SPORT TK-EuroAmerican Journal of Sport Sciences

https://revistas.um.es/sportk Online ISSN: 2340-8812

Received: **01/01/2023.** Accepted: **05/07/2023.** Published: **10/02/2024**

Effect of cognitive multisensory rehabilitation on upper extremity function in stroke patients: A randomized controlled trial

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ABSTRACT

The aim of this study was to examine the impact of upper extremity (UE) rehabilitation based on neurocognitive multisensory therapy in stroke patients, focusing on assessing its effects on the recovery of UE function and suggesting it as a post-stroke therapeutic method. The study was conducted as a randomized, prospective, controlled trial with a pre- and post-experimental design. Thirty stroke patients were equally divided into study and control groups and evaluated before and after treatment. Outcome measures included the Action Research Arm Test (ARAT), Manual Function Test (MFT), Motor Evaluation Scale for Upper Extremity in Stroke Patients (MESUPES), and Fugl Myer Assessment upper extremity (FMA-UE). Both groups received a specific physiotherapy program, while the study group also received Cognitive Multisensory Rehabilitation (CMR). All analyses were performed using SPSS (version 25). There were no significant differences between the groups in age, weight, height, BMI, duration of illness, MMSE, sex, or spasticity grade distribution ($p > 0.05$). Post-treatment comparison between both groups showed a statistically significant increase in the ARAT, MFT, MESUPES, and FMA-UE scores in the study group compared to the control group ($p < 0.05$). For stroke patients, CMR intervention is considered a beneficial neuro-rehabilitation strategy for enhancing upper extremity sensorimotor capabilities through physical therapy.

KEYWORDS

Stroke; Cognition; Cognitive Multisensory Rehabilitation; Upper Extremity

1. INTRODUCTION

The upper extremity (UE) is commonly affected post-stroke, causing long-term impairment (Poltawski et al., 2016). Synergistic patterns are considered the first voluntary movements that return post-stroke. Symptoms of upper motor neuron damage include incoordination, paresis, hypertonia, sensory and dexterity loss, and an imbalance of agonist and antagonist muscles, leading to abnormal posture (Faria-Fortini et al., 2011).

Cognitive exercise enables different motions or actions to be performed through cognitive learning programs, via the interplay between the body and the environment, to construct a brain schema (Lee et al., 2015). The mental capacity to direct thinking and activity in a way that advances goals is known as cognition (Miller and Wallis, 2009). The Neurocognitive Rehabilitation theory serves as the basis for Cognitive Multisensory Rehabilitation (CMR) (Chanubol et al., 2012).

CMR is recognized as a sensorimotor rehabilitation strategy, involving sensory classification training with and without visual input or through contrasting sensation patterns. Considering that CMR focuses on a therapist-directed method, cognitive functions are stimulated by requesting the patient to feel the motion or position of an extremity and to focus on the connection of extremity motions with other body parts and the environmental spatial characteristics (Van et al., 2020).

When performing functional activities, CMR emphasizes the integration of motions and body components while also taking into account spatial awareness and orientation. It is considered a potential treatment for stroke recovery of the upper extremities (UE) because it is a multimodal activity that involves the combination of inputs from kinesthetic awareness, visual, vestibular, and auditory systems. Therefore, CMR employs a variety of perceptual discrimination training, such as comparing kinesthetic feedback with imagery to incorporate multisensory input, or distinguishing textures, forms, sizes, lengths, or heights (Van et al., 2020).

The reconfiguration of the brain after an injury is significantly affected by stimulating both the patient's physical and cognitive processes (Lee et al., 2015). The cognitive, perceptual, and motor components should be considered, although no prior research has directly examined the impact of CMR on UE sensorimotor abilities. This study employed CMR in stroke patients to assess its effects on the recovery of UE function and to suggest it as a post-stroke therapeutic method.

2. METHODS

2.1. Study design and participants

Anonymity and confidentiality were ensured, and the inquiry was carried out as a randomized, prospective, controlled study with pre- and post-experimental design. Thirty post-vascular stroke patients were referred by a neurologist. All participants completed a consent form before the intervention. To ensure anonymity and confidentiality, all processes were carried out in accordance with existing laws and institutional regulations. Using the invisible closed-envelope approach, the patients were randomly divided into two equally balanced groups for eight weeks. The CMR was administered to the study group, while both groups received the specific physiotherapy program. After randomization and treatment, no participants left the program (Figure 1).

