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Effect of varied bimanual arm therapy on upper limb function, trunk function, balance, gait and cardiovascular endurance in stroke patients

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Siddharth S. Mishra[1], Susan Jose[1]

[1]*Maharasthra University of Health Sciences MUHS Nasik, India.*

Abstract:

Cerebrovascular accident-induced spasticity of one side of the body contributes to slowing down movement coordination, disturbed balance, and trunk control during gait that limits activities of daily living in stroke survivors. Bimanual therapy is an active, task-specific approach where limbs are constrained to act as a single unit by virtue of neural coupling. The present study aims to compare the effect of varied forms of bimanual arm therapy on upper limb function, trunk function, balance, gait, and cardiovascular endurance in stroke patients. Stroke patients (n=30) were randomly assigned to three treatment groups: Group A (loaded bimanual therapy with rhythmic auditory cueing); Group B (loaded bimanual therapy); and Group C (conventional therapy). Each group received 15 intervention sessions within 3 weeks. Results: an intragroup analysis showed a statistically significant difference ($p<0.05$) in WMFT, TIS, DGI, BBS, and 6MWD distance in all three groups individually. An intergroup analysis between the groups showed the highest improvements in WMFT, TIS, and MWD in Group A whereas Group B showed the highest improvement in TIS, BBS, and DGI. Hence, we conclude that loaded bimanual therapy with rhythmic auditory cueing leads to the maximum improvement in trunk function, balance, and gait. Loaded bimanual therapy demonstrated the maximum improvement in upper limb function and the distance covered in 6MWT compared to other groups.

Keywords: stroke rehabilitation, exercise therapy, postural balance

Corresponding author:

Siddharth S. Mishra
Assistant Professor MPTh (Neuro-PT), MGM Hospital,
Department of Neuro-Physiotherapy. MGM College of Physiotherapy,
Navi Mumbai.
siddharth24789@gmail.com

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Introduction

WHO definition of stroke is "rapidly developing clinical signs of focal disturbance of cerebral function, with symptoms lasting 24 hours or longer or leading to death, with no apparent cause other than of vascular origin"[1]. According to the 2013 epidemiological study, the incidence rate of stroke in India is 147 to 922 per 1,000,000 population [2]. Approximately 70-80% of stroke survivors have limited activities of daily living (ADLs) due to motor impairment of affected upper limb function and manual dexterity [3]. Muscle spasticity leads to significant slowing down of manual movements, alteration in multi-joint coordination, decrease in smoothness, and segmentation of reaching and grasping movements. This results in the uneasiness of upper limb and trunk movements, more likely to alter the stability and gait pattern of an individual [4,5]. Many patients do not regain functional use of the paretic side completely and, after 6 months post-stroke, a large population (28-50%) remains dependent on others for at least one of the activities of daily living (ADL) [6].

Conventional bimanual therapy is an active task-specific approach where the limbs are constrained to act as one unit that improves the strength of the paretic arm and coordination between the paretic and non-paretic arms [6]. Symmetrical tasks demand equal participation of both limbs, improving bilateral coordination which is strongly associated with high integrity of the corpus callosum, caudal cingulated motor area, and the supplementary motor area. In healthy individuals with an intact neuromuscular system; both hands work as a single unit by virtue of neural coupling in a coordinated fashion during activities of daily living, like upper and lower dressing, opening a bottle, lifting weights, toileting, etc. [7]. In loaded bimanual therapy, a load (weight) is added on the non-paretic arm while performing bimanual tasks. Adding rhythmic auditory cues sets up bimanual task frequency that might improve the accuracy of the task performance [6].

Conventional bimanual therapy, loaded bimanual arm training with rhythmic auditory cueing (BATRAC) and loaded bimanual therapy have shown significant improvements in motor function in stroke patients despite treatment variability and duration [2,3,6–10]. No research has been conducted on the effectiveness of all three therapies to bring improvement in motor function and cardiovascular endurance in stroke patients in a shorter time frame. Therefore, the present study aims to compare the effect of various forms of bimanual arm therapy on upper limb function, trunk function, balance, and cardiovascular endurance in stroke patients.

