International Journal of Advanced and Applied Sciences, 9(10) 2022, Pages: 40-49

Contents lists available at Science-Gate

International Journal of Advanced and Applied Sciences

Journal homepage: http://www.science-gate.com/IJAAS.html

A study of therapeutic intervention methods to improve proprioception among hemiplegic stroke patients

Jung-Ho Lee *

Department of Physical Therapy, Kyungdong University, Sokcho, South Korea

ARTICLE INFO

Article history:
Received 16 December 2021
Received in revised form
20 June 2022
Accepted 24 June 2022

Keywords:
Stroke
Hemiplegia
Proprioception
Rehabilitation

ABSTRACT

The present study uses proprioceptive neuromuscular stimulation (which can increase nerve plasticity by stimulating proprioception) and modified mirror therapy to provide feedback in order to investigate these treatments' effects on upper-limb functions and daily living activities among stroke patients. The experimental group (n=15) underwent a mirror therapy program after PNF for 30 minutes three times weekly, for a total of 18 treatment sessions. Meanwhile, the control group (n=15) underwent only PNF treatment three times weekly for a total of 18 treatment sessions. Evaluations of participants' paretic upper-limb functions and ability, as well as their daily living activities, were conducted using the Fugl-Meyer assessment scale (FMA), manual function test (MFT), motor activity log (MAL), and functional independence measure (FIM). The FMA, MFT, MAL, and FIM scores of the experimental group differed statistically significantly from those of the control group in terms of curative effects. Thus, the results of this study show that PNF and mirror therapy are effective interventions to improve upper-limb functions and activities, as well as the performance of daily living activities, among hemiplegic stroke patients.

1. Introduction

Motor learning refers to a series of processing abilities associated with practice and experience that induce relatively permanent changes to movement-related abilities. Additionally, these processes involve a series of events that induce concurrent outputs, states, and changes, and they are divided into several categories based on their characteristics. Various measurement tools have been used in many studies to prove the effects of motor learning and related variables. Among them, serial reaction time tasks have been frequently used to identify elements that affect motor learning, such as amounts of practice, kinds of feedback, and plans. Serial reaction time tasks distinguish between learning implicit knowledge and learning explicit knowledge (Sampaio-Baptista et al., 2018).

In particular, as one of the most widely used motor tasks in the field of cognitive science, randomized design and block design can be selectively used to examine procedural learning's effects, depending on a study's purpose. When acquiring motor skills, movements' speed and accuracy increase, leading to automation and adaptability; thus, behavioral changes result from changes to brain functions through motor learning. Additionally, when motor functions are lost due to brain damage, the motor skills can be restored through external therapeutic interventions alongside natural recovery, and this restoration is called motor re-learning. In this re-learning process, feedback from within and outside the body plays an important role (Baguma et al., 2020).

Feedback provides information about learners' knowledge of the results and performance when learners perform tasks. Sometimes, feedback is classified according to information types. Numerical information related to the size of a performance characteristic is called quantitative reinforcement information. Meanwhile, information about the state of a performance, regardless of numerical values, is called qualitative reinforcement information (Noh et al., 2019). Moreover, feedback provides information about errors in movements, methods with which to correct these errors, and methods with which to improve performance so that motor skills can be performed skillfully, achieving movement goals by increasing the speed of the learning process. Thus, feedback is a good method to motivate learners.

* Corresponding Author.
Email Address: ljhcivapt@naver.com
https://doi.org/10.21833/ijaas.2022.10.006
Corresponding author's ORCID profile:
https://orcid.org/0000-0002-0672-5817

Also, feedback can be used to motivate people to perfect skills during physical education. Information about more accurate performance through such skill acquisition can effectively promote movements among learners (Kiper et al., 2018).

In the motor learning field, generalized motor programs can explain how motor learning is achieved. Generalized motor programs derive from the concept that motor programs stored in the brain adjust movements to fit qualitative changes in motor skill performance. This theory suggests that the values of the parameters involved in movements are optimized so that movements are performed more efficiently. Generalized motor programs were developed through systematic ideas called schema theory (Dahms et al., 2020). Schema theory is a cognitive system of such systematic ideas formulated as a series of rules about the information necessary for movements. Motor schema theory emphasizes a cognitive aspect, holding that—if the amount and diversity of practice increase—the motor schema will be strongly acquired, and new movements that had not been performed during practice will become possible. Therefore, schema can be learned through motor learning so that movements can be performed effectively (Mooney et al., 2020).

The brain-region functions of the central nervous system can deteriorate or degenerate due to nervous-system diseases, aging, et cetera. Such damage to the brain's functions negatively affects muscle strength, the sense of balance, somatesthesia, and nervous system functions, reducing the body's motor ability in functional movements, gait, et cetera throughout daily life while restricting daily movements (Li et al., 2021). The loss of some upper-limb functions reduces the functions of not only damaged regions but also the hands since the upper limbs and the hands are organically and intimately related, and the wrists relate to the forearm when posing the hands to touch, grab, or manipulate objects. The hands' proprioception is most important in daily living activities. Therefore, the loss of the hands' proprioception makes perceiving the positions of each body part impossible, negatively affecting stability, the hands' recognition of objects, the control of hand movements, and the rehabilitation of motor functions (Kumar et al., 2018).

Stroke patients experience various symptoms, such as sensory disturbances, cognitive impairment, motor disturbances, perceptual disturbances, speech disorders, visual field defects, and dysphagia. In such cases, many patients live with permanent disabilities because they cannot recover their normal movements due to the spasticity and muscular weakening those results from motor function disorders. This factor naturally encourages the use of the non-paretic side during activities that require substantial upper-limb movements. Most stroke patients become accustomed to using their non-paretic upper limbs in daily life due to a long-term decrease in the use of their paretic sides. This shift is defined as the learned behavior of avoiding paretic upper-limb use (Knight-Greenfield et al., 2019).