The criteria for inclusion were as follows: age between 45 and 60 years, Body Mass Index (BMI) ranging from 18.5 to 29.9 kg/m², onset of vascular stroke six months or longer, UE functional level ranging from 32 to 52 (mild to moderate) according to Fugl-Meyer (Hoonhorst et al., 2015), less than grade 2 on the modified Ashworth scale for spasticity (Ansari et al., 2008), and a Mini-Mental State Examination (MMSE) score of more than 23 (Toglia et al., 2011). The exclusion criteria were: any additional brain pathologies, severe cognitive impairment, serious impairment or lack of sensation (superficial, deep, or cortical sensation), other causes of hemiplegia, other dysfunction of UE, severe apraxia, severe aphasia, contractures that could limit the patient from maintaining the extended arm in a comfortable position, vestibular or visual impairment, and any other musculoskeletal or neurological illnesses. The study received permission from the Faculty of Physical Therapy Institutional Ethics Committee at Cairo University in Egypt (PT REC/012/003797; and clinical trials.gov ID NCT05485740).

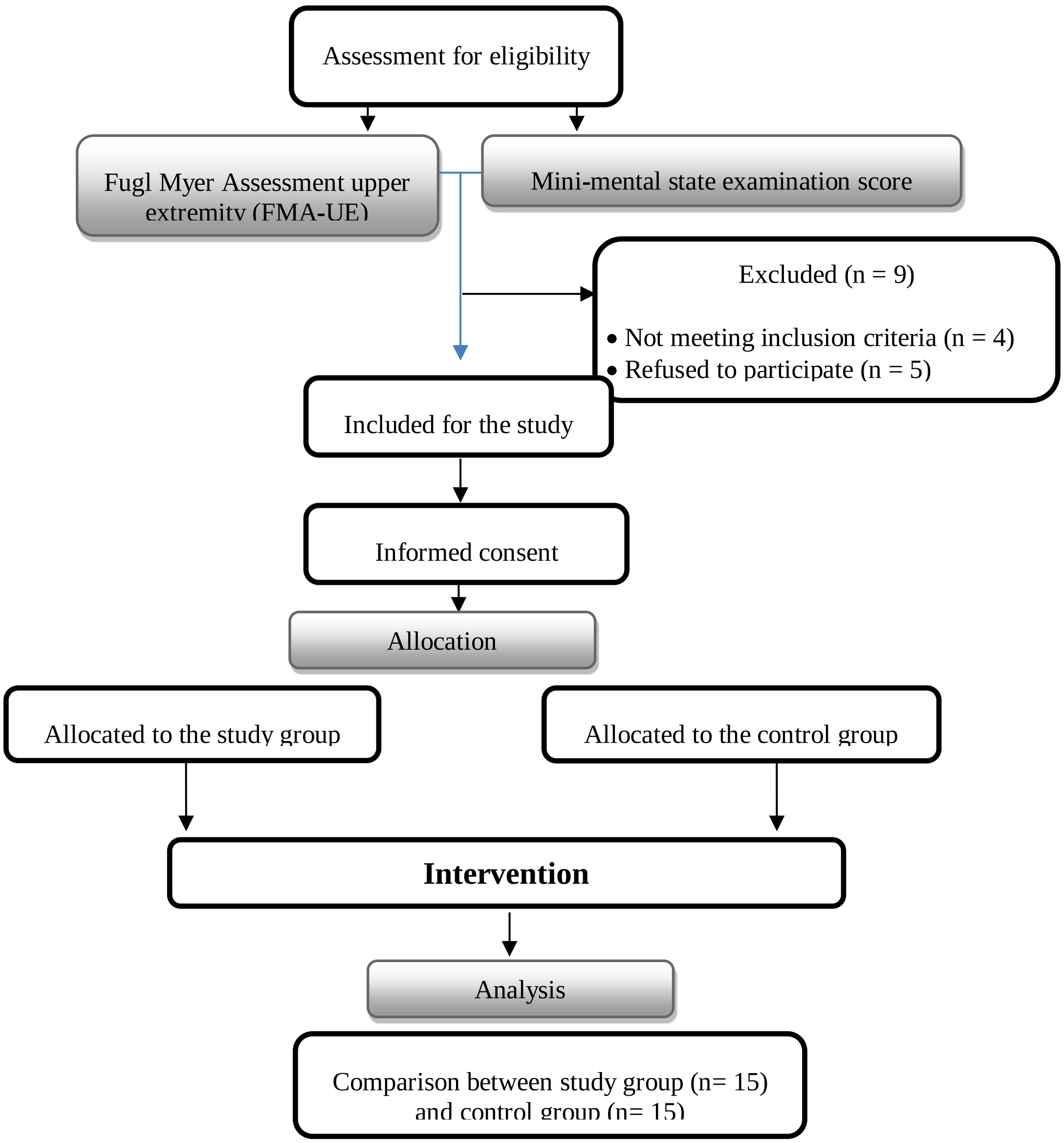

Figure 1. Flow chart showing the experimental design of the study.

2.2. Sample size

Based on data on measures gathered from the prior work by Law et al., 2018 indicated that the proper sample size for this study was thirty patients (N=30). The sample size calculation was carried out utilizing G-POWER statistical software (version 3.1.9.2; Franz Faul, Universitat Kiel, Germany), which indicated that the suitable sample size for this study was N=30. Using a t-test, the following calculation was used with α=0.05, power 80%, and effect size = 1.1.

2.3. The outcome of measures

2.3.1. Action research arm test (ARAT)

The ARAT is among the most often employed UE outcomes for measuring stroke therapy performance (Hoonhorst et al., 2015). It includes the grasp, grip, pinch, and gross motion subtests, which together measure a participant's UE performance across a total of 19 functional aspects. Each task is given a score between 0 (completely unable to accomplish the task in sixty seconds), one (partial completion), two (accomplish task abnormally), and 3 (carry-out a task normally in five seconds).