Material and Methods

The study commenced after approval by the institutional ethical review board was obtained. A total of forty-five stroke patients from outpatient and inpatient departments of two tertiary care setups were screened based on inclusion and exclusion criteria. The inclusion criteria were first-time stroke survivors within 1 year of diagnosis by computerized tomography or magnetic resonance imaging, individuals aged between 45 and 70 years, normal BMI, and class I obesity classified according to the Quetelet's Index [11], ability to ambulate 10 meter distance with or without assistive devices, Mini Mental Scale Examination Score more than 24 [12], Brunnstorm stage 2 and above [13], upper limb muscles tone 2 or less as per Modified Ashworth scale [14], and patients with corrected visual impairments**.** The exclusion criteria were unstable medical conditions, musculo-skeletal disorders affecting arm mobility such as shoulder subluxation or impingement, reflex sympathetic dystrophy, and other neurological comorbidities e.g. seizures. Study criteria were fulfilled by 30 stroke patients and 15 stroke patients were excluded. Patients were randomly allocated into 3 treatment groups (10 in each group): Group A (loaded bimanual therapy with rhythmic auditory cueing), Group B (loaded bimanual therapy), and Group C (conventional therapy) (Tab.1). Each patient signed a written informed consent before the commencement of the study.

trunk rotation in a circular manner, (3) controlled rolling of the ball on a wedge, (4) controlled rolling of the towel (wall cleaning) up and down, side to side and circular motions, and (5) moving the ball in proprioceptive neuromuscular facilitation (PNF) diagonal chopping and lifting pattern (Fig.1). Tasks 1, 2, and 3 were performed in a high sitting position whereas the other two tasks were performed in standing. In tasks involving

Table 1. Study Flow Chart

<table>
<tr><th colspan="4">Ethical Committee Approval</th></tr>
<tr><th colspan="4">Screening of stroke patients (N=45)</th></tr>
<tr><th colspan="3">N=30 met inclusion criteria</th><th>(N= 15) excluded</th></tr>
<tr><td>Group A (N=10)

loaded bimanual therapy with rhythmic auditory cues</td><td>Group B (N=10)

loaded bimanual therapy</td><td>Group C (N=10)

conventional therapy</td><td rowspan="3">-Stroke duration >1 year (N=8)
-MAS > 3 (N=4)
-MMSE score < 24 (N=3)</td></tr>
<tr><td colspan="3">15 intervention sessions within 3 weeks.</td></tr>
<tr><td colspan="3">Duration each session 45-60 minutes</td></tr>
</table>

Intervention

Group A (loaded bimanual therapy with rhythmic auditory cueing) and Group B (loaded bimanual therapy) received calibrated load (weight cuff) of 912g [9] tied over the non-paretic forearm. Weight cuff of 912g was calibrated using a standardized calibration procedure, eccentricity, and test-retest reliability test. In Group A, a metronome was used as an auditory cue that was rhythmic in nature with a beat frequency of 20 beats per minute. The metronome was turned off during the rest phase. Bimanual tasks performed included five gross upper limb and trunk movements: (1) transferring the ball from one side to the other with a vertical separator in between, (2) transferring and passing the ball to the therapist from one side to the other using

ball movements, the ball was held in between both hands with the elbow extended. Straps were used for stabilization if the patient was unable to hold the ball. Group B performed the same bimanual tasks with a calibrated cuff over the forearm without auditory cueing (metronome). The conventional therapy group performed a weight-bearing exercise, stretching and strengthening exercise, pegboard exercise, functional object grasp exercise, and the bimanual task without any added load and auditory cues. Conventional therapy was administered to all three groups. Each group received 15 intervention sessions within 3 weeks, with each session lasting 45-60 minutes.

