

## ORIGINAL REPORT

## COMPARATIVE EFFECTIVENESS OF ROBOT-ASSISTED TRAINING VERSUS ENHANCED UPPER EXTREMITY THERAPY ON UPPER AND LOWER EXTREMITY FOR STROKE SURVIVORS: A MULTICENTRE RANDOMIZED CONTROLLED TRIAL

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**Objective:** Robot-assisted neuro-rehabilitation therapy plays a central role in upper extremity recovery of stroke. However, the efficacy of robotic training on the upper extremity is not yet well defined, and little attention has been devoted to its potential effect on the lower extremity. The aim of this study was to compare the efficacy of robot-assisted training and therapist-mediated enhanced upper extremity therapy on the upper and lower extremities.

**Methods:** A randomized clinical trial involving 172 stroke survivors was conducted in China. All participants received either robot-assisted training or enhanced upper extremity therapy for 3 weeks. Fugl-Meyer assessment upper extremity subscale (FMA-UE), Fugl-Meyer assessment lower extremity subscale (FMA-LE), and Modified Barthel Index were administered at baseline, mid-treatment (1 week after treatment start), and post-treatment.

**Results:** Participants in the robot-assisted training group showed a significant improvement in the hemiplegia extremity, which was non-inferior to the enhanced upper extremity therapy group in FMA-UE ( $p < 0.05$ ), while suggesting greater motor recovery of lower extremity in FMA-LE ( $p < 0.05$ ) compared with the enhanced upper extremity therapy group. A marked increase in Modified Barthel Index was observed within groups; however, no significant difference was found between groups.

**Conclusion:** Robot-assisted training is non-inferior but not better in reducing impairment of the upper extremity and appears to be superior in reducing impairment of the lower extremity compared with enhanced upper extremity therapy for stroke survivors.

**Key words:** stroke; rehabilitation; robotic training; upper extremity; lower extremity.

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## LAY ABSTRACT

Although post-stroke robot-assisted training of the upper extremity has been widely studied, its efficacy is not yet well defined, and its effects on the lower extremity are unknown. This study aimed to evaluate the effects of upper extremity robot-assisted training on the upper and lower extremities in stroke survivors. Robot-assisted training is non-inferior in improving the function of the upper extremity and superior in improving the function of the lower extremity compared with enhanced upper extremity therapy. Robot-assisted training can be used for functional recovery of the upper and lower extremities in stroke survivors.

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Stroke leads to devastating neurological deficits and various levels of dysfunction (1), presenting significant public health and social problems. Upper extremity paresis, spasticity, and poor spatiotemporal coordination are common features following stroke (2), leading to impairment of reaching, grasping, and manipulation abilities (3). Rhythmic arm and leg movements share common elements of neural control, and the flexor synergy mode in the upper extremity disrupts the coordination patterns in stroke survivors. Previous studies have shown an underlying relationship between upper and lower extremities, whereby improvement in the upper extremity redressed the hemiplegic gait of stroke individuals (4) and gait alteration resulted in strapped arm in normal subjects (5). Kamper et al. (6) reported exaggerated interlimb neural coupling following stroke. According to this, restoration of both upper and lower extremities by interlimb coupling plays a critical role in stroke recovery.

Recent technological advances in upper extremity rehabilitation have made it possible for robotic devices to provide safe and intensive training through accurate repetitive movements (7). Robots could be appropriately designed to provide repetitive and high-intensity training in a cost-effective manner (8) and offer task-specific treatment (9) with introduction of games or interactive upper extremity tasks (10). However, the effectiveness and appropriateness of robot-mediated training are not yet well defined. A 2018 Cochrane systematic review (11) of robot-assisted arm training showed a significant improvement in arm function, activities of daily living, and arm muscle strength. In contrast, the largest study ( $n=770$ ) of the robotic training field, published in *The Lancet* (12), reported no significant improvement in upper extremity with robot-assisted therapy (assessed using the Arm Motor Ability Test, ARAT) vs usual care or matched-dose enhanced upper limb training. These controversial findings require further investigation. However, variations in the intensity, amount, duration, device type, the initial motor impairment of stroke survivors, and measurements should be taken into consideration (13). Beyond this, previous studies (12, 14, 15) on robot-assisted upper extremity training were restricted to effects on the upper paretic extremity, but not generalized to lower extremity performance. The preservation of common rhythmic locomotor control and interlimb coupling after stroke should not be overlooked in robot-assisted training. This issue of whether upper extremity robotic training results in improvement in lower extremity concomitant with arm recovery is particularly critical.

