Journal of Hand Therapy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Hand Therapy

journal homepage: www.elsevier.com/locate/jht

Research Paper

Is early graded motor imagery training effective after upper extremity peripheral nerve injury? A randomized controlled preliminary study

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A R T I C L E I N F O

Article history:
Received 24 December 2024
Revised 4 August 2025
Accepted 24 September 2025
Available online xxxx

Keywords:
Peripheral nerve injuries
Graded motor imagery
Physiotherapy and rehabilitation
Function
Kinesiophobia

A B S T R A C T

Background: Peripheral nerve injuries (PNI) result in pain and functional impairments, significantly affecting quality of life. Early rehabilitation is essential, and graded motor imagery (GMI) has demonstrated potential in improving recovery outcomes.
Purpose: The aim of the study was to determine the effect of GMI training in addition to the Physiotherapy and Rehabilitation (PTR) program in PNI.
Study Design: Randomized controlled trial.
Methods: Pain levels were assessed by Visual Analog Scale, range of motion by goniometer, hand grip strength by Jamar Dynamometer, and pinch grip strength by pinch meter. The Disabilities of the Arm, Shoulder, and Hand, and the Michigan Hand Outcome Questionnaire were used. Kinesiophobia was evaluated with the Tampa Kinesiophobia Scale.
Results: A total of 20 participants (4 F, 16 M) were followed up for 6 weeks. Group-I (n = 10) received GMI training in addition to the PTR program and Group-II (n = 10) received only the PTR program. Both groups were similar in all parameters before treatment ($p > 0.05$). After treatment, GMI training was more effective on functionality ($p = 0.029$), appearance perception ($p = 0.003$), and kinesiophobia level ($p = 0.050$).
Conclusions: GMI training can be added to PTR programs in PNI.

Introduction

Peripheral nerve injuries (PNI) cause pain, sensory impairment, and motor loss depending on the size and severity of the lesion and negatively affect the individual's quality of life. Early surgical intervention and rehabilitation process after injury are of great importance in regaining the functional level of the upper extremity (UE).[1] The main goals of rehabilitation in PNI include maintaining joint mobility and contractile properties, preventing muscle overtension, atrophy, and deformity formation, while gaining control over unaffected muscles.[2]

PNI can often cause sensorimotor deficits, pain, loss of function, and kinesiophobia. Traditional physiotherapy and rehabilitation (PTR) methods used for PNI include exercises, electrophysical agents, manual therapies, orthotics, and sensory therapies. Therefore, evaluating patients, determining the rehabilitation plan, and guiding the treatment process are very important.[3]

Motor imagery (MI) is the mental interpretation of movement without eliciting actual movement. Thinking about movement is predicted to fire similar motor areas to eliciting movement. The neurophysiological characteristic is similar for other types of learning acquired through repetition of movement by thinking about it. In the neurophysiological aspect, learning by doing a movement is not different from learning by imagery.[4] In graded motor imagery (GMI), it is aimed to provide the individual with the normal cortical neuronal activation patterns necessary for normal movement in a progressive manner.[5] The first stage includes laterality training, the second stage includes MI, and the third stage includes mirror therapy. GMI training is used to relieve chronic pain and improve motor functions in the treatment of secondary musculoskeletal pain.[6,7] This study aimed to examine the effect of GMI training, applied as an adjunct to the PTR program, on UE functions in individuals with PNI.

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0894-1130/
https://doi.org/10.1016/j.jht.2025.09.010

Materials and methods

The study was conducted between March 2023 and June 2024 at Biruni University, Physiotherapy and Rehabilitation Department. The study was approved by the Bezmiâlem Vakıf University Clinical Research Ethics Committee (04.04.2023/E.102918) and was conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from all participants before starting the study.

Participants aged 18-65 years who were diagnosed with flexor tendon injury in any zone and median and/or ulnar nerve injury, were native Turkish speakers, and possessed the cognitive ability to comprehend written and verbal instructions in Turkish were included in the study. Participants with extensor tendon and radial nerve injuries, fractures in the UE, bilateral injuries, and malignant conditions were excluded.