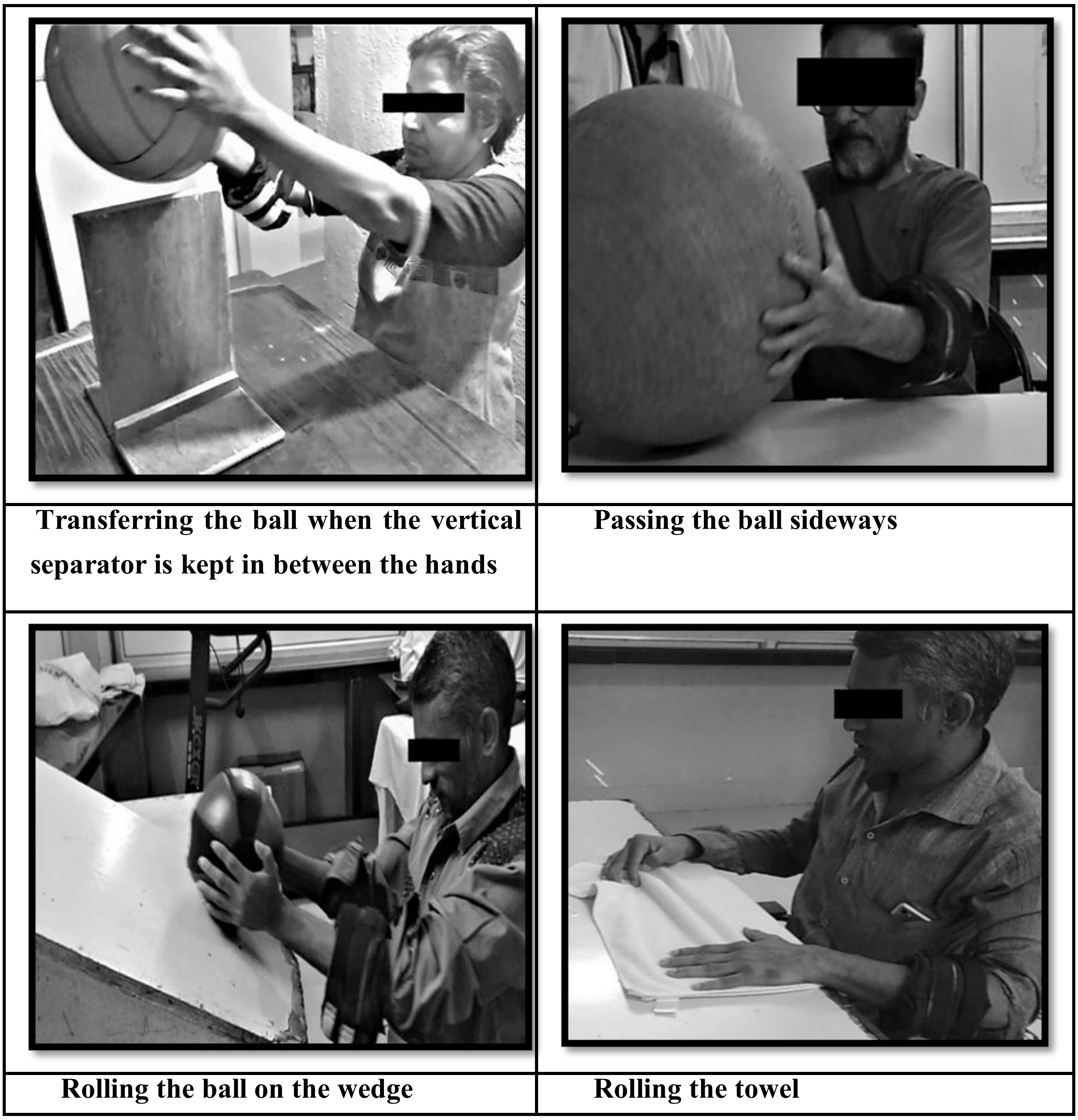

Figure 1. Bimanual movement task

Outcome Measures

The Wolf's Motor Function Test was used to assess upper limb function based on time-based functional tasks [15]. The Trunk Impact Scale was used to assess motor impairment in the body trunk after stroke [16,17]. The Berg's Balance Scale was used to assess proactive balance control and risk of fall [18]. The Dynamic Gait Index [19] was used to assess gait and balance. The 6 Minute Walk Test was employed to assess cardiovascular endurance and the distance covered [20].

Statistical analysis

Statistical analysis was carried out using IBM SPSS (International Business Machines, Statistical Package for the Social Sciences 2016 version 24. The normality of data was computed using the Shapiro-Wilk test. For normally distributed data, parametric tests were carried out whereas for the data which did not follow a normal distribution, we used non-parametric tests. Means and standard deviations were computed for all variables. The level of significance was set at 0.05 for all inferential statistics.

Results

A total of 30 stroke patients (22 males and 8 females) participated in the study. The demographic details of the participants are presented in Table 2. All demographic variables demonstrated no statistically significant differences, suggesting a uniform distribution among stroke patients.

On pre-post comparison, Group A (loaded bimanual therapy with rhythmic auditory cueing) demonstrated statistically significant differences (p=0.00) in scores of WMFT, TIS, BBS, DGI, and 6MWT (Tab. 3).

Also on pre-post comparison, Group B (loaded bimanual therapy) demonstrated statistically significant differences (p=0.000) in scores of WMFT, TIS, BBS, DGI and 6MWT (Tab. 4).

On pre-post comparison, Group C (conventional therapy) demonstrated statistically significant differences (p=0.000) in scores of WMFT, TIS, and BBS (Tab. 5).