The grades for each activity vary from 0 (inability to finish any section in 1 minute), one (incomplete performance), two (abnormal performance), and three (in 5 seconds normal performance) (Spence et al., 2020). The overall grades were between 0 and 57, as the ARAT outcomes were classified into four categories: none UE ability (0–10), poor UE ability (11–21), limited UE ability (22-42), remarkable UE ability (43-54), and complete UE ability (55-57) (Spence et al., 2020).

2.3.2. Manual function test (MFT)

The MFT is a measure for assessing UE paresis caused by a stroke. It includes 32 criteria for eight activities in three classifications arm movements, grip and pinch, and arm and hand tasks. It is regarded as a valid and accurate approach for evaluating stroke patients' paretic UE. The range of the overall MFT result is 0 (profoundly disabled) to 32 (complete ability) (Miyamoto et al., 2009).

2.3.3. Motor Evaluation Scale for Upper Extremity in Stroke patients (MESUPES)

The MESUPES is considered a measure to evaluate hemiparetic UE movement. It is distributed into MESUPES-arm in addition to MESUPES-hand. The MESUPES could receive a maximum total score of 58. The MESUPES-arm has eight skill criteria for the shoulders and elbows, with a possible score of 40. Every item got from Zero (incapability to adjust muscle tone to the motion) to 5, (capability to finish movement without assistance). The nine wrist and finger components on the MESUPES-hand were graded on three grades as follows: Zero for incorrect or no motion; one for a partial motion; two for a whole motion, and the total scores = 18 (Johansson & Häger 2012).

2.3.4. Fugl Myer Assessment upper extremity (FMA-UE)

The FMA-UE is a scale that examines four aspects including motor, sensation, passive movement as well as joint pain. The scoring for motor functions is as follows: 0/22 denotes none upper-limb ability, 23 /31 denotes poor UE ability, 32 /47 denotes limited UE ability, 48 /52 denotes remarkable UE ability, and 53 /66 denoting complete UE ability (Platz et al., 2005), with 12 points full UE sensation, and 24 points that score the passive joint mobility, and 24 points for no UE joint pain (Hoonhorst et al., 2015).

