

Combined effect of transcranial direct current stimulation (tDCS) and functional electrical stimulation (FES) on upper limb recovery in patients with subacute stroke

Background

“Stroke” is the second common cause of morbidity and long term disability.¹The World Health Organization (WHO) defines stroke as “The rapidly developing clinical signs and symptoms of focal disturbance of cerebral function, with symptoms lasting more than 24 hours or leading cause of death with no apparent cause”.² Universally, 16 million people have stroke every year.³

Approx 40% stroke sufferers have impaired function in their arm . The motor and sensory problems leads to long term disability. Upper limb neuromuscular weakness occurs frequently after stroke. The loss of muscle strength and dexterity together is considered to produce the largest impact on functional recovery of the stroke survivors.⁴ Recently studies indicated that neuroplasticity and cortical reorganization facilitate motor sensory recovery in stroke patients.⁵ Despite the traditional treatment strategies, Now a day’s advanced treatment protocols are also used for recovery of upper extremity which include Task Oriented Activities, CIMT, Virtual Reality Therapy, Mirror Therapy, Functional Electrical Stimulation ((FES)) and Non Invasive Brain Stimulation ((tDCS)).

Non Invasive Brain Stimulation (NIBS) is a powerful method to modulate the human brain function.⁶ Transcranial Direct Current Stimulation ((tDCS)) is a non-invasive brain stimulation technique. ((tDCS)) is a convenient, inexpensive and easy to operate and it can effectively increase or decrease neural excitability of the area being stimulated. ((tDCS)) application causes decrease in the cortical excitability with cathodal stimulation and increase in the neural excitability with anodal stimulation.⁶ ((FES)) is electrical stimulation of motor neurons such that muscle groups stimulate to contract and create a moment about a joint. ((FES)) is applied during the voluntary movement of the targeted extremity. ((FES)) basically uses short electrical impulses to produce contraction in paralyzed muscles.⁷ Till date enormous studies are present on individual effectiveness of ((tDCS)) and ((FES)) but very less literature is evidenced on the combined use of ((tDCS)) and ((FES)) hence the present study to examine the combined effectiveness of upper limb (tDCS) along with (FES) compared to conventional treatment in improving motor functional activities in subacute stroke survivors.

Methodology

The present study was randomized controlled in trial in participants were randomized according to computer generated randomization table into two groups. i.e (Group A) (Experimental Group) and (Group B) (Control Group). Participants of the (Group A) received ((tDCS)), ((FES)) and Conventional physiotherapy treatment, while Participants

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of (Group B) Received ((tDCS)) and Conventional physiotherapy treatment. Total Treatment was given for the period of 21days (5days per week for 3weeks, 60min each session).

The ethical approval was obtained from the Institutional ethical committee, Punjabi University, Patiala before the commencement of study. All the participants gave their written consent prior to the start of the study. For ((tDCS)) application, electrode placement was done based on 10-20 EEG Classification system at points C3 and C4, with intensity 1.2mA, for the duration of 20Minutes in Experimental Group. (FES) was applied at wrist extensor origin with Frequency 20-40Hz, pulse 30-500 μ s, Intensity \leq 100mA, (10min task oriented exercises mode) in both the Groups. Conventional Physiotherapy treatment was focused on the Gross motor activities, Muscle strengthening exercises, Upper extremity training, Balance Training and task oriented exercises.

In the present study, objective assessment for upper extremity and hand function was done with fugl meyer assesment scale for upper extremity (FMA- UE), Chedock Arm and Hand Inventory ((CAHAI)). Nine Peg Hole (NPHT) for assessment of Manual Dexterity , Hand Dynamometer for measurement of power grip strength and Pinch gauge for assessment of pinch strength). Objective measurements were taken on (Day 0) and Post Intervention i.e at (Day 21). Data was collected and statistically analyzed using SPSS Version16.