Participants were assigned to either the intervention group (PTR + GMI) or the control group (PTR only) using simple randomization. A list of random numbers was generated through the online tool *Research Randomizer* (www.randomizer.org), and participants were allocated sequentially based on their enrollment order. Pre-treatment assessments were completed in the 6th week following surgery. After the assessments, the groups received sessions consisting of 45 minutes each, 2 days a week for 6 weeks. Post-treatment assessments were performed at the 12th week following surgery (Fig. 1).

Outcome measures

The sociodemographic and clinical characteristics of the participants were recorded in the Case Report Form prepared by the researchers.

Primary outcome

Disabilities of the Arm, Shoulder, and Hand (DASH)

It is a self-assessment outcome measurement questionnaire that measures physical disabilities and symptoms in all UE disorders. It consists of a total of 30 questions. The total score of the questionnaire varies between 0 and 100 points, with a low score indicating high function.[8]

Secondary outcomes

Visual Analog Scale (VAS)

The pain levels of the participants were questioned with Visual Analog Scale (VAS). The participants were asked to rate their pain intensity by marking on a 10-cm line (0: no pain, 10: very severe

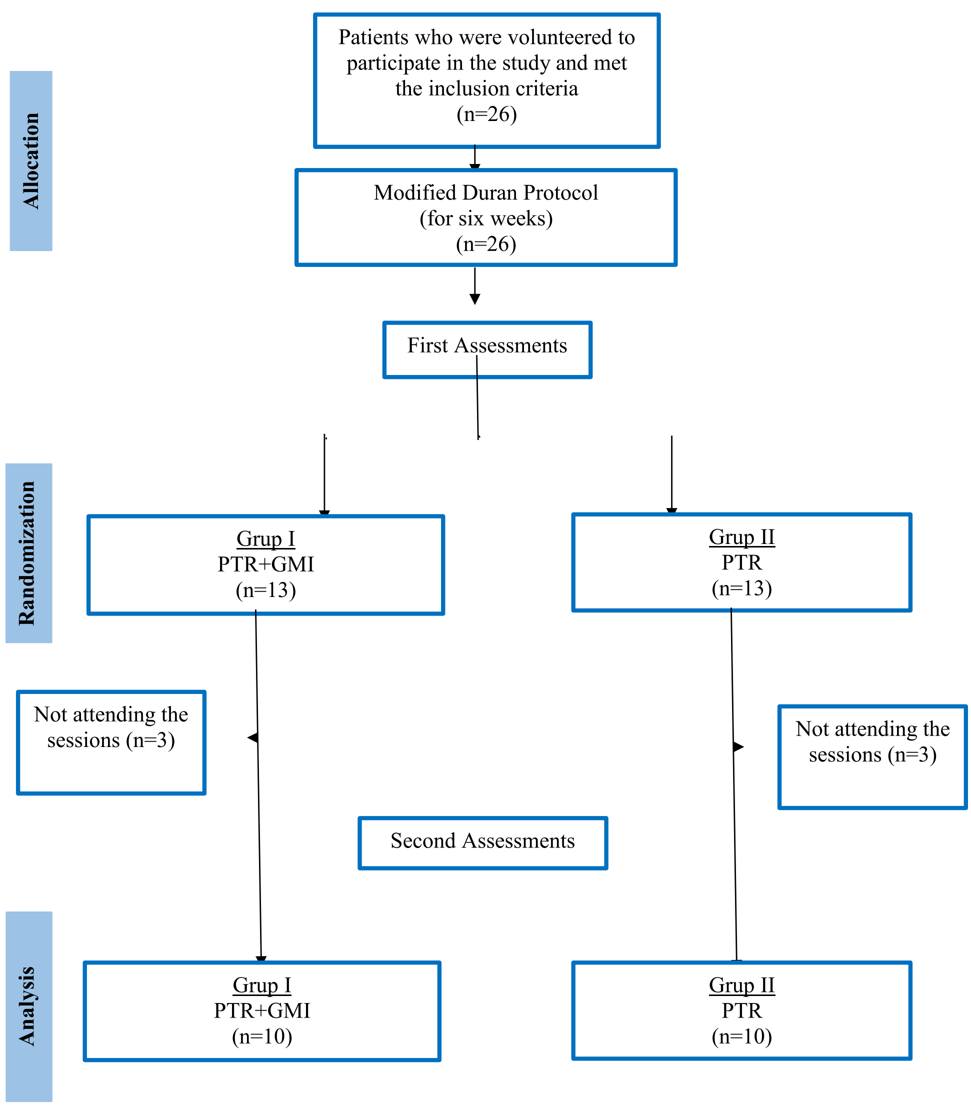

Fig. 1. Flowchart. PTR = physiotherapy and rehabilitation; GMI = graded motor imagery.

pain). Pain intensity was assessed separately as rest, activity, and night.[9]

Range-of-motion measurements

The assessment of the hand and wrist range-of-motion (ROM) of the participants was performed with a universal goniometer. In a comfortable sitting position, the ROM measurements of the active fingers (total active motion) and wrists (flexion/extension) were repeated three times and the best measurement value was recorded.[10]

Gross grip strength

The hand grip strength measurement of the participants was evaluated using the Jamar Hand Dynamometer. Measurements were taken with the individual in a sitting position with the shoulder adducted, the elbow at 90° flexion, and the forearm in a neutral position, and they were asked to clench their fists with the highest possible force. Measurements were made in three repetitions and the average of the repetitions was recorded in kilograms. A 1-minute rest period was given between repetitions.[11]

Fine grip strength

Fine grip strength of the participants was assessed with Jamar pinch meter. The participants sat on a examination table with knees flexed at 90° and trunks straight. With arms at 0° adduction, elbows at 90° flexion, and wrists in neutral position, the participants were asked to squeeze the dynamometer between their thumbs and index fingers with the highest possible force. Three repetitions were performed for pinch, lateral, and triple grip, and the average values were recorded in kilograms. A 1-minute rest period was given between repetitions.[12,13]