Moreover, stroke patients' abnormal movements negatively affect the recovery of their functional movements through rehabilitation. Thus, normal movements of the paretic upper limb are important for stroke patients. Accordingly, in clinical practice, postural correction feedback is used to create harmonious movements of the non-paretic and paretic upper limbs. The main disabilities that occur after a stroke are spasticity, muscle weakening, and hypertonia, which affect the proper control of the upper limbs' movements and reduce the joints' range of motion, limiting independent daily living. Consequently, the use of normal movements of patients' affected sides becomes difficult (Fousse et al., 2020). To solve this problem, compensatory action of the unaffected side can become inefficient, leading to abnormal movements. Posture correction feedback affects muscle activity by controlling the movements that must be corrected through a therapist's hands, alongside verbal instructions for accurate muscle mobilization and posture during exercises. Therapists can also use their hands to improve poor posture, effectively restoring body functions during movements (Dimyan and Cohen, 2011).

Movement disorders due to damage to the central nervous system—such as stroke—make normal movements difficult. Therefore, patients often use compensatory movements. Through postural correction, therapists control or correct movements with their hands. Thus, they convert patients' abnormal movements into normal movements. This method is generally used to evaluate patients' movements and during therapeutic interventions (Baizabal-Carvallo et al., 2019). According to a study that examined the curative effects of upper-limb rehabilitation treatment for stroke patients, neuromuscular development therapies (proprioceptive neuromuscular facilitation [PNF], NDT, etc.) based on cerebral cortex activation theory and movement therapies based on motor re-learning theory can restore the upper limbs' motor functions. Such major movement therapies include mirror therapy, bilateral training, constraint-induced movement therapy, task-oriented movement approach, robotic treatment, and functional electrical stimulation (Vaughan-Graham et al., 2015; Smedes and da Silva, 2019).

Among neuromuscular development therapies, PNF uses isometric contractions in a unique spiral pattern to improve joints' range of motion and muscle strength while relieving pain. Additionally, it maintains the muscles' physiological elasticity and contractility while providing sensory feedback from the contractile muscles to improve circulatory-system ability, prevent blood clots, improve motor functions, and improve muscle coordination. Moreover, PNF uses appropriate resistance to induce isotonic or isometric contractions in order to improve body stability, strengthen muscles, and improve motor control. Mirror therapy, meanwhile, provides feedback—through visual information—on the movement of paretic or non-paretic limbs. This feedback helps improve the paretic limb's functional movements (Chaturvedi et al., 2020).

Optical illusions lead patients to feel as if both their hands are simultaneously and symmetrically moving through mirror reflections, activating the cerebral hemispheres and the primary motor cortex. Thus, this treatment becomes a neurological mechanism to promote brain plasticity. Similarly, the authors of a brain image study with motor-disease-free patients reported that the cerebrum's motor areas were activated even when hand movements were imitated or observed. Therefore, the relationship between observation through feedback and motor learning has been proven. The perception or recognition of movements is, thus, converted into actual movements through a series of processes. A preliminary study reported that the joints' range of motion, as well as the movement speed and accuracy of the upper limbs, improved after stroke patients, were treated with mirror therapy (Hara, 2015).

Some studies have presented exercises that can improve mobility and functional balance among stroke patients. However, these studies have not clearly explained the advantages of concrete and intensive exercise programs or mechanisms that help improve patients' conditions. Additionally, even if bare-handed exercise treatment methods or concrete training methods are presented to stroke patients, active muscle contraction of their paretic sides has remained difficult, and limitations have persisted in applying only task-oriented training. Therefore, the present study used proprioceptive neuromuscular stimulation (which can increase nerve plasticity by stimulating proprioception) and modified mirror therapy to provide feedback in order to investigate these treatments' effects on upper-limb functions and daily living activities among stroke patients.

2. Study methods

2.1. Subjects

To exclude the therapeutic effect of the upper limbs' neurological recovery, the current study examined 30 stroke patients whose Brunnstrom's recovery had been at least at stage 4 for at least six months after the patients' disease onset. Each participant randomly selected one of 30 cards, 15 of which were blue and 15 of which were red. Through this method, participants were randomly assigned to an experimental group or a control group. The experimental group underwent a mirror therapy program after PNF for 30 minutes three times weekly, for a total of 18 treatment sessions. Meanwhile, the control group underwent only PNF treatment three times weekly for a total of 18 treatment sessions.

Preliminary evaluations of participants' paretic upper-limb functions and ability, as well as their daily living activities, were conducted using the Fugl-Meyer assessment scale (FMA), manual function test (MFT), motor activity log (MAL), and functional independence measure (FIM) before the studied intervention. Additionally, a post-test was conducted during the sixth week after the intervention had been completed. All evaluations were conducted by the same physical therapist, who had more than 10 years of clinical experience, to maintain consistency. (Fig. 1).

2.1.1. Inclusion criteria

This study's criteria for selecting participants were that patients needed to have met the basic standards of the "Mini-Mental State Exam-Korean" (MMSE-K), had no congenital anomalies of the arms or legs, were not taking psychiatric medications related to depression, and could follow the researcher's instructions. The MMSE-K is a standardized cognitive ability evaluation tool with high reliability and validity.

It comprises 12 questions in a total of six categories: orientation, memory registration, memory recall, attention concentration and calculation, language functions, and understanding and judgment. For uneducated respondents, 1 point is added for time orientation, 2 points are added for attention concentration and calculation, and 1 point is added for language functions—provided that the participants' score does not exceed the full score in each area. The total score possible is 30 points. Respondents who received 24 or more points were considered "definitely normal," while respondents who received 20 to 23 points were considered "suspected of dementia," and respondents who received 19 or fewer points were considered to have "definite dementia." For this study, respondents who received at least 24 points and were judged to have no cognitive impairment were recruited as participants.