Results

FMA-UE

All the participants completed their study and data of all the participants was used for the purpose of statistical analysis Assessment with FMA-UE revealed that the mean values of FMA-UE scores on (Day 0) and (Day 21)for (Group A) participants was 112.70 \pm 4.27 and 118.90 \pm 4.23 respectively. In the (Group B), the mean scores for FMA-UE score was 108.70 \pm 10.33 and 112.60 \pm 10.28 at (Day 0) and (Day 21) respectively. The change scores in the form of mean difference

between (Day 0) and (Day 21) of (Group A) and (Group B) participants of FMA-UE score was 6.20 ± 0.92 and 3.90 ± 0.88 respectively. The (t value) of FMA-UE score at 95% significance at (Day 0) and (Day 21) was 1.132 and 1.79 respectively between (Group A) and (Group B) which signifies non-significant difference between two groups. While MD (Day 0) vs (Day 21) was 5.73 between (Group A) and (Group B) which indicates significant difference between two Groups.

(CAHAI)

In the present study the chedock arm and Hand recovery scores of (Group A) increased from (40.30 ± 10.07) to (47.00 ± 10.27) and for the control Group the mean scores increased from (37.30 ± 17.19) to (40.40 ± 17.78) after 3 weeks of intervention. The calculated (t value) for experimental (Group A) and Control group was 25.735 and 7.6 with (p value) .000 and .000 respectively, indicating significant (at $P < 0.05$) results in both the groups. An independent t-test found there was a significant difference between (Group A) and (Group B) respectively with ((t value) -25.735, $p = .000 < 0.05$) indicating significant results. The mean score on (Day 21) were (37.30 ± 17.19) and (40.40 ± 17.78) for (Group A) and (Group B) respectively with ((t value) -2.619, $p = .000 < 0.05$) showing significant results. The mean comparison of change scores between both groups revealed significant results with mean scores as (6.70 ± 0.82) and (3.10 ± 1.29) and (Group A) and (Group B) respectively with ((t value) 7.453, $p = .000 < 0.05$).

Nine peg hole test

The mean scores of assessment of upper extremity function according to NPHT. It is observed that for Group the mean score of NPHT increased from (3.36 ± 2.73) to (1.92 ± 1.70) and for the (Group B) the mean scores increased from (1.97 ± 2.58) to (1.32 ± 1.90) . The calculated (t value) for experimental (Group A) and Control group was -9.992 and -5.600 with (p value) .000 and .000 respectively, indicating significant (at $P < 0.05$) results in both the groups. The mean scores of (NPHT) among (Group A) and (Group B) respectively with ((t value) 3.976 (p .003 < 0.05). Post intervention result between (Group A) and (Group B) respectively with ((t value) 2.521, $p = .033 < 0.05$) showing significant results. The mean comparison of change scores between both groups revealed non-significant results with mean scores as (-1.44 ± 1.14) and (-0.64 ± 0.81) and (Group A) and (Group B) respectively with ((t value) -1.798, $p = .089 > 0.05$).

Power grip strength: The mean scores LPG increased from (12.95 ± 7.34) to (17.70 ± 8.00) in the experimental (Group A) and for

the control Group the mean scores increased from (16.30 ± 11.16) to (18.75 ± 12.25) after 3 weeks of intervention. The calculated (t value) for experimental (Group A) and Control group was -9.992 and -5.600 with (p value) .000 and .000 respectively, indicating significant difference between two groups (at $P < 0.05$). The mean comparison of change scores between both groups revealed significant results with mean scores (4.75 ± 1.51) and (2.45 ± 1.38) for (Group A) and (Group B) respectively with ((t value) 3.547, $p = .002 < 0.05$).

Lateral pinch

It was observed that for experimental group the mean score of LPG increased from (3.20 ± 1.89) to (4.20 ± 1.75) and for the control Group the mean scores increased from (4.53 ± 2.42) to (4.99 ± 2.51) after 3 weeks of intervention. The calculated (t value) for experimental (Group A) and Control group was -6.708 and -4.929 with (p value) .000 and .000 respectively, indicating significant (at $P < 0.05$) results in both the groups. The mean comparison of change scores between both groups revealed significant results with mean scores as (1.00 ± 0.47) and (0.46 ± 0.30) and (Group A) and (Group B) respectively with ((t value) 3.070, $p = .007 < 0.05$).