Intragroup analysis between the three groups using Friedman's test demonstrated statistically significant differences in scores of all outcome variables ($p<0.05$). Group A (loaded bimanual therapy with rhythmic auditory cues) reported the highest mean rank values for BBS and DGI compared to Group B (loaded bimanual therapy) and Group C (conventional therapy). Group B (loaded bimanual therapy) showed the highest mean rank values for WMFT and 6MWT compared to Group A (loaded bimanual therapy with rhythmic auditory cues) and Group C (conventional therapy). Both Group A and B demonstrated the highest mean rank value for TIS when compared to Group C (Tab. 6).

Table 2. Demographic information about patients

Variables	**Group A**	**Group B**	**Group C**	**X^2 value /t value**	**p value**
Age years [Mean ± SD years]	59.2 ± 8.216	52.5 ± 9.21	52.5 ± 10.99	1.84	0.17 [1]
Body Mass Index m^2/kg [Mean ± SD]	25.89 ± 3.41	23.76 ± 2.27	25.19 ± 4.03	1.06	0.37 [1]
Duration months [Mean ± SD]	6 ± 3.59	7.9 ± 3.24	7.9 ± 3.81	1.95	0.39 [1]
Gender [N= 30]				1.41	0.26 [2]
Male [n=22]	5	9	8		
Female [n=8]	5	1	2		
Affected side [N=30]				2.08	0.39 [2]
Right [n=14]	3	5	6		
Left [n=16]	7	5	4		

*Legend: * SD= standard deviation; N = numbers. Group A- loaded bimanual therapy with rhythmic auditory cues, Group B- loaded bimanual therapy, Group C- conventional therapy; subscript no: t value[1]; chi-square x^2 value[2]*

Table 3. Intragroup comparison of Wolf Motor Function Test, Trunk Impairment Scale, Berg's Balance Scale, Dynamic Gait Index, and 6 Minute Walk Test Peak Heart in stroke patients that received loaded bimanual therapy with auditory cues (Group A)

Outcome measures	Pre-test value (Mean ± SD)	Post-test value (Mean ± SD)	Mean Difference	z value / # t value	p value
WMFT	180.42 ±18.56	155.29±104.30	23.43±26.65	-2.80	0.00*
Trunk Impairment Scale	13.9±2.84	17±2.58	7.1±1.19	2.82	0.00*
Berg's Balance Scale	37.7±8.11	41.6±9.58	3.1±1.85	2.81	0.00*
Dynamic Gait Index	12.3±5.83	14.3± 6.44	3.9±1.15	2.69	0.00*
6MWT peak heart rate	107.5 ± 41.70	105.9±41.39	2±3.82	1.36	0.17
6MWD	223.95±106.07	243.1± 10.7	1.2±3.82	# -4.08	0.00*

*Legend: # T value; SD: standard deviation, * statistically significant*

Table 4. Intragroup comparison of Wolf Motor Function Test, Trunk Impairment Scale, Berg's Balance Scale, Dynamic Gait Index, and 6 Minute Walk Test Peak Heart in stroke patients that received loaded bimanual therapy (Group B)

Outcome measures	Pre-test value (Mean ± SD)	Post-test value (Mean ± SD)	Mean Difference	z value / # t value	p value
WMFT	518.56 ± 3.37	485.92±2.32	32.64 ±5.38	-2.80	0.00*
Trunk Impairment Scale	12.5±2.27	15.8±1.61	4.4±0.99	2.82	0.00*
Berg's Balance Scale	43.3±4.19	46.2±3.64	3.3±0.73	2.84	0.00*
Dynamic Gait Index	15.2 ± 4.59	16.9 ± 3.95	2.9±0.81	2.63	0.00*
6MWT peak heart rate	111.7±10.73	111.2±10.51	1.7±2.48	1.89	0.06
6MWD	290.94 ± 94.50	322.20 ± 9.42	0.5±4.17	#-5.01	0.00*

*Legend: # T value; SD: standard deviation, * statistically significant*

Table 5. Intragroup comparison of Wolf Motor Function Test, Trunk Impairment Scale, Berg's Balance Scale, Dynamic Gait Index, and 6 Minute Walk Test Peak Heart in stroke patients that received conventional therapy (Group C)