The aim of this large clinical multicentre trial was to assess: (i) if robot-assisted training is non-inferior to enhanced upper extremity therapy in reducing upper extremity impairment; and (ii) if robot-assisted upper extremity training could promote lower extremity repairment.

## METHODS

### *Trial design*

This study used a multicentre single-blind randomized controlled trial (registered at Chinese clinical trial registry, ChiCTR2000038676) with a non-inferiority design. Participants affected by stroke were enrolled from 4 neurological rehabilitation centres in China (Shanghai Jing'an District Central Hospital, Shanghai Fifth People's Hospital, First Rehabilitation Hospital of Shanghai, and China Rehabilitation Research Centre). Participants were randomized 1:1 to a robot-assisted training (RAT) group or an enhanced upper extremity therapy (EUET) group. Evaluators were blinded to group assignment. Participants were asked to refrain

from discussing study activities with the evaluator or other participants. They were informed that there were 2 study groups and that all participants would receive active interventions that differed in pattern. It was not practicable to prevent participants learning of another participant's schedule when more than 1 subject was enrolled at each site. Researchers were trained in robotic system operation and all aspects of data collection before conducting the study. The trial was overseen by an independent data and safety monitoring committee. To ensure consistent results across the 4 centres, quality control of the registered data was performed. The clinical quality control group was established, and investigators in each centre were responsible for quality control. In addition, the evaluators documented the data in the paper Case Report Form (CRF), which was double-checked by quality inspectors. The supervisor inspected the progress of the trial at regular intervals in each centre.

### *Participants*

This study recruited 172 patients (8.43% of screened patients) between May 2019 and July 2020. Inclusion criteria were: (i) unilateral paresis with first ischaemic or haemorrhagic stroke confirmed by computed tomography (CT) or magnetic resonance imaging (MRI) that occurred between 1 week and 2 years before enrollment; (ii) the ability to perform no or some active movements in the shoulder and/or elbow joints in the sitting position, allowing for trunk compensation if needed; (iii) the ability to understand and follow simple instructions. Exclusion criteria were: (i) bilateral impairment; (ii) multiple strokes; (iii) inability to sign informed consent; and (iv) medical conditions that could interfere with training (severe auditory or visual impairments, orthopaedic contracture, and severe cardiovascular disease). The study was approved by the ethics committee of Shanghai Jing'an District Central Hospital (LUN 2019-01). Written informed consent was obtained from all participants before the study.

### *Interventions*

In both groups, participants performed a rehabilitative treatment focused on recovery of the upper extremities combined with conventional rehabilitation. The RAT group performed robot-assisted training using the FLEXO-Arm1 robot (Shanghai Electric GeniKIT Medical Science and Technology Co., Ltd, Shanghai, China). In the EUET group, participants received time-matched enhanced occupational therapy. The RAT or matched EUET was administered for 15 sessions each lasting 30 min, scheduled 5 days per week for 3 weeks. Both types of training were provided by a physiotherapist with a high level of experience in

stroke rehabilitation at each site, who was not involved in the assessment. The training was separated from other treatments by at least a 30-min break. Therapists completed an intervention record form (date, intervention start/end time) for each participant's therapy session to improve adherence to protocols.

The conventional rehabilitation was provided 5 days a week for 3 weeks, divided into two 30-min sessions of physiotherapy and occupational therapy. Physiotherapy included gentle stretching for upper and lower extremities, range of motion exercises, exercises to improve balance, endurance, strength and gait, and facilitation of active voluntary movement. Occupational therapy for the paretic upper extremity consisted of passive stretching to inhibit spasticity, active-assisted movements, activities of daily living, and functional tasks, all progressed individually.