Chuck pinch grip

The mean score of (CPG) on (Day 0) was (2.80 ± 1.44) and (4.25 ± 2.42) for (Group A) and (Group B) respectively with ((t value) -8.143, $p = .000 < 0.05$). The mean score on (Day 21) were (4.20 ± 1.75) and (4.99 ± 2.51) for (Group A) and (Group B) respectively with ((t value) -4.929, $p = .000 < 0.05$) showing significant results. The mean comparison of change scores between both groups revealed significant results with mean scores as (0.95 ± 0.37) and (0.37 ± 0.24) and (Group A) and (Group B) respectively with ((t value) 4.530, $p = .000 < 0.05$).

Pulp pinch grip

The comparison of mean score of Pulp to pulp index finger Grip (PPG) of among (Group A) and (Group B) participants. The mean score of (PPG) on (Day 0) was (2.50 ± 1.51) and (2.85 ± 1.47) for (Group A) and (Group B) respectively with ((t value) -7.236, $p = .000 < 0.05$). The mean score on (Day 21) were (3.30 ± 1.36) and (3.70 ± 1.92) for (Group A) and (Group B) respectively with (t value) -2.684, $p = .025 < 0.05$) showing significant results. The mean comparison of change scores between both groups revealed non-significant results with mean scores as (-0.525) and (-0.538) and (Group A) and (Group B) respectively with (t value) -0.149, $p = .884 > 0.05$ as described in Table 1 and (Table 2) and in Figure 1 and Figure 2.

Table 1 Improvement within Group comparison of FMA-UE, (CAHAI), NPHT, PG, LPG, CPG, PPG among (Group A) and (Group B)

Outcome measurers	(GROUP A)		(GROUP B)		(t value)	(p value)	
	Baseline 0 Day	Post 21 st Day	Baseline 0 Day	Post 21 st Day		Group A	Group B
FMA-UE	112.70 ± 4.27	118.90 ± 4.23	108.70 ± 10.3	112.60 ± 10.2	-21.33	-14.08	.000
(CAHAI)	40.30 ± 10.07	47.00 ± 10.27	37.30 ± 17.19	40.40 ± 17.7	-25.735	-7.6	.000**
NPHT	3.36 ± 2.73	1.92 ± 1.70	1.97 ± 2.58	1.32 ± 1.90	3.976	2.521	.003**
PG	12.95 ± 7.34	17.70 ± 8.00	16.30 ± 11.16	18.75 ± 12.2	-9.992	-5.600	.000**
LPG	3.20 ± 1.89	4.20 ± 1.75	4.53 ± 2.42	4.99 ± 2.51	-6.708	-4.929	.000**
CPG	2.80 ± 1.44	3.75 ± 1.55	4.25 ± 2.42	4.57 ± 2.38	-8.143	-4.226	.000**
P to P	2.50 ± 1.51	3.30 ± 1.36	2.85 ± 1.47	3.70 ± 1.92	-7.236	-2.684	.000**

Table 2 Comparison of mean value & SD and t-statistics FMA-UE, (CAHAI), NPHT ,PG ,LPG,CPG, (PPG) of score at different intervals ((Day 0) and (Day 21)) between (Group A) and (Group B) Participants