Outcome measures	**Pre-test value** (Mean ± SD)	**Post-test value** (Mean ± SD)	**Mean Difference**	**z value / # t value**	**p value**
WMFT	273.83±82.74	265.97±81.13	7.96±5.38	-2.80	0.00*
Trunk Impairment Scale	12.7±2.45	13.8± 2.34	0.6±0.99	2.41	0.01*
Berg's Balance Scale	18.6±10.63	19.5±10.69	1.1±0.73	2.46	0.01*
Dynamic Gait Index	39.4±9.14	40.4±9.61	0.9±0.81	-2.42	0.01*
6MWT peak heart rate	109.3±20.05	109.1±19.71	1±2.48	1.65	0.09
6MWD	268.72±4	275.73±6.81	2.2±4.17	#-6.96	0.30

*Legend: # T value; SD: standard deviation, * statistically significant*

Table 6. Intergroup comparison using Friedman's test between loaded bimanual therapy with rhythmic auditory cues, loaded bimanual therapy and conventional therapy for the Wolf Motor Function Test, Trunk Impairment Scale, Berg's Balance Scale, Dynamic Gait Index, and 6 Minute Walk Distance

Outcome Variables	**p value**	**Groups**	**Mean Ranks**
WMFT Score	0.00*	Group A	2.10 [2]
		Group B	2.70 [1]
		Group C	1.20 [3]
Trunk Impairment Scale	0.00*	Group A	2.40 [1]
		Group B	2.40 [1]
		Group C	1.20 [2]
Berg's Balance Scale	0.00*	Group A	2.80 [1]
		Group B	2.10 [2]
		Group C	1.10 [3]
Dynamic Gait Index	0.02*	Group A	2.60 [1]
		Group B	1.95 [2]
		Group C	1.45 [3]
6MWD	0.00*	Group A	1.90 [2]
		Group B	2.80 [1]
		Group C	1.30 [3]

*Legend: Group A- loaded bimanual therapy with cues, Group B- loaded bimanual therapy, Group C- conventional therapy, superscript number [1,2] and [3] is mean rank for outcome variable, * statistically significant*

Discussion

The present study explored the effect of varied bimanual arm therapy on upper limb function, trunk function, balance, gait, and cardiovascular endurance in stroke patients. All 3 groups showed significant changes in the WMFT, TIS, DGI, BBS and 6MWT distance but no improvement was found in fine motor movement timings and functional grades of WMFT, 6MWT peak heart rate, and recovery heart rate.

In loaded bimanual therapy, the improvement in upper limb function can be speculated to be due to load application over the non-paretic limb while performing bimanual tasks producing a stabilizing effect generated by strong activation of weak extensor muscles and increased bombardment of proprioceptive stimuli transmitted to bilateral hemispheres. These bilateral coordinated movements normalize the inhibitory effect induced by a healthy hemisphere on the affected hemisphere, leading to improvement in upper limb function [3]. Loaded bimanual therapy with rhythmic auditory cueing involved added load over the non-paretic arm along with rhythmic auditory cue. This can be speculated to help maintain the quality of each movement pattern at a defined frequency. It would also help develop self-competencies to complete the assigned task. Recent studies report that bimanual arm therapy with rhythmic auditory cueing (BATRAC) and conventional bimanual therapy showed improvement in upper limb movements and activities [2,7]. In addition to bimanual tasks, the present study used an additional load that increased muscle recruitment and strength in order to help perform tasks smoothly assisting rehabilitative goals in stroke survivors.

Improvements in trunk function could be because loaded bimanual therapy with and without rhythmic auditory cues and conventional therapy involved various symmetrical and diagonal movement patterns of the upper limb thereby involving trunk movements [4,23,24]. While performing bimanual tasks, there was a demand for increased control for the mobility of the upper limb and stability of other body components. In order to fulfill the stability demand, there was increased activation of body trunk muscles throughout the task movement that produced trunk stability and mobility as movement included trunk rotational activities and sustained truncal weight shifts. This lengthened spastic trunk muscle thereby reducing truncal spasticity by antagonistic contraction and reciprocal inhibition principle, thus leading to the improved truncal movement and coordination to fulfil the bimanual task. A study by Lee et al. used symmetrical and asymmetrical bilateral upper limb functional task training and reported a positive effect on trunk function and mobility in stroke patients [25]. This is consistent with our study as our treatment protocol also involved various trunk movements that improved trunk function. Rhythmic cueing leads to maintaining the upright body posture, improves the sense of timing, and provides ongoing feedback during task performance. A recent study on kinematic analysis reports upper limb movement to be strongly influenced by trunk muscles resulting in an improvement in arm and trunk function in stroke patients [4,25]. Our study showed similar results as it involved various bimanual upper limb activities demonstrating improvement in trunk function.