Initially, participants were instructed on the ROM measurements, as well as gross and fine grip strength assessments, using the healthy extremity. Subsequently, the injured extremity was evaluated.

Michigan Hand Outcomes Questionnaire (MHQ)

It is a hand-specific outcome measurement questionnaire consisting of six sections and 57 items. Each item is scored from 1-5. Each section is scored from 0-100, with 0 representing the worst and 100 representing the best score in each section, except pain.[14,15]

Tampa Scale for Kinesiophobia (TSK)

A 17-item scale measures the level of an individual's kinesiophobia thoughts and behaviors. Each item on the scale, which focuses on fear or anxiety during a particular activity, is scored from 1 to 4. A high score indicates a high level of kinesiophobia.[16,17]

All outcome measures were assessed at both the 6th and 12th postoperative weeks, except for grip strength, which was evaluated only at the 12th week.

Interventions

The participants with flexor tendon and nerve injuries were followed up with the Modified Duran protocol in the first 6 weeks. According to this protocol, the orthosis with the wrist in 20° flexion, the metacarpophalangeal joint in 40°-50° flexion, and the interphalangeal joints in full extension was used for 5 weeks. The participants were given passive flexion and active extension exercises for the proximal Interphalangeal and distal Interphalangeal joints and passive composite flexion and active composite extension exercises in the dorsal orthosis for 10 repetitions every 2 hours for 4-5 weeks. Afterward, active movements and blocking exercises for the fingers were started. Partial movement was started in the fifth week and the orthosis was used only at night. Friction massage and contrast bath were recommended for edema control and adhesion reduction. They were allowed to return to simple daily living activities in the sixth week.[18]

The participants with isolated nerve injuries were followed by 2 weeks of complete immobilization using an orthosis with the wrist in 30° flexion and the thumb in abduction. After the stitches were removed in the second week, edema control, friction for scar tissue mobilization, and active and passive flexion/extension exercises were performed on the fingers. Starting in the third week, the use of the orthosis was discontinued, and active wrist flexion/extension exercises were added to the program in addition to other exercises.