Outcome measure	(GROUP A)		(GROUP B)		Mean		t-value		(p value)		MD	
	BASELI-NE 0 Day	Post 21 st Day	Baseline 0 Day	Post 21 st Day	(Group A)	(Group B)	0 day	21 st day	0 Day	POST	t-value	(p value)
FMA-UE	112.70±4.27	118.90±4.23	108.70±10.3	112.60±10.2	6.20±0.92	3.90±0.88	1.132	1.79	.273*	.090*	5.730	.000**
(CAHAI)	40.30±10.07	47.00±10.27	37.30±17.19	40.40±17.7	6.70±0.82	3.10±1.29	0.476	1.016	.640*	.323*	7.45	.000**
NPHT	3.36±2.73	1.92±1.70	1.97±2.58	1.32±1.90	-1.44±1.14	-0.64±0.81	1.174	0.743	.256*	.467*	-1.798	.089**
PG	12.95±7.34	17.70±8.00	16.30±11.16	18.75±12.2	4.75±1.51	2.45±1.38	-0.793	-0.227	.438*	.823*	3.547	.002**
LPG	3.20±1.89	4.20±1.75	4.53±2.42	4.99±2.51	1.00±0.47	0.46±0.30	-1.370	-0.815	.187*	.426*	3.070	.007**
CPG	2.80±1.44	3.75±1.55	4.25±2.42	4.57±2.38	0.95±0.37	0.37±0.24	-1.630	-0.914	.120*	.373*	4.530	.000**
P to P	2.50±1.51	3.30±1.36	2.85±1.47	3.70±1.92	0.80±0.35	0.85±1.00	-0.525	-0.538	.606*	.597*	-0.149	.884*

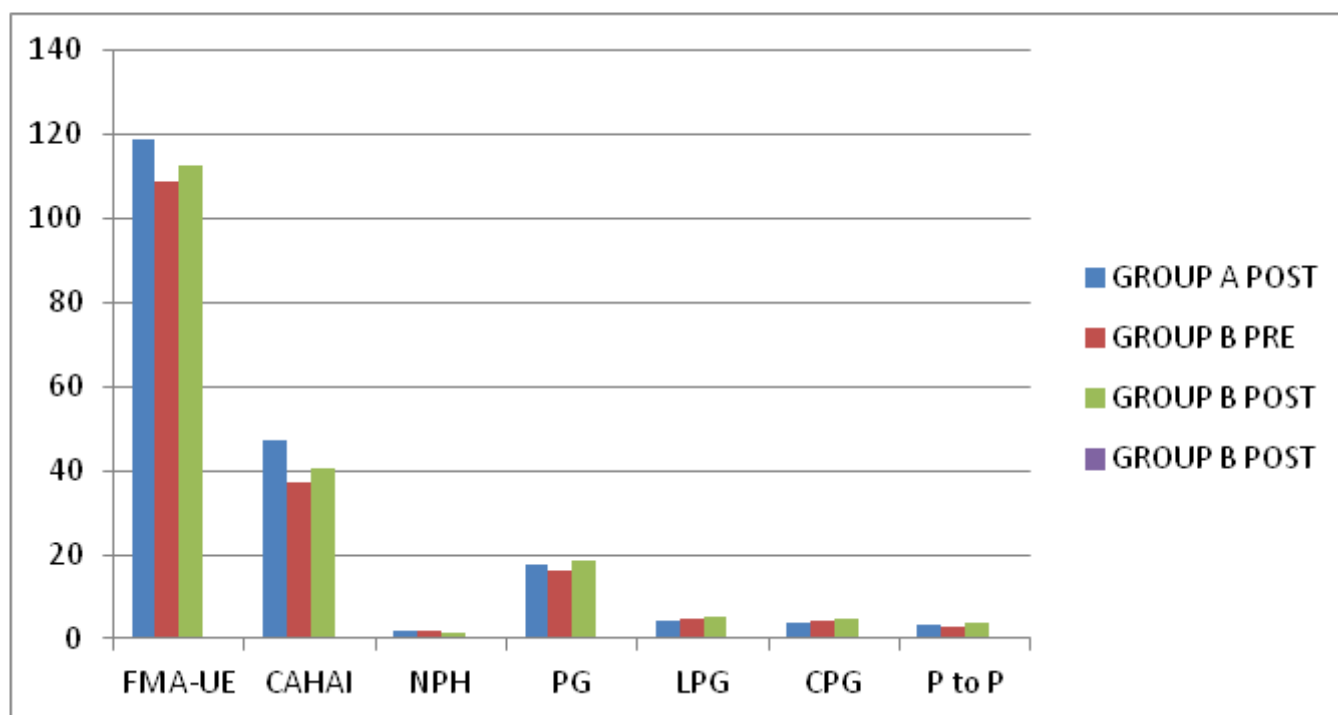


Figure 1 Improvement within Group comparison of mean value of FMA-UE, (CAHAI), NPHT , PG ,LPG, CPG, PPG among (Group A) and (Group B).