The FLEXO-Arm1 robot consisted of 2 types of movement patterns (teaching training (16) and task-oriented training (17)) with 5 degrees of freedom: shoulder flexion-extension and adduction-abduction, horizontal and vertical elbow flexion-extension, and wrist flexion-extension. The teaching training was customized smoothing trajectory-directed passive movements basing on the impairment. The task-oriented training was self-directed active-assisted movements through interactive gaming with focus on reaching (e.g. reaching digital balloon in the order from small to large and sweeping the floor). The movements required for the trainings were vertical flexion-extension and horizontal abduction-adduction in the shoulder and flexion-extension in the elbow with the hand in neutral position. The teaching training was used in the first 10 min and the task-oriented training was conducted in the second 20 min of the programme with no rest in between. The EUET was identical to occupational therapy of the conventional rehabilitation. Participants in the EUET group were offered the choice of RAT after their final study session.

#### Outcomes

Assessments were performed before treatment (pre-treatment), 1 week after treatment start (mid-treatment), and after 3 weeks' treatment (post-treatment).

The primary outcome was FMA-UE motor score, which assesses the degree of synergistic movements in the paretic upper extremity, with 33 items (scores ranging from 0 to 66, whereby higher scores indicate better performance) (18). Individual items pertaining to the shoulder/elbow (proximal subscale; 18 items; score range 0–36 points) and hand segments (distal subscale; 12 items; score range 0–24 points) are scored on a 3-point ordinal scale (0–2).

The secondary outcomes were FMA-LE (18) and Modified Barthel Index (MBI) (19). The FMA-LE

assesses the degree of motor impairment in the paretic lower extremity. The MBI is a scale that measures basic aspects of daily life activities related to self-care and mobility. The MBI comprised 10 items and 5 ranks (1–5) per item, whereby higher scores represent greater independence. The 10 items are: continence of bowels, continence of bladder, feeding, dressing, entering and leaving a toilet, grooming, bathing, moving from a wheelchair to a bed and return to a wheelchair, walking on a level surface for 45m, and ascending and descending stairs. The total MBI score ranges 0 (total dependence) to 100 (complete independence).

#### Sample size

The original sample size estimation was driven by the non-inferiority margin ( $\delta = -1$ ) in FMA-UE and based on the assumption that the mean change of FMA-UE between groups was equal and the standard deviation was 2 points. An estimated total sample size of 154 stroke survivors (with 77 in each of RAT and EUET arms) yielded 85% power to detect a significant difference at 1-sided statistical significance threshold of  $p=0.025$ . The sample size requirement was increased to 172 for 10% attrition. Reasons for loss from the trial were recorded.

#### Randomization

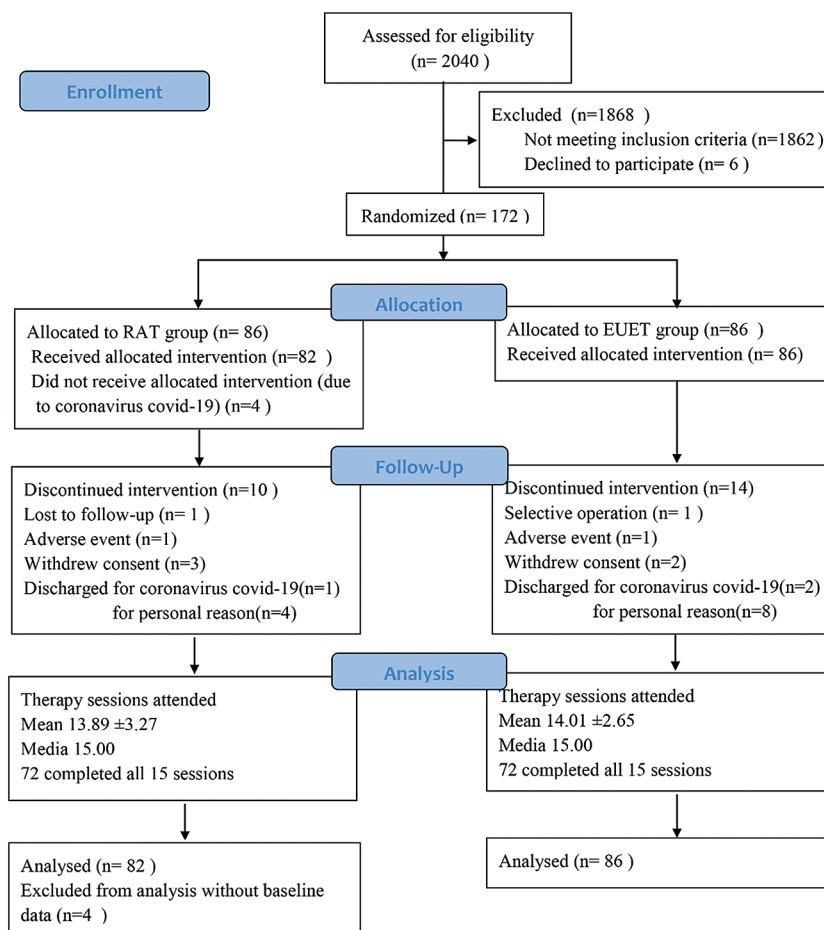
Eligible participants were enrolled sequentially and randomly assigned to either the RAT or EUET group by an administrator using a software program to generate random assignments. Group allocation was concealed. The randomization list was locked and accessible only to the principal investigator.