All participants who completed their initial assessments in the sixth week were randomized into two groups as GMI training in addition to the PTR program (Group-I) or the PTR program alone (Group-II) (Supplementary Material 1). Both groups participated in a total of 12 sessions of 45 minutes, 2 days a week for 6 weeks. The study was completed with final assessments at the 12th week after surgery.

All assessments and interventions were conducted by the same physiotherapist.

Statistical analysis

The data in the study were analyzed using IBM SPSS Statistics for Windows, Version 23.0 (IBM Corp., Armonk, NY). Descriptive statistics were given as the mean, standard deviation, and percentage (%). The Shapiro-Wilks test was used to examine the normality of the data. Since the data were not normally distributed, the Wilcoxon signed-rank test and the Mann-Whitney U test were used for intragroup and inter-group comparisons, respectively. The statistical significance level was accepted as $p \leq 0.05$.

Results

This study recruited a convenience sample of 20 participants over a defined period. Due to the time-based recruitment design, an a priori power analysis was not conducted. Therefore, at the end of the study, a post hoc power analysis was performed based on the primary outcome variable, the Disabilities of the Arm, Shoulder, and Hand (DASH) score. With an assumed effect size of 0.7 and an alpha-level of 0.05, the post hoc power of the study was calculated to be 0.67.

The sociodemographic and clinical characteristics of the groups are given in Table 1. All participants were found to have injuries located in Zone 5, and the groups were similar in terms of age, gender, education level, dominant side, and affected side ($p > 0.05$).

The comparison of the results of the groups at the 6th week and the 12th week within and between groups is given in Table 2. The groups were similar to each other according to all evaluation results at the sixth week ($p > 0.05$). According to the results of the 12th week between groups, wrist extension degree ($p = 0.025$) was found to be statistically significant in favor of Group-II; Michigan Hand Outcomes Questionnaire (MHQ)-Total score ($p = 0.029$), MHQ-Aesthetics score ($p = 0.003$), and Tampa Scale for Kinesiophobia (TSK) score ($p = 0.050$) were found to be statistically significant in favor of Group-I.

Discussion

In this study, we found that a group that received GMI training in addition to PTR demonstrated superior outcomes in pain control, functionality, appearance, and kinesiophobia. However, patient satisfaction was found to be higher in the group that received the PTR program alone. To ensure the reliability of our results, it was important that the participants' injured structures were similar. Furthermore, both groups contained an equally low number of participants with isolated nerve injuries.

Table 1
Sociodemographic and clinical characteristics

		Group-I (PTR + GMI) (*n* = 10)	Group-II (PTR) (*n* = 10)		
		n (%)	*n* (%)	Z	*p*[*]
Age		31.6 ± 13.5	36.3 ± 12.1	−1.060	0.854
Gender	Men	9 (90.0)	7 (70.0)	−1.090	
	Women	1 (10.0)	3 (30.0)		0.582
Education level	Primary	4 (40.0)	4 (40.0)	0.00	
	High school	5 (50.0)	5 (50.0)		1.000
	University	1 (10.0)	0 (0.0)		
	Illiterate	0 (0.0)	1 (10.0)		
Dominance	Right	8 (80.0)	6 (60.0)	−0.951	
	Left	2 (20.0)	4 (40.0)		0.628
Affected side	Right	6 (60.0)	8 (80.0)	−0.951	
	Left	4 (40.0)	2 (20.0)		0.628
Repaired nerve and tendon	Median nerve	3 (30.0)	2 (20.0)		
	Median nerve + FDS	1 (10.0)	0 (0.0)		
	Median nerve + FDP	1 (10.0)	0 (0.0)		
	Median nerve + FPL	0 (0.0)	1 (10.0)		
	Median nerve + FDS + FDP	1 (10.0)	1 (10.0)		
	Median nerve + FDS + FCR	1 (10.0)	0 (0.0)		
	Median nerve + ulnar nerve	0 (0.0)	1 (10.0)		
	Median nerve + ulnar nerve + FDS + FDP + FCR	1 (10.0)	0 (0.0)		
	Ulnar nerve + FDS	0 (0.0)	1 (10.0)		
	Ulnar nerve + FDP	2 (20.0)	0 (0.0)		
	Ulnar nerve + FPL	0 (0.0)	1 (10.0)		
	Ulnar nerve + FDS + FDP	0 (0.0)	2 (20.0)		
	Ulnar nerve + FDS + FDP + FCU	1 (10.0)	0 (0.0)		
Zone of injury	Zone 5	10 (100)	10 (100)		