2.4. Interventions

All treatment procedures were discussed with the patient prior to the beginning of the intervention, and also the treatment environment was free of any distractions or noise. The control group only obtained the specific physiotherapy treatment, whereas the study group obtained both CMR and the specific physiotherapy treatment three sessions a week for eight weeks for both groups.

2.4.1. The Cognitive multisensory rehabilitation

The patient was seated comfortably, and all therapy techniques, as well as the use of instruments such as wooden cubes and letter shapes, were explained to the patient. Two different types of cognitive-motor rehabilitation (CMR) exercises were used: Shape Discrimination Training and Height Discrimination Training. For each exercise, the patient first performed the task with their eyes open and then with their eyes closed (Van et al., 2020).

Shape Discrimination Exercise: The patient sat in front of a wooden board with letter "H" shapes. Variations of the letter "H," with different widths for the horizontal and vertical bars, were presented to the patient. After viewing the letters, the patient put on a blindfold, and the therapist guided the patient's finger along the edges of each letter to help them identify the correct letter "H." The patient felt the breadth and length of the bars and recognized the letter through imagery, perception, and attention to accompanying shoulder movements. This CMR training combined concentration, sensory processing, motor activity, and body posture perception.

Height Discrimination Exercise: For this exercise, the therapist presented various heights and sizes of wooden cubes to the blindfolded patient. The therapist guided the patient's finger along the edge of a wooden cube, stopping at the top, and asked the patient to identify the height and size of the cube. The patient was instructed to sense the motion and position through the metacarpophalangeal joint while keeping their fingers relaxed.

At the end of the session, the patient integrated what they had learned by opening their hand appropriately to grip a bottle, performing the learned postures and actions in a real-life context.

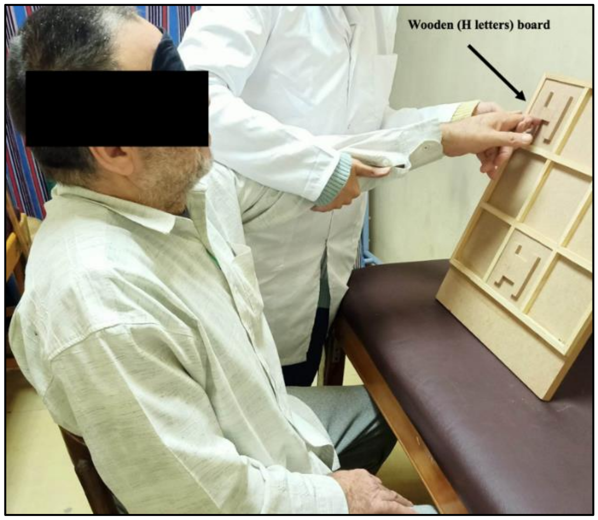

Figure 2. Shape Discrimination Exercise

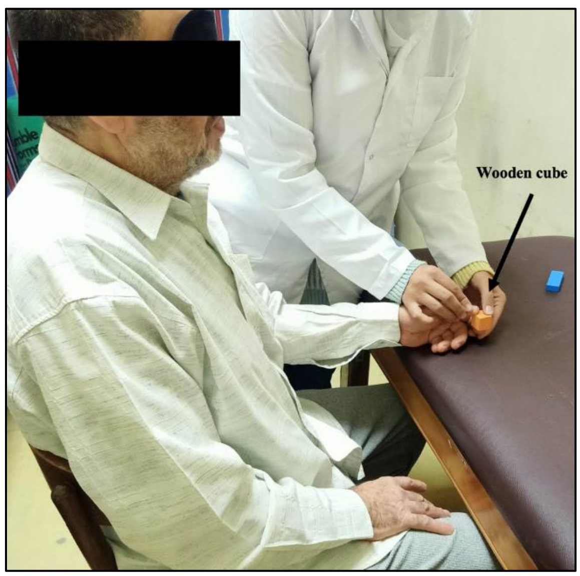

Figure 3. The height discrimination exercise

2.4.2. The specific upper extremity physiotherapy program

Patients in both study and control groups received the specific UE exercises program that involved:1) UE Range of motion (ROM) exercises in form of passive ROM and active assisted ROM, for all UE movements of the involved side, 2) Passive prolonged stretching exercises for the spastic UE flexors muscles, 3) weight-bearing exercises on affected UE from sitting position and maintained for ten minutes, 4) Bilateral arm training: as both arms performed simultaneous identical movements at the same time, in the form of reaching forward and grasping (Pomeroy et al., 2011). Every exercise was performed three times/session.

