist extension:

Table 4 shows the median and IQR values of the error in the angle reproduction test by LP-ART before as well as after treatment in both groups.

The Wilcoxon Signed Rank Test for the right-hand error in angle reproduction of wrist extension: pre-and post-treatment revealed significant differences between LP-ART for 45° ($P=0.001$ and 0.001) within groups A and B, respectively. Also, for the left-hand, the error in angle reproduction of wrist extension: pre-and post-treatment, it revealed significant differences between LP-ART at 45° ($P=0.001$, and 0.001) in groups A and B, respectively (Table 4).

The Mann-Whitney U Test for the right-hand error in angle reproduction of wrist extension revealed a non-significant difference between groups A and B in Pre-Treatment ($P=0.174$). Nevertheless, after treatment, there was a statistically significant difference in 45° wrist extension between the two groups ($P=0.010$). There was no statistically significant difference in left wrist extension among the two groups before treatment ($P=0.086$), but there was after treatment ($P=0.020$).

- Angle reproduction for wrist flexion:

Table 4 shows the median and IQR values of the error in the angle reproduction test by LP-ART before and after

treatment in both groups for the right-hand wrist flexion.

The Wilcoxon Signed Rank Test, for error in angle reproduction of wrist flexion for the right-hand: pre-and post-treatment showed a significant difference ($P=0.001$ and 0.006) within groups A and B, respectively. Also, for the error in the angle reproduction test for wrist flexion of the left-hand: pre-and post-treatment, it revealed significant differences ($P=0.001$ and 0.009) within groups A and B, respectively (Table 4).

Comparing groups A and B using the Mann-Whitney U test, we found no statistically significant difference before treatment ($P=0.598$), but there was a significant difference after treatment ($P=0.007$). The pre-treatment difference among Group A as well as Group B in left-hand wrist flexion was not statistically significant ($P=0.213$), but it became statistically significant ($P=0.047$) after treatment. Pre-treatment comparisons between Group A and Group B showed very small to small effect sizes across all variables ($\eta^2 \approx 0.01-0.05$), indicating good baseline comparability between groups. On the other side, post-treatment comparisons between Group A and Group B demonstrated notably larger effects, ranging from medium to large across all variables ($\eta^2 \approx 0.10-0.19$), favoring the potential effect of adding the sensory re-education paradigm to the traditional physiotherapy program on proprioception (deep sensation) in patients with post-COVID-19 polyneuropathy.

Discussion

The present study demonstrates that sensory re-education combined with traditional physiotherapy enhances quality of life and proprioceptive acuity in individuals recovering from long COVID; however, it does not confer additional benefits in tactile threshold improvement compared with traditional physiotherapy alone.

The primary outcome of the present study, assessed using the Arabic version of the WHOQOL-BREF, demonstrated statistically significant differences between Groups A and B. The observed improvement in quality of life among patients with post-COVID-19 polyneuropathy may be attributed to enhanced hand proprioceptive and sensory feedback, which facilitates improved perception, interpretation, and functional use of sensory input. Consequently, tasks such as dressing, grooming, and object manipulation can be performed more effectively, promoting greater independence and self-reliance and ultimately enhancing overall quality of life. These findings are consistent with those of Verma et al. (2017)²⁷, who reported a moderate correlation between quality of life and hand functional ability. Furthermore, our results align with the systematic review by Costa-López et al. (2021)²⁸, which highlighted a strong association between improvements in enhanced quality of life and hand sensation.

The results demonstrated statistically significant pre-post improvements in SWM scores for both hands in Groups A and B. However, there were no statistically significant

changes between Groups A and B in pre- or post-treatment comparisons. Accordingly, the addition of sensory re-education to the standard physical therapy program did not result in superior improvement in tactile sensation compared with conventional physical therapy alone. This finding may be explained by the relatively short intervention duration, as the effectiveness of sensory re-education is known to depend on sufficient time for sensory learning and cortical reorganization. This came in accordance with findings of Yousuf et al., (2020)²⁹, who indicated that successful somatosensory rehabilitation, particularly sensory re-learning, necessitates regular and frequent practice in tasks involving tactile discrimination. Also, our research findings agree with the findings of the systematic review of Manoli et al., (2016)³⁰, which suggested that sensory re-education is effective in improving sensory function after peripheral nerve injuries in the upper limb.