PTR = physiotherapy and rehabilitation; GMI = graded motor imagery; FDS = flexor digitorum superficialis; FDP = flexor digitorum profundus; FCR = flexor carpi radialis; FPL = flexor pollicis longus; FCU = flexor carpi ulnaris.
[*] Mann-Whitney U test.

Table 2
Comparisons of groups at 6th and 12th weeks

	Group-I (PTR+GMI) (*n* = 10)			Group-II (PTR) (*n* = 10)			Between groups		
	6th week Mean ± SD	12th week Mean ± SD	*p*[*]	6th week Mean ± SD	12th week Mean ± SD	*p*[*]	Z	6th week *p*[†]	12th week *p*[†]
VAS-Rest	2.5 ± 2.0	0.50 ± 1.6	*0.002*	2.6 ± 2.3	0.80 ± 1.1	0.060	−0.156	0.971	0.353
VAS-Activity	4.3 ± 2.2	2.3 ± 2.4	*0.008*	3.8 ± 3.3	2.0 ± 1.8	0.236	−0.144	0.651	0.853
VAS-Night	1.4 ± 2.11	0.90 ± 1.7	0.589	2.6 ± 3.6	0.30 ± 0.67	0.076	−1.201	0.529	0.631
ROM-Wrist flexion (degree)	64.0 ± 19.4	73.3 ± 7.4	*0.030*	62.1 ± 21.4	74.2 ± 7.2	*0.006*	−0.582	1.000	0.596
ROM-Wrist extension (degree)	28.9 ± 28.9	41.3 ± 41.3	*0.009*	44.8 ± 21.2	56.0 ± 11.5	*0.008*	−1.841	0.324	*0.025*
ROM-Fingers—total active motion	162.9 ± 71.5	229.6 ± 33.8	*0.008*	158.6 ± 48.4	218.0 ± 21.5	*0.007*	−0.038	0.739	0.684
Gross grip strength (kg)	NA	23.9 ± 13.5	NC	NA	31.0 ± 18.5	NC	−0.937	NC	0.481
Pinch grip strength (kg)	NA	4.2 ± 2.8	NC	NA	7.2 ± 4.11	NC	−0.038	NC	0.089
Lateral grip strength (kg)	NA	5.8 ± 2.9	NC	NA	9.5 ± 5.8	NC	−1.097	NC	0.165
Triple grip strength (kg)	NA	4.4 ± 3.0	NC	NA	7.5 ± 3.7	NC	−1.097	NC	0.105
DASH-FS	56.0 ± 22.5	29.3 ± 17.6	*0.003*	63.0 ± 27.4	44.9 ± 26.4	*0.001*	−0.303	0.579	0.143
DASH-W	70.6 ± 39.4	33.1 ± 30.8	*0.005*	50.6 ± 41.3	51.9 ± 29.0	0.091	−2.244	0.353	0.190
DASH-SM	36.3 ± 46.1	11.9 ± 24.0	*0.050*	51.9 ± 45.0	21.9 ± 40.3	0.096	−0.313	0.529	0.853
MHQ-Total	40.8 ± 12.9	59.9 ± 6.9	*0.005*	47.8 ± 10.6	55.7 ± 11.1	*0.014*	−1.971	0.204	*0.029*
MHQ-Function	42.0 ± 29.5	62.0 ± 14.9	*0.028*	47.0 ± 21.8	59.0 ± 22.9	0.231	−0.380	0.671	0.739
MHQ-Daily living	40.5 ± 26.6	75.0 ± 16.6	*0.005*	48.7 ± 17.3	71.0 ± 22.5	*0.047*	−0.832	0.426	0.436
MHQ-Work	48.5 ± 35.4	55.9 ± 30.4	0.499	49.0 ± 22.5	38.0 ± 27.3	0.373	−0.569	0.970	0.579
MHQ-Pain	25.5 ± 19.6	27.5 ± 23.1	0.833	42.3 ± 21.0	38.5 ± 25.6	0.779	−0.342	0.081	0.739
MHQ-Aesthetics	39.0 ± 18.9	74.8 ± 14.4	*0.007*	58.1 ± 25.6	59.0 ± 21.9	0.528	−2.845	0.075	*0.003*
MHQ-Satisfaction	49.3 ± 32.7	64.3 ± 20.5	0.202	41.5 ± 30.0	68.5 ± 30.9	*0.008*	−0.530	0.585	0.631
TSK	38.2 ± 11.6	34.1 ± 11.0	0.387	38.1 ± 9.9	42.5 ± 7.0	0.097	−1.552	0.971	*0.050*