The "Motor-Free Visual Perception Test" (MVPT) is a tool used to evaluate patients' visual field defects or hemineglect. It comprised 36 items in five areas: figure-ground, visual discrimination, visual memory, visual completion, and spatial relation. Each item is scored with 1 point so the raw score is 36 points, and higher scores indicate better visual perceptual abilities. For this study, respondents who were determined to have no impairment in visual perceptual abilities—including hemineglect—through the MVPT were recruited as patients.

Additionally, the study's contents, procedures, side effects, and compensation were sufficiently explained to all study participants before they participated in the study's experiment. This research was conducted after participants had signed a consent form for participation in this study. All experimental procedures were carried out based on the Declaration of Helsinki.

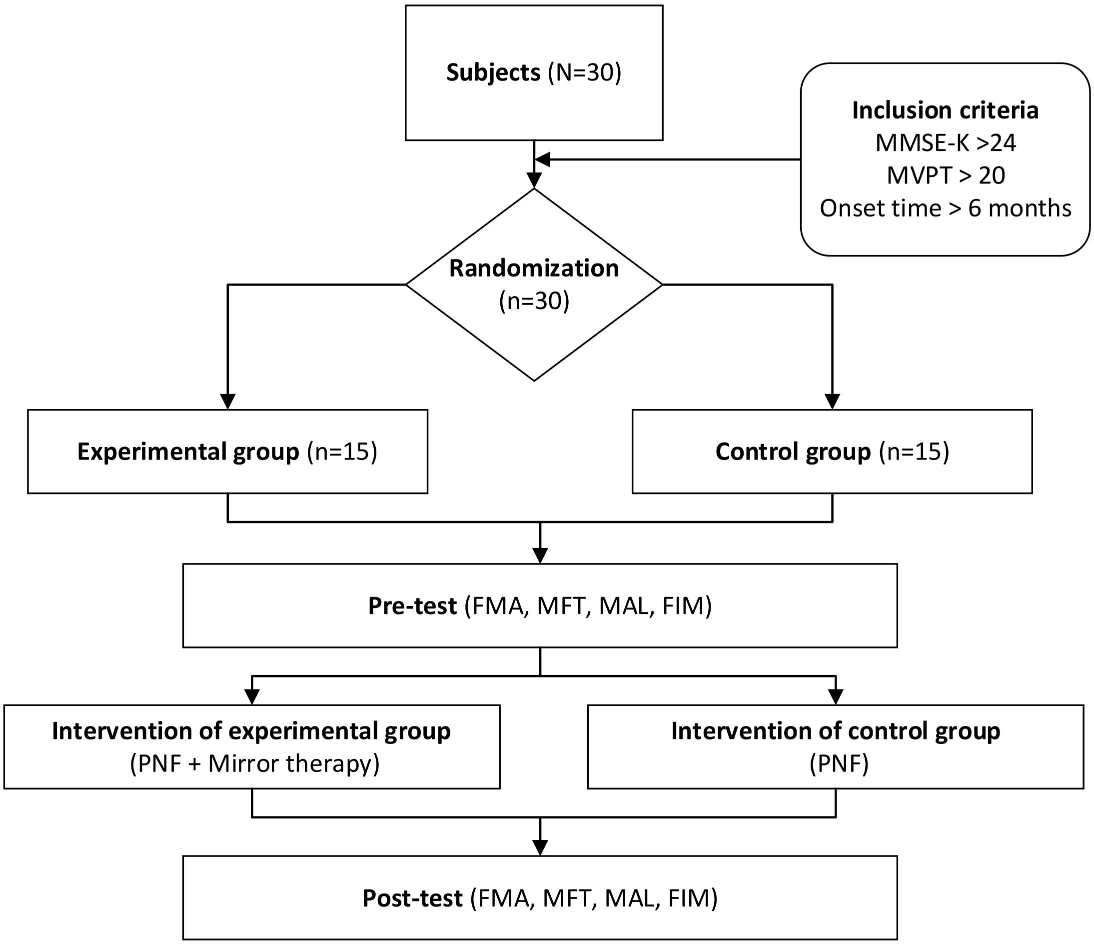

Fig. 1: Flow chart for improving the proprioceptive sensation of this study

2.2. Evaluation methods

2.2.1. Fugl-Meyer assessment scale

The Fugl-Meyer assessment scale of the upper limb (FMA-UE) was developed to quantitatively evaluate stroke patients' degrees of motor recovery. It was also designed to measure motor functions, balance, sensations, joints' range of motion, and pain after a stroke. This measurement evaluates patients' paretic and non-paretic sides, and it comprises a scale of 0 to 3 points with a sequential scoring system (0 points=unable to perform, 1 point=partially performed, and 2 points=completely performed). Higher scores indicate better function. In this study, the scale's upper-limb items were tested. The upper-limb items comprise 18 items for the shoulder, elbow, and forearm, five items for the wrist, seven items for the hand, and three items for upper-limb coordination. The maximum score is 66 points, and the scale's degree of recovery can also be expressed as a percentage.

2.2.2. Manual function test

The manual function test (MFT) was developed to measure and record changes in stroke patients' upper-limb motor functions. Not only can it measure short-term changes in patients' neurological recovery period, but it is also a widely used tool in measuring upper-limb functions and movement ability. This study used the test's stroke upper-limb function assessment, which comprises four items for upper-limb movements, two items for grip strength, and two items for finger manipulation, and it evaluates both upper limbs together to predict the level of functional recovery.

2.2.3. Motor activity log

Through interviews, the motor activity log (MAL) tool examines the amount of use and quality of movements of the paretic upper limb among hemiplegic patients after a stroke in actual daily life. This tool is classified into the amount of use (AOU) of the paretic upper limb and the quality of movements (QOM) of how the paretic upper limb is used. This tool comprises six-point scales. AOU scores range from 0 points (not used at all) to 5 points (the paretic side is used as much as before the onset), and the QOM scores range from 0 points (the paretic side cannot be used for activities) to 5 points (the paretic side can be used identically to before the onset). Higher scores indicate more use and better QOM of the paretic side.