2.5. Statistical analysis

An unpaired t-test was used to assess differences in subject characteristics between the two groups. Spasticity and gender were analyzed with the chi-squared test. The Shapiro-Wilk test checked for normal distribution, while Levene's test assessed homogeneity of variances. Treatment effects on the ARAT, MFT, MESUPES, and FMA-UE were analyzed using mixed MANOVA, with Bonferroni post hoc testing for multiple comparisons. Statistical significance was set at $p < 0.05$. All analyses were performed using SPSS version 25 (IBM SPSS, Chicago, IL, USA).

3. RESULTS

3.1. Patients' characteristics

Table 1 shows the characteristics of patients in both the study and control groups. There were no significant differences between the groups in age, weight, height, BMI, duration of illness, MMSE, sex, or spasticity grade distribution ($p > 0.05$).

Table 1. Comparison of subject characteristics between study and control groups

	Study group	Control group			
	Mean ±SD	Mean ±SD	MD	t- value	p-value
Age (years)	54.8 ± 4.33	53.6 ± 3.5	1.2	0.83	0.41
Weight (kg)	74.87 ± 4.42	74.67 ± 6.2	0.2	0.1	0.92
Height (cm)	162.6 ± 3.52	163.93 ± 4.37	-1.33	-0.92	0.36
BMI (kg/m²)	28.28 ± 1.53	27.76 ± 1.76	0.52	0.86	0.39
Duration of illness (months)	17.53 ± 8.59	16.33 ± 8.58	1.2	0.38	0.71
MMSE	26.87 ± 1.51	26.20 ± 1.01	0.67	1.42	0.16
Sex distribution, n (%)					
Females	6 (40%)	7 (47%)	($\chi^2 = 0.13$)		0.71
Males	9 (60%)	8 (53%)			
Spasticity grade, n (%)					
Grade I	6 (40%)	8 (53%)	($\chi^2 = 0.53$)		0.46
Grade I+	9 (60%)	7 (47%)			

BMI: Body Mass Index; MMSE: Mini-Mental State Examination Score; SD: Standard Deviation; MD: Mean Difference; χ^2: Chi-Squared Value; p-value: Probability Value.

3.2. Impact of treatment on ARAT, MFT, MESUPES, and FMA-UE

Mixed MANOVA revealed a substantial interaction effect of treatment as well as time (F = 93.79, p = 0.001). There was a substantial main impact of treatment (F = 15.32, p = 0.02). There was a substantial main impact of time (F = 704.35, p = 0.001).

3.2.1. Within group comparison

There was a significant increase in ARAT, MFT, and hand, arm, and total of MESUPES scores after-treatment in both groups as compared to that before-treatment ($p < 0.05$). The percentage of change in ARAT, MFT, and hand, arm and total of MESUPES scores of the study group were 37.66, 65.78, 96.03, 26.09 and 33.48% respectively, and that in the control group was 18.92, 31.73, 62.41, 10.48 and 19.86% respectively (Table 2).

There was a substantial improvement in motor function, sensation, as well as passive joint motion scores and a significant improvement in joint pain of FMA-UE in both groups as compared to that pre-treatment ($p < 0.05$). The percentage of change in motor function, sensation, passive joint motion, as well as joint pain scores of FMA-UE of the study group was 30.77, 45, 31.53 and 30.68% respectively, and in the control group was 16.47, 21.25, 14.13 and 8.89% respectively (Table 3).

3.2.2. Between-group comparison

Pre-treatment data showed no statistically significant differences between groups ($p > 0.05$). Post treatment, the study group improved greater than the control group on the ARAT, MFT, and also the hand, arm, and total MESUPES ($p < 0.05$) (Table 2). FMA-UE joint pain improved significantly in the study group in comparison with the control group, and scores for motor function, sensation, as well as passive joint mobility also increased significantly ($p < 0.05$) (Table 3).