Kinetic analysis of normal gait primarily involves phasic coordinated movement of the lower limbs and trunk and the use of the upper limbs for arm swing [26]. Bimanual movement patterns can be speculated to improve upper limb-trunk coordination, the strength of the paretic arm, and trunk mobility.

Application of load to two groups

added to the above-mentioned effect. It is known that trunk-limb coordination plays a vital role to produce an improvement in gait, but our study protocol precisely focused on arm-trunk coordinated activities that would have activated lower limb muscles in order to gain stability during the task, which is constantly challenged with respect to the base of support. The improved dynamic coordination led to the improvement in static and dynamic balance in stroke patients. Our results are consistent with recent studies reporting gait deviations in normal healthy participants and demonstrating a connection of the upper limb and trunk with gait [27,28]. Another study by Bronas et al. reported similar results consistent with our study demonstrating the improvement in gait with the repetitive use of progressive arm ergometer cyclic movements [29].

Our protocol involved varied forms of upper limb-trunk movement, load that acted as resistance, and repetition which improved the balance component. Additionally, the use of rhythmic auditory cues contributed to gaining the sense of timing during dynamic tasks, leading to increased coordination between bilateral arm with trunk and passive activation of the lower limb muscles during dynamic events like gait. A similar result was obtained by cueing the upper limb, trunk, and lower limb during functional tasks in parkinsonian patients resulting in improved balance [30]. In our study, rhythmic auditory cueing could have helped in gaining control of movement at the multi-joint level resulting in improved gait.

The present study reported no improvement in cardiovascular endurance in all three groups. However the distance covered during the 6 Minute Walk test demonstrated marked improvement. The therapy protocol was not intense and progressive in nature, hence could not bring out any improvement in cardiovascular endurance. This is consistent with recent literature reporting progressive aerobic training as an important factor to induce cardiovascular endurance changes [31-34]. The improvement in distance covered during the 6 Minute Walk test could be because improved strength and coordination between the body trunk and limbs would have lowered the physiological cost of ambulation and reset the delay in fatigue during walking, thereby leading to improved physical function.

The intragroup analysis demonstrated improvements in upper limb function, trunk function, balance, and functional capacity in all three groups. On intergroup comparison, loaded bimanual therapy showed significant improvements in the Wolf Motor Function Test, Trunk Impairment Scale, and 6 Minute Walk Distance, followed by loaded bimanual therapy with rhythmic auditory cues and conventional therapy. Added load over the non-paretic arm stimulates the nervous system to analyze discrepancies in bilateral movement patterns. This increases demand on the paretic arm, leading to increased muscular activation to fulfil bimanual movement tasks. Conventional therapy did not use any kind of load, thereby demonstrating the minimal improvements compared to loaded bimanual tasks.

Loaded bimanual therapy with rhythmic auditory cues demonstrated the maximum improvements on the Trunk Impairment Scale, Berg Balance Scale, and Dynamic Gait Index followed by loaded bimanual and conventional therapy. Loaded bimanual therapy with rhythmic auditory cues provided constant feedback and motivation using pre-set rhythmic beats to perform tasks accurately. This made the exercise program more intense and immersive by increasing task-specific attention and improving the motor program. Both loaded therapies can be speculated to have generated new neural circuits of motor programming that influenced neural plasticity resulting in an improvement in functional abilities. The absence of added load and rhythmic auditory cues in conventional therapy could have resulted in a slower pace with the poor quality of movement and lack of the sense of timing while performing tasks in stroke patients.

The limitation of the present study is a low sample size. Future studies can explore the effect of varied bimanual arm therapy with a larger sample size to get more insight into the problems discussed. Time-based task performance and progressive training can be explored to study their effect on cardiovascular endurance in stroke patients.

In conclusion, the present study found that varied bimanual arm therapy is effective in improving upper limb function, trunk function, balance, gait, and 6MWT distance in stroke patients. Loaded bimanual therapy with rhythmic auditory cueing demonstrated the maximum improvement in trunk function, balance, and gait compared to loaded bimanual and conventional therapy. Loaded bimanual therapy demonstrated the maximum improvement in upper limb function and distance covered in 6MWT compared to loaded bimanual therapy with rhythmic auditory cueing and conventional therapy. Varied bimanual arm therapy can be easily incorporated in the neurorehabilitation settings for the management of stroke patients. It would serve as a multifactorial approach to rehabilitation, improving upper limb function, trunk function, balance, gait, and functional capacity in stroke patients.

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