2.2.4. Functional independence measure

The functional independence measure (FIM) is used to evaluate daily life activities, and it is widely used to objectively evaluate the ability of patients with disabilities to perform daily living activities. In this study, the FIM was used to evaluate stroke patients' ability to perform daily living activities. The FIM objectively evaluates is sensitive to functional changes. It comprises 18 sub-items in six categories: six items for self-help activities, two items for bowel movement/urination control, two items for walking, two items for communication, and three items for social cognition. Unlike other evaluation tools, the FIM evaluates social cognition and scores each item on a seven-point scale, ranging from complete dependence to independence, depending on the degree of help needed. The scale's total score is 126 points.

2.3. Treatments

2.3.1. Proprioceptive neuromuscular facilitation

This study used participants' PNF patterns to develop a therapeutic intervention. To perform an upper-limb extension, adduction, and intorsion pattern, participants were asked to adopt a hooked posture in which the hip and knee joints were bent in a supine position. In this hooked posture, the right arm (on the participants' movement side) was positioned at an 11 o'clock position, and the left arm was placed comfortably next to the body. Next, the upper-limb extension, adduction, and intorsion pattern were performed according to the researcher's instructions.

To perform an upper and lower limb combination pattern, participants were asked to place their left lower limb on the therapist's leg, with their hip and knee joints at 90° of flexion in a supine position, and to adopt the upper-limb extension, adduction, and intorsion pattern's start posture with their right upper limbs, bringing their right upper limbs into contact with the therapist's hand. These movements started with the therapist's verbal instructions, and the upper-limb extension, adduction, and intorsion pattern and lower limb flexion, adduction, and extorsion patterns were performed simultaneously.

To perform a chopping pattern, participants were asked to adopt a starting posture with their paretic-side shoulder joint performing flexion, adduction, and extorsion, followed by scapula anterior elevation, elbow joint extension-supination, wrist flexion, and radial deviation, and non-paretic-side scapula flexion, abduction, and extorsion. Participants were also asked to hold and move their left wrists. Participants were asked to adopt a final posture with their paretic-side shoulder joint's extension, abduction, and intorsion, scapula posterior descending, elbow joint extension and pronation, and wrist extension-ulnar deviation. This chopping pattern was performed with both hands alternately.

2.3.2. Mirror treatment

For this study's mirror treatment, participants in the experimental group took a seated position on a chair. Mirrors were placed vertically 10 cm away from patients, on the sagittal plane, on a desk. To apply a modified mirror therapy, two-way mirrors were used so that participants' paretic and non-paretic sides were reflected in the mirrors. Patients' non-paretic and paretic hands were placed between the mirrors, and patients were asked to maintain a neutral line.

When the first treatment started, patients were asked to stare at their non-paretic upper limb reflected in the mirror. Thereafter, the patients were asked to stare at their paretic upper limb while performing the same movements as those performed with the non-paretic upper limb. Paretic and non-paretic forearm pronation and supination, wrist and finger flexion, and extension movements were sequentially performed. Additionally, feedback was given by the therapist to patients while the therapist verbally explained errors in their movements.

2.4. Data analysis

The collected data were analyzed using the SPSS, version 18.0, statistical processing program. The means and standard deviations of the dependent variables were obtained. Descriptive statistics were used to represent participants' general characteristics, and independent-sample t-tests were used to test the homogeneity of their upper-limb functions and ability to perform daily living activities between the experimental group and control group before our therapeutic intervention. Paired-sample t-tests were conducted for an intragroup comparison of upper-limb functions and the ability to perform daily living activities between the experimental group and the control group before and after the study's intervention. Independent t-tests were also conducted to compare the curative effects on upper-limb functions and the ability to perform daily living activities between the groups. The statistical significance level α was set to 0.05.

3. Results

The differences between Fugl-Meyer assessment scores before and after treatment in the experimental group and the control group were statistically significant ($P<0.05$). When the effects of the therapeutic interventions were compared, there was a statistically significant difference in the amount of change between the experimental group and the control group (Fig. 2) ($P<0.05$).

There were statistically significant differences in the manual function test before and after treatment in the experimental group and control group, respectively (Fig. 3) ($P<0.05$). When the effects of the therapeutic interventions were compared, there were no statistically significant differences in the amounts of change between the experimental group and the control group ($P>0.05$).

In the AOU results of the motor activity log test, a statistically significant difference was found between the pre-test and post-test comparisons in both the experimental group and the control group (Fig. 4) (P<0.05). When the effects of the therapeutic interventions were compared, there was a statistically significant difference in the amount of change between the experimental group and the control group (P<0.05).

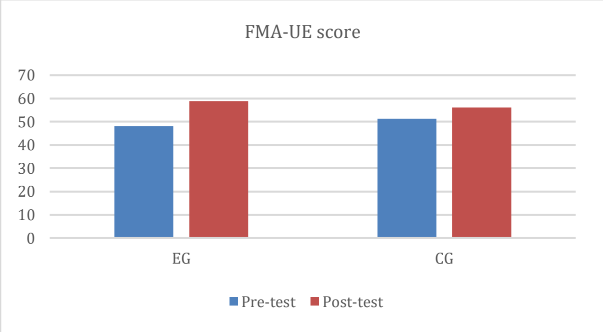

Fig. 2: Comparisons of Fugl-Meyer assessment between groups; p<0.05, Mean±SD; Mean±standard deviation

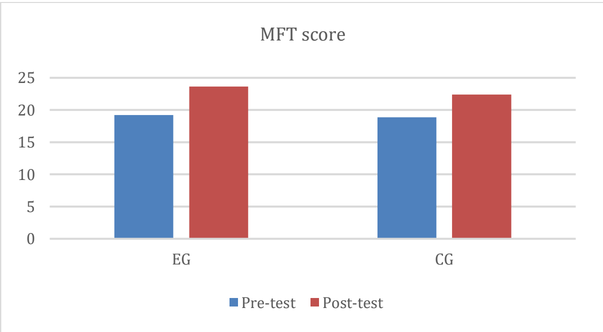

Fig. 3: Comparisons of manual function test between groups; p<0.05, Mean±SD; Mean±standard deviation