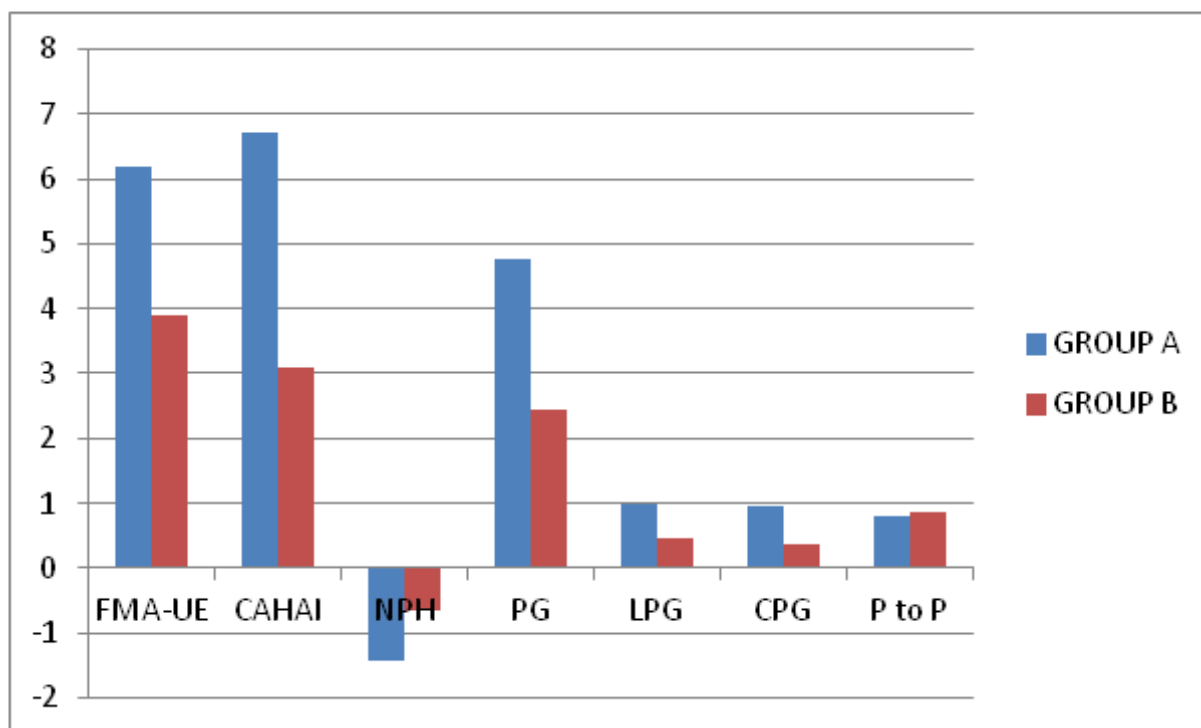


Figure 2 Comparison of mean value & SD and t-statistics FMA-UE, (CAHAI), NPHT, PG, LPG, CPG, PPG of score at different intervals (Day 0) and (Day 21) between (Group A) And (Group B).

Discussion

Stroke is the second most common cause of mortality and the third leading cause of death (WHO, 2016). Every year 15 million people worldwide suffer from stroke (WHO, 2011) and nearly six million survivors die and 90% of the stroke survivors have motor dysfunctions and hemiparesis that is frequently associated with ischemia.⁸ That further leads to immobility. Immobility can recruit more sequence of motor impairment problems including peripheral soft tissue changes, abnormal muscle synergy, abnormal limb posturing, pain, nonuse and decrease function of upper limb.⁹

Hand function impairments induce problems in common activities such as reaching, grasping, picking up objects and holding objects.¹⁰ Perseverance of motor impairment for long time can make patients become functionally dependent on others.¹¹ Inadequacy in reaching and grasping has an important role into inducing their daily activities and creating great impact on quality of life. Wishwah et al.¹² suggested that with motor cortex damage shows a drop in performance during intervals of no training. Functionally troubled motor tasks performance requiring somatosensory information, the motor problems causing from sensory problems after stroke like impairment in recognition of sensory information.¹³ So additional neurorehabilitation is much required to get better recovery.