PTR = physiotherapy and rehabilitation; GMI = graded motor imagery; VAS = Visual Analog Scale; DASH = Disabilities of the Arm, Shoulder, and Hand; FS = function, symptoms; W = work; SM = sport, music; MHQ = Michigan Hand Outcomes Questionnaire; TSK = Tampa Scale for Kinesiophobia; kg = kilogram; NA = not assessed; NC = not calculated; SD = standard deviation.
Italic value indicates $p \le 0.05$.
[*] Wilcoxon signed-rank test.
[†] Mann-Whitney U test.

In studies examining the effects of MI and GMI training on hand function in the literature, Lu et al suggest that one of the reasons for insufficient recovery in hand function after injury is changes in brain plasticity. In their study examining the activation of the motor area in the brain during MI after brachial plexus injury, they emphasized that MI is clinically important and applicable to understanding the relationship between brain and hand function after injury and developing rehabilitation strategies.[19] For this reason, we applied GMI training to improve UE function in patients with PNI.

Post-PNI pain can occur within months following repair and can negatively affect UE function and the healing process. Therefore, assessment and management of pain after PNI are the keys to treatment success. Various methods are used for the assessment of pain in PNI. Among these methods, the most practically used method in the clinic is defined as VAS.[9] In our study, VAS was used to assess pain, and no difficulty was encountered during the assessment.

In the literature, there are studies examining the effect of GMI training on pain in different clinical situations. Moseley examined the effects of GMI training on phantom pain and function in patients with brachial plexus injury, and amputees, and reported that when GMI training was used in combination with physiotherapy, it reduced pain and functional limitations in patients with phantom pain.[20] In another study, it was reported that pain was affected by changes in the brain in women with pain syndrome after distal radius fractures, and GMI training applied in addition to physiotherapy to treat pain and motor dysfunctions in fractures followed by immobilization was effective in improving the pain sensation of the affected extremity.[21] Consistent with the literature, our findings indicate that GMI training, when added to the PTR program, was effective in reducing pain both during activity and at rest. We attribute this reduction to the motor imagery component of GMI, which activates cortical motor areas and facilitates a painless movement experience. Although the group receiving only the PTR program also showed a decrease in mean pain scores, this change was not statistically significant. While there was no statistically significant difference between the groups regarding pain outcomes, the significant improvement within the GMI group suggests that both treatment programs were beneficial for pain management.

In the literature, there are studies examining the effects of GMI training on ROM gain in UE rehabilitation. In a meta-analysis, it was stated that imagery can be effective in relieving pain and improving range of motion in chronic musculoskeletal problems.[22] Birinci et al reported that GMI training applied as a motor-cognitive intervention program was effective in increasing elbow ROM and reducing pain in elbow ROM limitation after trauma.[23] In PNI, restoration of ROM is important for nerve recovery and muscle function.[24] In our study, patients with both nerve and flexor tendon injuries followed the Modified Duran protocol for the first six weeks post-surgery. Beginning in the sixth week, both groups initiated progressive exercises to increase ROM as outlined in our PTR program. Although both groups demonstrated improvements in ROM, no significant difference was found between the treatments for wrist flexion or active finger motion gains. The only exception was wrist extension, where the PTR program alone showed superior results. We attribute this general similarity in most ROM gains to the natural, ongoing recovery process of the patients, which may have been the dominant factor during this phase.