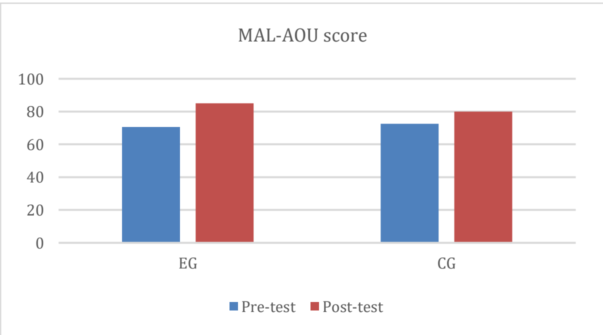

Fig. 4: Comparisons of AOU of motor activity log between groups; p<0.05, Mean±SD; Mean±standard deviation

In the QOM results of the motor activity log test, a statistically significant difference was found between the pre-test and post-test comparisons in both the experimental group and the control group (Fig. 5) (P<0.05). When the effects of the therapeutic interventions were compared, there was a statistically significant difference in the amount of change between the experimental group and the control group (P<0.05).

In the functional independence measure, a statistically significant difference was found between the pre-test and post-test comparisons in both the experimental group and the control group (Fig. 6) (P<0.05). When the effects of the therapeutic interventions were compared, there was a statistically significant difference in the amount of change between the experimental group and the control group (P<0.05).

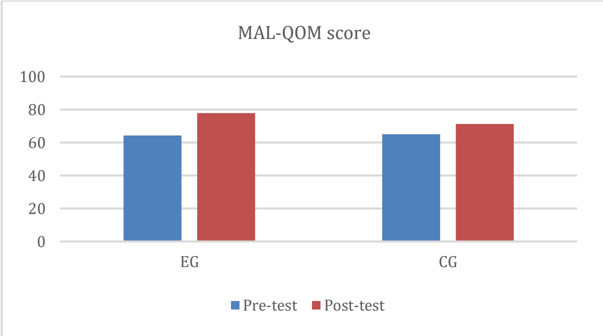

Fig. 5: Comparisons of QOM of motor activity log between groups; p<0.05, Mean±SD; Mean±standard deviation

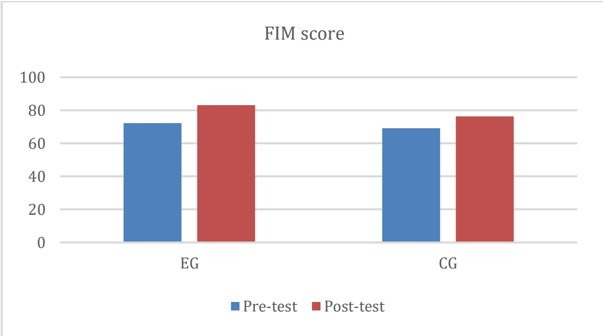

Fig. 6: Comparisons of functional independence measure between groups; p<0.05, Mean±SD; Mean±standard deviation

4. Discussion

The ability to independently perform daily living activities refers to the ability to perform activities independently in one's life, such as mobility, self-management, communication, and the use of environmental tools. The main goals of upper-extremity rehabilitation for stroke patients are independent living and the acquisition of the skills needed to perform the most basic daily living activities. Interventions to help stroke patients with upper-extremity movement control and functional improvement have been proven to support neural circuit reorganization, reportedly through changes to neural networks (Smith et al., 2017).

The degree of patients' recovery of their upper-limb functions differs, depending on the degree of paralysis in the early stage of stroke. Most recoveries start in the proximal regions, and the motor functions of proximal regions have been reported to recover faster than the distal regions because of the activation of the ipsilateral corticospinal tract and cortico-reticular tract—present in the normal hemisphere—is easier in the proximal regions. The recovery of hemiplegia patients' neurological functions is mainly achieved through a reorganization of the neural network, which results from the compensation and replacement of the damaged neurons' functions by the less-damaged neural network. To promote such reorganization of a damaged brain, the damaged region should be externally stimulated through motor interventions (Raghavan, 2015).

Brain tissues damaged due to stroke do not regenerate as new brain tissues, and most patients cannot evade sequelae completely. However, they can recover to the extent that they can lead daily lives. To that end, though, they should receive rehabilitation treatment continuously for long periods. Rehabilitation treatment prevents joint contracture and muscular atrophy due to spasticity in stroke patients' damaged sides, repeatedly performing muscle contraction and relaxation movements so that cells around the damaged brain tissues take over the role played by the damaged brain tissues. This process enables patients to effectively overcome their paralysis (Cai et al., 2017).

The recovery of activity abilities after stroke comprises both natural recovery and recovery through treatment, but predicting the degree of recovery and patients' prognoses is difficult. Compared to the recovery of the lower limbs' activity, the recovery of the upper limbs—which perform many complex movements, such as holding and grabbing—is slower despite intensive and long-term treatment. Moreover, the proper use of damaged limbs is restricted in many cases. Among upper-limb abilities, hand movements play the most important role in daily life or occupational environments, greatly affecting patients' movements and quality of life. The hands can undergo severe damage among stroke patients and take the longest to benefit from treatment (Colomer et al., 2016).

Proprioception processes information on limb positions and muscle force through proprioceptors; thus, the central nervous system monitors and controls limb movements and ensures that planned motions or movements are intensively executed through precise feedback and feed-forward control mechanisms. Additionally, proprioception plays an important role in maintaining and securing neuro-muscles and balance, as well as reducing new joint damage or functional instability (Morreale et al., 2016). Proprioceptors are position receptors located in the joint capsules, muscles, and ligaments. Joint and ligament receptors include Golgi-type receptors, free nerve endings, and Pacinian corpuscles, which are the most frequently distributed in the body. These receptors recognize not only the signals related to the speed of body movements but also body parts' states of adaptation to provide information and balance the body. Among these receptors, muscle spindles and the Golgi tendon organ also play important roles in proprioception. Muscle spindles detect changes in muscle lengths, and the Golgi tendon plays a role in identifying changes in muscle tension (Tasseel-Ponche et al., 2015).