By theoretical understanding, a stroke rehabilitation protocol for upper limb motor recovery should include global motor learning, neurofacilitatory concepts, electrical brain stimulation and Functional Electrical Stimulation. Nitsche et al., shows that a current Non

Invasive Brain Stimulation (NIBS) like Repetitive Transcranial Magnetic Stimulation (rTMS) and Transcranial Direct Current Stimulation ((tDCS)) influence the function of the corticospinal tracts by modulating the corticomotor excitability. Transcranial Direct Current Stimulation ((tDCS)), a non-invasive brain stimulation is very effective, safe, portable and easily accessible protocol. Brain activity changes when the weak direct current (1-2mA) is given to the scalp through sponge electrodes to modulate cortical activity.¹⁴

The functional improvement seen due to (FES) therapy is a preprogrammed stimulation that integrates electrical stimulation of sensory motor system and repetitive muscle contraction in synergistic manner and simultaneously, sensory signals generated by the excitation of afferent pathway in the stimulated peripheral nerves and accomplish the arm motion with proper effort. So, the present study was conducted to analyze the combined effect of transcranial direct current stimulation and Functional electrical stimulation along with conventional physiotherapy for upper limb recovery among sub acute stroke survivors.

The effect of (tDCS) and (FES) and conventional treatment was measured on Upper limb before and after the implementation of the intervention by using Fugl Meyer Assessment –Upper Extremity. In (Group A) the mean score of (FMA-UE) at baseline (Day 0) and (Day 21) were (112.70±4.27) and (118.90±4.23) respectively. And in (Group B) was (108.7±10.33 and 112.60±10.28) at baseline i.e. (Day 0) and (Day 21) respectively.

The mean difference of (Day 0) Vs (Day 21) within experimental

group FMA –UE score was 6.20 ± 0.92 and which was showing significant improvement in FMA-UE Score and noted improvement seen in upper limb function, activities and stroke impact among subacute stroke survivors. According to Vafadar et al.¹¹ (FES) can increase the activity of muscles in the arm and also facilitates the joint motion by directly stimulating the nerves or their motor points in specific sequence and magnitude, which lead to improvement in motor function. On the other hand, according to Chae et al.¹⁵ significant improvement in FMA-UE scores in experimental group with application of (tDCS) to stroke patients by increasing motor performance of upper extremity was found. (tDCS) provide a nonspecific input to the motor cortex, facilitating changes with neural activation and synaptic plasticity which improve the functional recovery and enhance the voluntary ADL activity, facilitating the function of the damaged cerebral hemispheric area.

In present study, Chedock Arm and Hand inventory has been used to check the upper limb arm and hand recovery. On within group comparison mean score of (CAHAI) at baseline (Day 0) was 40.30 ± 10.07 and on (Day 21) was 47.00 ± 10.27 for (Group A) with (t value) - 25.735 and $p = .000$. In (Group B) mean score at baseline (Day 0) was 37.30 ± 17.19 and on (Day 21) was 40.40 ± 17.78 with ((t value) -2.619) the (p value) ($p < 0.05$) showing significant results. The between groups comparison revealed significant results with mean scores as (Group A) and (Group B) (6.70 ± 0.89 and 3.10 ± 1.29) respectively with (t value) 7.453. Results of our study noted the significant improvement in grasping holding and releasing objects in (CAHAI) score assessment.¹⁶ Effect of (tDCS) for motor performance improve significantly with both cathodal stimulation of the unaffected hemisphere and anodal stimulation of affected hemisphere. (tDCS) has a bidirectional regulatory effect on the target cortical regions.¹⁷ Vafadar¹¹ who conducted study on effectiveness of (FES) in upper limb clinical outcome they found significant results with (FES) directly activation of intact lower motor neurons or near innervating nerve fibers of the paralyzed muscles.