Table 2. Mean ARAT, MFT, and MESUPES pre and post-treatment of study and control groups

	Pre-treatment	**Post-treatment**			
	Mean ±SD	**Mean ±SD**	**MD**	**% of change**	**p-value**
ARAT					
Study group	33.8 ± 5.26	46.53 ± 5.55	-12.73	37.66	0.001
Control group	32.46 ± 4.94	38.6 ± 4.27	-6.14	18.92	0.001
MD	1.34	7.93			
p-value	***p = 0.48***	***p = 0.001***			

MFT					
Study group	15.4 ± 1.35	25.53 ± 1.64	-10.13	65.78	0.001
Control group	15.13 ± 1.51	19.93 ± 1.38	-4.8	31.73	0.001
MD	0.27	5.6			
p-value	***p = 0.61***	***p = 0.001***			
MESUPES (Hand)					
Study group	6.8 ± 1.14	13.33 ± 2.25	-6.53	96.03	0.001
Control group	6.73 ± 1.27	10.93 ± 1.57	-4.2	62.41	0.001
MD	0.07	2.4			
p-value	***p = 0.88***	***p = 0.002***			
MESUPES (Arm)					
Study group	30.66 ± 2.09	38.66 ± 1.34	-8	26.09	0.001
Control group	30.53 ± 1.45	33.73 ± 1.79	-3.2	10.48	0.001
MD	0.13	4.93			
p-value	***p = 0.84***	***p = 0.001***			
MESUPES (Total)					
Study group	37.46 ± 1.68	50 ± 2.51	-12.54	33.48	0.001
Control group	37.26 ± 2.15	44.66 ± 2.63	-7.4	19.86	0.001
MD	0.2	5.34			
p-value	***p = 0.77***	***p = 0.001***			

ARAT: Action Research Arm Test; MFT: Manual Function Test; MESUPES: Motor Evaluation Scale for Upper Extremity in Stroke; SD: Standard Deviation; MD: Mean Difference; p-value: Probability Value

Table 3. Mean FMA-UE pre and post-treatment of study and control groups

	Pre-treatment	**Post-treatment**			
	Mean ±SD	**Mean ±SD**	**MD**	**% of change**	**p-value**
Motor function					
Study group	39.46 ± 1.64	51.6 ± 1.59	-12.14	30.77	0.001
Control group	38.86 ± 1.35	45.26 ± 1.75	-6.4	16.47	0.001
MD	0.6	6.34			
p-value	***p = 0.28***	***p = 0.001***			
Sensation					
Study group	7.4 ± 0.51	10.73 ± 0.45	-3.33	45.00	0.001
Control group	7.53 ± 0.63	9.13 ± 0.74	-1.6	21.25	0.001
MD	-0.13	1.6			
p-value	***p = 0.53***	***p = 0.001***			
Passive joint motion					
Study group	15.86 ± 1.24	20.86 ± 0.74	-5	31.53	0.001
Control group	16 ± 0.92	18.26 ± 0.88	-2.26	14.13	0.001

MD	-0.14	2.6			
p-value	***p = 0.74***	***p = 0.001***			
Joint pain					
Study group	16.07 ± 0.88	21 ± 0.65	-4.93	30.68	0.001
Control group	16.53 ± 1.12	18 ± 0.92	-1.47	8.89	0.001
MD	-0.46	3			
p-value	***p = 0.21***	***p = 0.001***			

FMA-UE: Fugl-Meyer Assessment Upper Extremity; SD: Standard Deviation; MD: Mean Difference; p-value: Probability Value

4. DISCUSSION

The brain has a high capacity to automatically interpret and integrate inputs from multiple senses simultaneously (Ghazanfar & Schroeder, 2006). This ability enhances the detection, distinction, and recognition of sensory stimuli by integrating feedback from various senses (Gentile et al., 2011). Therefore, the aim of the present study was to evaluate how post-stroke upper extremity (UE) functions were affected by cognitive-motor rehabilitation (CMR) in combination with a specific physiotherapy program. The findings demonstrated that, compared to the control group, the study group showed significant improvements in UE functions, including motor, sensory, fine, and gross aspects due to CMR.