Proprioception greatly contributes to joint stability and protects the body from external stimuli. Additionally, it can maintain the body continuously, correct wrong postures, and make the body move consciously. Therefore, when proprioception is reduced, the body's protective reflexes and motor abilities are reduced. Proprioception comprises position sense, which recognizes joint positions, and motor sensation, which recognizes movements. The information transmitted through the afferent nerves plays a key role in maintaining the stability of proximal joints when performing tasks to move toward accurate targets. To maintain the body's stability, normal proprioception and vision—as well as a sense of balance—are necessary. When proprioception is reduced, repetitive damage is induced because neuromuscular control is difficult and body functions become unstable (Ghai et al., 2017).

Feedback facilitates the motor-learning process and enables the acquisition of more sophisticated and complex skills, helping achieve movements' purpose. Additionally, feedback provides information on accurate movements and resultant errors, enabling an individual to perform accurate movements. Feedback provides the information necessary to detect errors in the process of performing motor skills and forming a system of movements to be performed. Feedback also provides information with which to determine whether movements are accurate after they are finished (Maeda et al., 2020).

The elements of neuromuscular control comprise proprioception, motor sensation, dynamic stability, the control of neuromuscular responses, and functional activities. Although proprioception plays a very important role in rehabilitation for the recovery of motor control ability movement methods using appropriate visual information and proprioception have been said to enable more accurate movements than only proprioception (Rhea and Kuznetsov, 2017). Visual feedback is integrated with afferent information from the vestibular and somatosensory senses, contributing to postural control and possibly improving movement control by reducing agitation during movements. Previous studies have reported that various senses can be perceived directly through feedback training, and the integration of sensory inputs from the vestibular organ affects balance control. Additionally, previous studies have indicated that, after visual feedback, forward-backward movements of the center of pressure were fewer than when no feedback was given (Sanford et al., 2021).

Among the continuous tasks studied in the field of motion control, tracking tasks are the most used. Tracking tasks use visual perceptual movements that require coordination between the vision and the hands, and closed-loop movements that require visual feedback. Visual perception functions comprise visual-motor coordination, figure-background discrimination, homeostasis perception, spatial position perception, and spatial relation perception (Huber et al., 2019). Visual-motor coordination describes actions based on coordination between the vision and bodily movements or parts of the body. It involves mutual coordination activities to visually recognize an object and hold or manipulate it by hand. A previous study measured non-motor visual perception tests and functional independent scales among stroke patients. According to that study's results, visual perception ability correlates with motor functions (Germano et al., 2013).

Proprioceptive neuromuscular facilitation (PNF) is a method of promoting or enhancing neuromuscular mechanisms' responses by providing proprioceptive stimuli to patients. It is often used as an alternative to progressive resistance exercise in order to improve damage during stroke rehabilitation. It is also used in stroke rehabilitation to train patients in functional activities or improve various types of damaged regions. PNF patterns are large-scale muscle movements of the limbs and trunk, and they occur on spiral and diagonal lines. They comprise a combination of flexion and extension on the sagittal plane, abduction and adduction on the coronal plane, and intorsion and extorsion on the horizontal plane. Such combined functional movements have been said to increase muscle activity and spread muscle activity distally and proximally (Hindle et al., 2012).

As a therapeutic technique, PNF approaches not just the problem of one segment or a certain part of the body but wider bodily problems from an integrative perspective, based on the basic theories of a positive approach, a functional approach, motor control, and motor learning, and preservation of remaining abilities. It is also known to promote neuromuscular activation and functional activities using basic procedures, techniques, and facilitation patterns to stimulate the proprioceptors involved in movements. In human movement, the trunk, upper limbs, and lower limbs work together as completely synergic muscles (Takasaki et al., 2019). Through resistance patterns, the upper and lower limbs or the trunk can be strengthened, diffusing strong muscles' power into weak muscles. A recent PNF-related study examined the combined effects of upper and lower limb patterns on functional improvements among patients, rather than the effects of movements using a single pattern. This approach was adopted because PNF combination patterns are known to improve functional activities by enhancing coordination between and within the upper and lower limbs (Birinci et al., 2019).

In the present study, PNF patterns related to the upper limbs were used to examine improvements to the upper-limb functions and activities and activities of daily living (ADL). The results revealed that upper-limb functions and activities, as well as ADL, increased after the experiment compared to before the experiment for both the experimental group and the control group treated with PNF. Therefore, the results are thought to be attributable to the continuous stimulation of the proprioceptors throughout the experiment yielding more information on proprioception compared to the information obtained before the experiment stimulated participants' cortical brain areas.

Mirror therapy leads to the activation of mirror neurons, activating the motor cortex as patients observe the movements of their non-paretic limbs reflected in a mirror. It emphasizes visual stimuli, unlike most sensorimotor training strategies. Like the well-known task-oriented therapy for stroke patients, mirror therapy also promotes brain plasticity and recovery since stroke patients perform purposeful, direct, and task-oriented movements of their arms and hands (Deconinck et al., 2015). Additionally, therapeutic training using mirrors presents an intervention method that can be easily applied in clinical practice, helping patients improve their motor functions firsthand. A previous study reported that, when exercise therapy and observation were applied to stroke patients along with the use of a mirror, visual feedback to restore functions was facilitated, and that the stimulation of observing non-paretic-side movements facilitated stroke patients' recovery while reducing the temporal and spatial neglect that can occur after a stroke (Madhoun et al., 2020).