Moreover, the absence of superior effectiveness of sensory re-education in tactile sensation compared to traditional physical therapy in our study agreed with the findings of the systematic review of Quintal et al., (2021)³¹. Their review suggested that regardless of the technique employed for sensory re-education, tactile stimulation should be administered between 1 to 12 times per day for approximately 10 minutes, and adjustments should be made according to the patient's reaction, such as tolerable symptoms or absence of increased pain. Additionally, the systematic review concluded that further high-quality studies with rigorous methodology are necessary to create optimal practices for tactile stimulation programs utilized to address hand dysesthesia.

In our study, the absence of a significant post-treatment improvement in tactile sensation between patients receiving the sensory re-education paradigm and those undergoing traditional physical therapy disagrees with the findings of Mohamed et al. (2022)³². In their study, sensory re-education was shown to be effective and superior to standard physical therapy in improving both tactile sensation and postural stability among patients with chemotherapy-induced peripheral neuropathy (CIPN). This disagreement may be explained by differences in participant characteristics (post-COVID-19 polyneuropathy vs. post CIPN), sensory re-education protocols (texture discrimination training and tactile object recognition vs. sensory cuing therapy through vision and auditory), and measurement location (hands vs. feet), all of which may influence the magnitude and detectability of sensory improvements.

In the current study, there were statistically significant differences in scores of the angle reproduction error LP-ART test for wrist flexion as well as extension in each group (A and B) for both right and left hands. These findings verified the efficacy of sensory re-education in enhancing the proprioceptive sense of the wrist joint in patients with polyneuropathy. That agreed with the systematic review of Winter et al., (2022)³³, who reported that progressive rehabilitation methods, including sensory relearning, along

with a combination of passive and active movements with or without external feedback, yielded the most advantageous outcomes.

The limitations of this study are: First, the study was carried out on a small sample size, the applied model only lasted for a short time, and the single-center design. Second, outcome assessors were not blinded to group allocation, which could have introduced detection bias, particularly in the assessments of tactile sensation (SWM) and proprioception (LP-ART). This lack of blinding may have influenced the results, and future studies should implement blinding for the outcome assessors to minimize potential bias. Third, the inclusion of participants aged 30–40 years was intentional to reduce age-related variability in quality of life measures and sensory function and to enhance sample homogeneity. Restricting recruitment to individuals residing in Egypt during the pandemic was necessary due to logistical constraints and uniformity of healthcare access and COVID-19 management protocols during the study period. These criteria limit the generalizability of the findings to other age groups, regions, and healthcare settings. Fourth, Sensory assessment of the upper limbs does not capture the full spectrum of length-dependent neuropathic involvement, particularly in the lower extremities. Therefore, we recommend that future studies include lower-limb sensory assessments and functional outcomes, such as gait and balance, to provide a more comprehensive evaluation. However, a key strength of this study is its novel evaluation of quality of life in addition to sensory outcomes following sensory re-education in post-COVID-19 polyneuropathy, with additional assessment of the multidimensional aspects of the condition after COVID-19 infection.

Conclusions

It can be concluded that adding a sensory re-education paradigm to the traditional physical therapy program is beneficial for improving the quality of life and proprioceptive sense in patients with post-COVID-19 polyneuropathy. However, the sensory re-education paradigm did not demonstrate a significantly greater effect than traditional physical therapy alone in improving tactile sensation. Larger studies with increased sample sizes are encouraged to confirm these findings.

Ethics approval

The study was approved by the Institutional Review Board, the Research Ethical Committee of the Faculty of Physical Therapy, Cairo University (approval no. P.T.REC/012/004416) and was conducted in accordance with the Declaration of Helsinki (1964) and its later amendments.

Consent to participate

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

Consent to publish

Written informed consent has been obtained from the patients to publish this paper.

Authors' Contributions

Conceptualization, H. M.A. and Y.A.K.; methodology, Y.A.K and F.A.K.; software, E.M.F. and R.S.M; validation, W.M.R., A.A.D. and E.M.F.; formal analysis, M.G.A.; investigation, H.M.A. and Y.A.K.; resources, A.S.A.K.; data curation, F.A.K.; writing—original draft preparation, Y.A.K.; writing—review and editing, H.M.A., R.S.M and M.G.A.; visualization, W.M.R., A.A.D; supervision, H.M.Z.; project administration, H.M.Z.; funding acquisition, A. S.A.K. All authors have read and approved the final version of the manuscript.

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