The evaluation of grip strength after PNI plays an important role in the treatment process. In a study, it was reported that hand functions were related to grip strength in PNI.[25] Evaluation of grip strength helps to create a treatment plan by providing detailed and accurate follow-up of the injury and hand functions.[26] Following the literature, Jamar Hand Dynamometer was used to evaluate gross motor grip strength, and a pinch meter was used to evaluate fine motor grip strength in our study. Since these devices were easy to use in clinical conditions and the commands given to the patient during the evaluation were simple and understandable, no negative situation was experienced. Kablanoğlu et al compared the effects of a 6-week physiotherapy program and mirror therapy applied in addition to the physiotherapy program on sensation, pain, and functionality in patients with PNI. After the treatment, the groups were evaluated with the Jamar Hand Dynamometer and were not found to be superior to each other in terms of gross motor grip strength.[27] In our study, grip strength was not measured at the sixth week to protect the surgical repair during the early postoperative period. At the 12-week follow-up, although no statistically significant difference was found between the groups, the mean grip strength was higher in the group that received the PTR program alone. This finding can likely be attributed to the nature of GMI, which is not a strength-focused intervention. Instead, its therapeutic effect is thought to stem from re-establishing the perception of painless movement to improve function, rather than directly increasing muscle force.

The evaluation of UE functionality is important in physiotherapy programs for hand injuries. In studies, it is recommended that hand function measurements should be performed with simple, reproducible, and objective methods in patients with nerve injury. The use of functional tests plays a key role in managing the treatment process of patients and determining rehabilitation programs.[28] Approximately 96% of individuals with tendon injuries report persistent functional limitations in daily activities even in the long-term postoperative period.[29,30] It has been reported in the literature that there are inconsistencies in outcome measurements after PNI, and it has been stated that there is a need for effective outcome measures that evaluate function and disability.[28,31] Although the development of new outcome measures has been suggested in the literature, we used DASH and MHQ, which are currently the most commonly used functional assessments in hand injuries. Rostami et al examined the effects of the mirror therapy program on functionality in individuals with hand injuries and evaluated the functionality of individuals with DASH. As a result of the study, they reported that functional recovery was better in the group receiving mirror therapy.[32] Our evaluation of UE functionality, using the DASH and MHQ questionnaires, revealed significant improvements within both groups. At the 6- and 12-week follow-ups, both groups showed significant gains in their overall DASH scores. The GMI+PTR group also demonstrated significant improvements in the DASH Work and Sports/Music subparameters. However, despite these positive intra-group changes, no statistically significant differences were observed between the groups for any of these measures. The lack of a superior effect for the GMI intervention, even though components like mirror therapy are supported by the literature, may be attributable to several factors. Our results could have been influenced by our small sample size or the early implementation of the GMI protocol. It is also noteworthy that much of the research on mirror therapy has investigated its effects on functionality in populations with chronic pain or fractures, rather than in the context of acute tendon and nerve injuries. Therefore, a primary strength of our study is the investigation of GMI's effectiveness in this specific PNI population. In another study in which the functional status of the UE was evaluated with the DASH, the effect of GMI training on hand functions was investigated in the treatment of radius fracture. As a result of the study, it was reported that GMI training provided improvements in hand functions.[33] In another study, Stenekes et al reported that MI training added to the PTR program in the immobilization process following flexor tendon injury had positive effects on UE functionality and recovery after orthosis use.[34] When UE functionality was evaluated, our results differed depending on the assessment tool. According to the DASH questionnaire, the groups started at a similar pre-treatment functional level, and neither intervention proved superior to the other. In contrast, the MHQ results revealed a clear advantage for the group receiving GMI training in addition to PTR, which demonstrated superiority in the MHQ-Total and MHQ-Aesthetics scores. We attribute this discrepancy to the fundamental difference between the two tools. The DASH assesses the functionality of the affected extremity unilaterally, whereas the MHQ allows for a bilateral evaluation, an approach recommended for individuals with PNI.[35] This suggests that GMI training significantly contributes to improving functionality, but its full effect is better captured by bilateral assessments. Therefore, our findings underscore the importance of bilateral evaluation for accurately interpreting treatment outcomes in the PNI population.