Many recently published studies of stroke patients have also proven that mirror therapy, combined with proprioception therapy, effectively improves the upper limbs' motor ability, hand agility, and the ability to perform daily living activities among stroke patients. Such studies have also reported that, since visual feedback is provided immediately in mirror therapy, patients can actively perform activities to move their non-paretic upper limbs and then their paretic upper limbs identically, taking an interest in the treatment process during and maximizing their motivation (Jan et al., 2019). In the present study, too, the upper limbs' functions and activities and ADL increased significantly among the experimental group after they received mirror treatment compared to before the experiment. These results are thought to be attributable to visual information's continuous transmission to the cerebral cortex and increased proprioception activity throughout the experiment, increasing participants' brain plasticity.

5. Conclusion

This study examined the effects of PNF (which can stimulate proprioception) and modified mirror therapy (which can provide visual feedback) on upper-limb functions and activities, as well as ADL, among stroke patients before and after such therapeutic interventions. Moreover, it compared upper-limb functions and activities, as well as, ADL before and after the therapeutic intervention. Participants' FMA, MFT, MAL, and FIM were evaluated, yielding the study's results. FMA, MFT, MAL, and FIM scores were found to increase significantly after the experiment compared to before the experiment in both the experimental group and the control treated with PNF. Moreover, the FMA, MAL, and FIM scores of the experimental group differed statistically significantly from those of the control group in terms of curative effects. Thus, the results of this study show that PNF and mirror therapy are effective interventions to improve upper-limb functions and activities, as well as the performance of daily living activities, among hemiplegic stroke patients.

Acknowledgment

This research was supported by Kyungdong University Research Fund, 2021.

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

Baguma M, Doost MY, Riga A, Laloux P, Bihin B, and Vandermeeren Y (2020). Preserved motor skill learning in acute stroke patients. Acta Neurologica Belgica, 120(2): 365-374. https://doi.org/10.1007/s13760-020-01304-7 **PMid:32152996**

Baizabal-Carvallo JF, Hallett M, and Jankovic J (2019). Pathogenesis and pathophysiology of functional (psychogenic) movement disorders. Neurobiology of Disease, 127: 32-44. https://doi.org/10.1016/j.nbd.2019.02.013 **PMid:30798005**

Birinci T, Razak Ozdincler A, Altun S, and Kural C (2019). A structured exercise programme combined with proprioceptive neuromuscular facilitation stretching or static stretching in posttraumatic stiffness of the elbow: A randomized controlled trial. Clinical Rehabilitation, 33(2): 241-252. https://doi.org/10.1177/0269215518802886 **PMid:30304958**

Cai W, Liu H, Zhao J, Chen LY, Chen J, Lu Z, and Hu X (2017). Pericytes in brain injury and repair after ischemic stroke. Translational Stroke Research, 8(2): 107-121. https://doi.org/10.1007/s12975-016-0504-4 **PMid:27837475 PMCid:PMC5350040**

Chaturvedi P, Singh AK, Tiwari V, and Thacker AK (2020). Post-stroke BDNF concentration changes following proprioceptive neuromuscular facilitation (PNF) exercises. Journal of Family Medicine and Primary Care, 9(7): 3361-3369. https://doi.org/10.4103/jfmpc.jfmpc_1051_19 **PMid:33102297 PMCid:PMC7567226**

Colomer C, NOé E, and Llorens Rodríguez R (2016). Mirror therapy in chronic stroke survivors with severely impaired upper limb function: A randomized controlled trial. European Journal of Physical and Rehabilitation Medicine, 52(3): 271-278.

Dahms C, Brodoehl S, Witte OW, and Klingner CM (2020). The importance of different learning stages for motor sequence learning after stroke. Human Brain Mapping, 41(1): 270-286. https://doi.org/10.1002/hbm.24793 **PMid:31520506 PMCid:PMC7268039**

Deconinck FJ, Smorenburg AR, Benham A, Ledebt A, Feltham MG, and Savelsbergh GJ (2015). Reflections on mirror therapy: A systematic review of the effect of mirror visual feedback on the brain. Neurorehabilitation and Neural Repair, 29(4): 349-361. https://doi.org/10.1177/1545968314546134 **PMid:25160567**

Dimyan MA and Cohen LG (2011). Neuroplasticity in the context of motor rehabilitation after stroke. Nature Reviews Neurology, 7(2): 76-85. https://doi.org/10.1038/nrneurol.2010.200 **PMid:21243015 PMCid:PMC4886719**

Fousse M, Grün D, Helwig SA, Walter S, Bekhit A, Wagenpfeil S, and Fassbender K (2020). Effects of a feedback-demanding stroke clock on acute stroke management: A randomized study. Stroke, 51(10): 2895-2900. https://doi.org/10.1161/STROKEAHA.120.029222 **PMid:32967576**

Germano GD, Pinheiro FH, Okuda PM, and Capellini SA (2013). Visual-motor perception in students with attention deficit with hyperactivity disorder. Codas, 25: 337-341. https://doi.org/10.1590/S2317-17822013000400007 **PMid:24408484**

Ghai S, Driller M, and Ghai I (2017). Effects of joint stabilizers on proprioception and stability: A systematic review and meta-analysis. Physical Therapy in Sport, 25: 65-75. https://doi.org/10.1016/j.ptsp.2016.05.006 **PMid:28262354**

Hara Y (2015). Brain plasticity and rehabilitation in stroke patients. Journal of Nippon Medical School, 82(1): 4-13. https://doi.org/10.1272/jnms.82.4 **PMid:25797869**

Hindle KB, Whitcomb TJ, Briggs WO, and Hong J (2012). Proprioceptive neuromuscular facilitation (PNF): Its mechanisms and effects on range of motion and muscular function. Journal of Human Kinetics, 31: 105-113. https://doi.org/10.2478/v10078-012-0011-y **PMid:23487249 PMCid:PMC3588663**

Huber ME, Folinus C, and Hogan N (2019). Visual perception of joint stiffness from multijoint motion. Journal of Neurophysiology, 122(1): 51-59. https://doi.org/10.1152/jn.00514.2018 **PMid:31017844 PMCid:PMC6689771**

Jan S, Arsh A, Darain H, and Gul S (2019). A randomized control trial comparing the effects of motor relearning programme and mirror therapy for improving upper limb motor functions in stroke patients. Journal of Pakistan Medical Association, 69(9): 1242-1245.