In the present study Nine Peg Hole test was used for the assessment of motor skills on stroke survivors. On within group comparison baseline score (at (Day 0)) for (Group A) participants were 3.36 ± 2.73 and post intervention scores (Day 21) was 1.92 ± 1.70 in (Group A) with $t = 3.976$, $p = .003$. In (Group B) mean score at baseline (Day 0) was 1.97 ± 2.58 and on (Day 21) 1.32 ± 1.90 with (t value) 2.521. However between group comparison revealed significant results while comparison between change scores (pre-post) between both groups mean score of baseline 3.36 ± 2.73 and 1.97 ± 2.58 for (Group A) and B respectively with (t value) 1.174, $p = .256$ reveal non-significant results.

Post interventions score were 1.92 ± 1.70 and 1.32 ± 1.90 for (Group A) and (Group B) respectively with (t value) 0.743, $p = .467$ showing nonsignificant findings. Comparison was also done in the improvement scores change in mean score (pre-post). Change in mean scores for (Group A) was -1.44 and for (Group B) was 1.14 with (t value) -1.798, showing non-significant findings.

Although statistically results were non-significant but, reduction of mean scores was observed in the outcome measure showing clinically improvement of dexterity function in the experimental group due to normal physiological basis of neural control of hand justifying difficulty and loss in regaining the individual digit movement when other digits are not assist for movement. Power grip strength was used to evaluate the combined effectiveness of (tDCS) and (FES) along with conventional physiotherapy among subacute stroke survivors.

In within group comparison baseline score (at (Day 0)) for (Group A) participants were 12.95 ± 7.34 and post intervention scores (Day 21) was 17.70 ± 8.00 in (Group A) with $t = -9.922$, $p = .000$. In (Group B) mean score at baseline (Day 0) was 16.30 ± 11.16 and on (Day 21) 18.75 ± 12.25 with (t value) -5.600. However between group comparison revealed significant results while comparison between change scores (pre-post) between both groups. Mean score of baseline 12.95 ± 7.34 and 16.30 ± 11.16 for (Group A) and (Group B) respectively with (t value) -0.793 Shows nonsignificant results.

Post interventions score were 17.70 ± 8.00 and 18.75 ± 12.25 for (Group A) and (Group B) respectively with (t value) -0.227 showing nonsignificant findings. Comparison was also done in the improvement scores change in mean score (post –pre). Change in mean scores for (Group A) was 4.75 ± 1.51 and for (Group B) was 2.45 ± 1.38 with (t value) 3.547 showing significant findings. This result supported by Heller et al. in which remarkable grip strength was first function to recovery following in individual finger grip.

This significant improvement was also supported by study conducted by Butler et al.,¹⁸ Small to moderate effect of (tDCS) for inducing improvement in the upper limb function was through remodulation of cortical function via anodal stimulation to the cortex thereby increasing neural firing and decreasing the cortical excitability with the cathodal stimulation.¹⁹ Eraifej et al.³ suggested that the (FES) stimulate the motor neurons of muscle groups and this stimulation induce the muscle contraction and joint movement of the hand that could be helpful in gripping the objects.^{20–26}

Conclusion

The present study concluded that the participants who underwent upper limb recovery treatment using transcranial direct current stimulation and Functional electrical stimulation along with conventional physiotherapy treatment, had significantly greater improvement in upper limb mobility and functional activity compared with participants who underwent transcranial direct current stimulation with conventional physiotherapy treatment alone.

Recommendations

(tDCS) and (FES) along with conventional physiotherapy may be effective interventions will be helpful in enhancing the upper limb recovery of stroke patients and make him/her a better living in their surrounding environment and independent in doing their daily activities of living (ADLs). So, it is recommended that the further studies using large samples, and follow up shall be done to evaluate the long term combined effects of both the interventions.

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Conflicts of interest

No conflict of interest.

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