#### Blinding

All outcomes were evaluated by a physiotherapist experienced in neurological rehabilitation, who was blinded to the group allocation (independent evaluator).

#### Statistical analysis

Statistical analyses were performed with SAS software (SAS, version 9.4; SAS Institute, Cary, NC, USA). Tests of normality were performed using Shapiro–Wilk test. For descriptive purposes, the demographics and baseline outcome measures were compared between the 2 groups using *t*-test or the Wilcoxon rank-sum test (continuous data) and  $\chi^2$  or Fisher's test (categorical data). Analysis of primary outcome included both intention-to-treat and per-protocol non-inferiority analyses. Non-inferiority of RAT was established if the lower bound of 95% confidence interval (95% CI) around the difference in FMA-UE was greater than  $-1$ . For the secondary outcome measures analysis, the before-after differences were calculated and compared



**Fig. 1.** Patient enrolment and outcomes. Overview of the study. The flow chart illustrates the study design and overview of patients screened and enrolled in the study. RAT: robot-assisted training; EUET: enhanced upper extremity therapy.

between the 2 groups using *t*-test or the Wilcoxon rank-sum test (continuous data) and  $\chi^2$  test (categorical data), following an intention-to-treat analysis. Values of  $p < 0.05$  were considered statistically significant.

## RESULTS

Of 2,040 stroke survivors consecutively screened, 172 were randomized to the RAT ( $n=86$ ) and EUET ( $n=86$ ) groups. Owing to the COVID-19 pandemic, 4 participants dropped out before study visits in RAT group and 3 participants (1 in RAT group and 2 in EUET group) dropped out without completing the programme. Fig. 1 shows the flow of participants through all phases of the study. The baseline demographic and clinical characteristics of participants were not significantly different between groups (Table I).

### Primary outcome (non-inferiority)

The mean difference of FMA-UE was 1.63 (95% CI  $-0.25$  to  $3.52$ ) following an intention-to-treat analysis and 1.39 (95% CI  $-0.64$  to  $3.42$ ) following the

per-protocol analysis comparing RAT with EUET. The difference in FMA-UE between groups for the 2 analysis sets met non-inferiority ( $p$ -value for non-inferiority test  $< 0.05$ ) (Table II).

**Table I.** Demographic data and baseline clinical characteristics

Characteristics	RAT ( $n=82$ )	EUET ( $n=86$ )	$p$ -value*
Age, years, mean (SD)	59.37 (10.96)	58.72 (12.89)	0.7266
Sex, $n$ (%)			0.8541
Male	60 (73.2)	64 (74.4)	
Female	22 (26.8)	22 (25.6)	
Type of stroke, $n$ (%)			0.8708
Haemorrhagic	27 (32.9)	30 (34.9)	
Ischaemic	55 (67.1)	56 (65.1)	
Duration, days, mean (SD)	142.30 (162.84)	158.23 (178.20)	0.6094
Affected side, $n$ (%)			0.7733
Left	35 (42.7)	41 (47.7)	
Right	47 (57.3)	45 (52.3)	
MMSE, mean (SD)	26.15 (4.55)	25.00 (5.19)	0.1306
FMA-UE, mean (SD)	31.23 (18.95)	25.69 (14.46)	0.1198
Proximal	18.29 (10.42)	16.00 (8.10)	0.0980
FMA-LE, mean (SD)	20.80 (7.39)	20.09 (7.41)	0.5340
MBI, mean (SD)	66.04 (23.47)	58.97 (24.19)	0.0680

SD: standard deviation; RAT: robot-assisted training; EUET: enhanced upper extremity therapy; MMSE: Mini-Mental State Examination; FMA-UE: Fugl-Meyer of upper extremity; FMA-LE: Fugl-Meyer of lower extremity; MBI: Modified Barthel Index. \*Statistically significant ( $p < 0.05$ ).