Kiper P, Szczudlik A, Agostini M, Opara J, Nowobilski R, Ventura L, and Turolla A (2018). Virtual reality for upper limb rehabilitation in subacute and chronic stroke: A randomized controlled trial. Archives of Physical Medicine and Rehabilitation, 99(5): 834-842. https://doi.org/10.1016/j.apmr.2018.01.023 **PMid:29453980**

Knight-Greenfield A, Nario JJQ, and Gupta A (2019). Causes of acute stroke: A patterned approach. Radiologic Clinics of North America, 57(6): 1093-1108. https://doi.org/10.1016/j.rcl.2019.07.007 **PMid:31582037 PMCid:PMC7040961**

Kumar A, Kaur H, and Singh A (2018). Neuropathic pain models caused by damage to central or peripheral nervous system. Pharmacological Reports, 70(2): 206-216. https://doi.org/10.1016/j.pharep.2017.09.009 **PMid:29475003**

Li L, Acioglu C, Heary RF, and Elkabes S (2021). Role of astroglial toll-like receptors (TLRs) in central nervous system infections, injury and neurodegenerative diseases. Brain, Behavior, and Immunity, 91: 740-755. https://doi.org/10.1016/j.bbi.2020.10.007 **PMid:33039660 PMCid:PMC7543714**

Madhoun HY, Tan B, Feng Y, Zhou Y, Zhou C, and Yu L (2020). Task-based mirror therapy enhances the upper limb motor function in subacute stroke patients: A randomized control trial. European Journal of Physical and Rehabilitation Medicine, 56(3): 265-271. https://doi.org/10.23736/S1973-9087.20.06070-0 **PMid:32214062**

Maeda RS, Gribble PL, and Pruszynski JA (2020). Learning new feedforward motor commands based on feedback responses. Current Biology, 30(10): 1941-1948. https://doi.org/10.1016/j.cub.2020.03.005 **PMid:32275882**

Mooney RA, Cirillo J, Stinear CM, and Byblow WD (2020). Neurophysiology of motor skill learning in chronic stroke. Clinical Neurophysiology, 131(4): 791-798. https://doi.org/10.1016/j.clinph.2019.12.410 **PMid:32066097**

Morreale M, Marchione P, Pili A, Lauta A, Castiglia SF, Spallone A, and Giacomini P (2016). Early versus delayed rehabilitation treatment in hemiplegic patients with ischemic stroke: Proprioceptive or cognitive approach. European Journal of Physical and Rehabilitation Medicine, 52(1): 81-89.

Noh HJ, Lee SH, and Bang DH (2019). Three-dimensional balance training using visual feedback on balance and walking ability in subacute stroke patients: A single-blinded randomized controlled pilot trial. Journal of Stroke and Cerebrovascular Diseases, 28(4): 994-1000. https://doi.org/10.1016/j.jstrokecerebrovasdis.2018.12.016 **PMid:30612892**

Raghavan P (2015). Upper limb motor impairment after stroke. Physical Medicine and Rehabilitation Clinics, 26(4): 599-610. https://doi.org/10.1016/j.pmr.2015.06.008 **PMid:26522900 PMCid:PMC4844548**

Rhea CK and Kuznetsov NA (2017). Using visual stimuli to enhance gait control. Journal of Vestibular Research, 27(1): 7-16. https://doi.org/10.3233/VES-170602 **PMid:28387688**

Sampaio-Baptista C, Sanders ZB, and Johansen-Berg H (2018). Structural plasticity in adulthood with motor learning and stroke rehabilitation. Annual Review of Neuroscience, 41: 25-40. https://doi.org/10.1146/annurev-neuro-080317-062015 **PMid:29490196**

Sanford S, Liu M, Selvaggi T, and Nataraj R (2021). Effects of visual feedback complexity on the performance of a movement task for rehabilitation. Journal of Motor Behavior, 53(2): 243-257. https://doi.org/10.1080/00222895.2020.1770670 **PMid:32496974**

Smedes F and da Silva LG (2019). Motor learning with the PNF-concept, an alternative to constrained induced movement therapy in a patient after a stroke: A case report. Journal of Bodywork and Movement Therapies, 23(3): 622-627. https://doi.org/10.1016/j.jbmt.2018.05.003 **PMid:31563380**

Smith MC, Barber PA, and Stinear CM (2017). The TWIST algorithm predicts time to walking independently after stroke. Neurorehabilitation and Neural Repair, 31(10-11): 955-964. https://doi.org/10.1177/1545968317736820 **PMid:29090654**

Takasaki H, Okubo Y, and Okuyama S (2019). The effect of proprioceptive neuromuscular facilitation on joint position sense: A systematic review. Journal of Sport Rehabilitation, 29(4): 488-497. https://doi.org/10.1123/jsr.2018-0498 **PMid:31094655**

Tasseel-Ponche S, Yelnik AP, and Bonan IV (2015). Motor strategies of postural control after hemispheric stroke. Neurophysiologie Clinique/Clinical Neurophysiology, 45(4-5): 327-333. https://doi.org/10.1016/j.neucli.2015.09.003 **PMid:26520051**

Vaughan-Graham J, Cott C, and Wright FV (2015). The Bobath (NDT) concept in adult neurological rehabilitation: What is the state of the knowledge? A scoping review. Part I: Conceptual perspectives. Disability and Rehabilitation, 37(20): 1793-1807. https://doi.org/10.3109/09638288.2014.985802 **PMid:25411026**