Kinesiophobia that may occur after UE injuries may affect the level of disability perceived by patients.[36] For this reason, TSK is frequently used to assess pain and fear of movement in UE problems.[37] In a study conducted on individuals with a traumatic hand injury, kinesiophobia levels of individuals were evaluated at the fifth, sixth, and eighth weeks of the rehabilitation process following the injury, and a significant decrease in kinesiophobia level was found only in the eighth week. It was emphasized that individuals should be encouraged to use their hands in daily life activities after the completion of the physiological process of tendon healing. Functional recovery of the hand was examined in individuals who underwent tendon repair surgery and discontinued the use of orthosis in the early period, kinesiophobia was observed in the majority of individuals, and a relationship was found between the level of kinesiophobia and hand function.[16] All individuals in our study were followed up with the same protocol in the first 6 weeks after surgery and the duration of orthosis use was similar. It was determined that kinesiophobia levels decreased in individuals who received GMI training in addition to the PTR program, whereas kinesiophobia levels increased in individuals who followed only the PTR program. This difference between the groups is thought to be due to the fact that the imagery performed in the GMI-trained group provided a pain-free perception of functionality. In addition, the functional gains seen in this group support the relationship between functionality and kinesiophobia level in compliance with the literature.

Limitations

Sensory evaluations were not performed because the patients were followed up in the early postoperative period, which can be considered a limitation of our study. Although all participants had injuries located in Zone 5, the small sample size and homogeneity of the injury zone may limit the generalizability of the findings. Additionally, the differences in the surgical interventions applied may have affected the internal homogeneity of the groups. Furthermore, the physiotherapist administering the rehabilitation program was not blinded to group allocation, which may have introduced performance bias. Pain was assessed only in terms of intensity using the VAS; specific pain characteristics, such as the presence of neuropathic pain, were not evaluated. Lastly, although the study primarily focused on nerve injuries, participants also had concomitant tendon injuries. This multitissue involvement may have influenced kinesiophobia levels in ways that could not be independently assessed.

Conclusion

In conclusion, this study demonstrated that adding GMI training to a PTR program has beneficial effects for post-surgical PNI patients. While GMI did not prove superior to PTR alone in terms of pain reduction or ROM gains, its significant impact on improving functionality and reducing kinesiophobia highlights its unique therapeutic value. Based on these findings, we recommend the integration of GMI training into PTR programs to specifically target functional recovery and fear of movement in individuals with PNI. However, these conclusions should be considered preliminary. The primary limitation of our study is its small sample size, which restricts the generalizability of the results to a broader population. Future research is essential to validate these findings. We strongly recommend conducting large-scale randomized controlled trials to investigate both the short- and long-term effects of GMI training. Furthermore, incorporating objective assessment tools, such as electromyography, would provide more robust evidence and a deeper understanding of the neurophysiological mechanisms underlying these interventions.

Ethical approval

Ethical approval for this study was obtained from Bezmiâlem Vakıf University Clinical Research Ethics Committee (04.04.2023/E.102918).

Funding

No funding was received from any institution for this study.

Authorship contributions

Zeynep Hoşbay: Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization. **Güldane Nalbantoğlu:** Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Kemalettin Yildiz:** Supervision, Resources. **Zeynel Karakullukçuoğlu:** Resources, Methodology, Conceptualization. **Gülsena Utku Umut:** Writing – review & editing, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

NA.

Informed consent

Written informed consent was obtained from all participants before the study.

Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jht.2025.09.010.

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