These results are consistent with Choi (2022), who examined the effects of cognitive exercise for 30 minutes a day, five sessions per week for one month on UE sensorimotor function and daily activities in stroke patients. Choi contrasted these outcomes with selected exercise therapies, which included passive movement activities to reduce spasticity in UE muscles, active joint exercises, and bilateral arm training. In contrast, the CMR intervention involved training to recognize the elbow and shoulder joints using a circular path plate to determine the shoulder joint's motion angle. Consequently, the study concluded that UE motor function, manual dexterity, and muscle power significantly improved through imagery training and cognitive therapy in stroke patients.

Ahn & Lee (2009) found that hemiplegic patients who underwent cognitive sensory therapy combined with spatial activities improved their orientation in the shoulder, elbow, and wrist joints. The outcomes demonstrated significantly enhanced joint awareness and movement direction on the hemiparetic side. Additionally, research by Lim & Lee (2014) on stroke patients with hemineglect showed that neurocognitive rehabilitation improved upper extremity (UE) motor abilities and grip test scores, with notable enhancements in the angles of the shoulder, elbow, and wrist joints, as well as spatial awareness.

The functional recovery of stroke patients was positively influenced by cognitive exercise therapy, as evidenced by the findings of the current study, which were consistent with the Fugl-Meyer Assessment for Upper Extremity (FMA-UE) and Manual Function Test (MFT). This aligns with a previous study by Lee et al. (2015), which demonstrated that cognitive exercise intervention significantly enhanced hemiparetic UE abilities.

Muscular recruitment and perception are directly related to the information obtained from neurocognitive rehabilitation, which encourages the practice of sensorimotor discrimination activities. After pathological injuries, a learning process is involved in motor recovery (Morreale et al., 2016). In agreement with the results from the MESUPES scale in the current study, previous research also showed improvements in the MESUPES scale following neurocognitive intervention in hemiplegic patients compared to conventional therapy (Sallés et al., 2017).

The frontoparietal brain regions are considered crucial for integrating the multimodal network, as somatosensory, motor, and visual inputs contribute to creating visuospatial body mappings that coordinate and regulate motor movements facilitated by cognitive-motor rehabilitation (CMR). This executive function of differentiating shape and size involves forming an image of the first shape, retaining it in working memory, and comparing the distinguishing characteristics of the first shape with the second shape (Van et al., 2020).

CMR may help hemiplegic patients reconfigure their mental body representations, providing precise, real-time feedback about their locations and movements in the environment (Oouchida et al., 2016). Consistent with the present study, previous research demonstrated the benefits of integrating multimodal stimulation with traditional training on stroke patients' UE motor recovery and self-care functions, showing that multisensory stimulation had a more significant improving effect compared to conventional training (Law et al., 2018).

The limitations of the current trial include the inability to assess the long-term effects of the intervention on UE functions and daily activities after the rehabilitation period. Future studies are recommended to investigate the impact of CMR on other neurological conditions and on gait or balance disturbances post-stroke.

5. CONCLUSIONS

Based on the results of this study, the implementation of CMR therapy in stroke patients has been demonstrated to enhance upper extremity (UE) functions significantly. Therefore, integrating CMR into the management of stroke patients could prove highly advantageous and beneficial.

6. RECOMMENDATIONS

- **Implementation of CMR in Rehabilitation Programs:** Clinicians should integrate CMR alongside traditional physiotherapy to maximize recovery outcomes for stroke patients. This combined approach can lead to more substantial improvements in UE function and daily activities.
- **Long-term Follow-up Studies:** Future research should focus on long-term follow-up to assess the sustained effects of CMR on UE functions and overall quality of life after rehabilitation. This will provide insights into the durability of treatment benefits.
- **Explore Other Neurological Conditions:** Investigate the efficacy of CMR in other neurological conditions, such as traumatic brain injury or multiple sclerosis, to determine its broader applicability and effectiveness.
- **Assessment of Gait and Balance:** Future studies should also evaluate the impact of CMR on gait and balance disturbances post-stroke, expanding the scope of recovery beyond upper extremity functions.

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AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

FUNDING

This research received no external funding.

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