**Table II.** Changes in Fugl-Meyer of upper extremity assessment scores

	RAT group	EUET group	Mean difference (95% CI)	Non-inferiority Test	
				t'	p-value
Intention-to-treat	n=82	n=86	1.63 (-0.25, 3.52)	2.76	0.0066
Per-protocol	6.62 (7.09)	4.99 (5.08)	1.39 (-0.64, 3.42)	2.33	0.0213
	7.01 (6.94)	5.63 (5.24)			

RAT: robot-assisted training; EUET: enhanced upper extremity therapy; CI: confidence interval.

**Table III.** Adjusted changes in Fugl-Meyer of upper extremity assessment scores for the per-protocol set

Group	Adjusted mean (95% CI)	Adjusted mean difference (95% CI)
RAT Group	6.98 (5.55, 8.42)	1.33 (-0.71, 3.37)
EUET Group	5.65 (4.22, 7.09)	

RAT: robot-assisted training; EUET: enhanced upper extremity therapy. Values have been adjusted for baseline scores and the study site in Table III.

An adjusted analysis for the per-protocol set did not alter the results for non-inferiority, as the lower 95% CI of  $-0.71$  was greater than the pre-specified non-inferiority margin of  $-1$  (mean difference in FMA-UE between groups  $1.33$ , 95% CI  $-0.71$  to  $3.37$ ) (Table III).

### Secondary outcomes

For the secondary outcomes, the RAT group improved significantly in the FMA-LE post-treatment compared with EUET group (difference,  $1.28$ ; 95% CI  $0.44$ – $2.12$ ,  $p < 0.05$ ). However, the analysis of between-group difference on the MBI, overall and proximal FMA-UE were not significant at mid-treatment and post-treatment (Fig. 2). In the within-group analysis, changes relative to baseline of overall and proximal FMA-UE, FMA-LE and MBI post-treatment showed significant differences in both groups (Table IV).

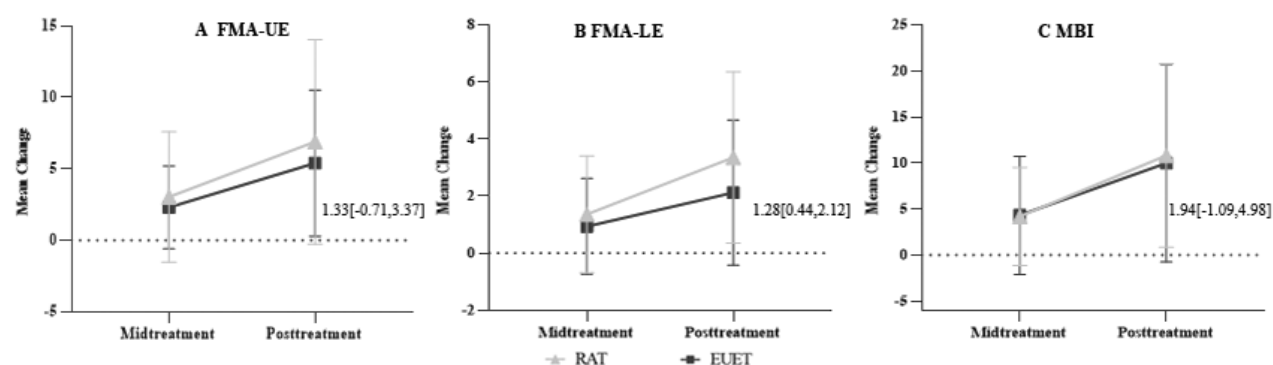
## DISCUSSION

This study was performed during the coronavirus disease 2019 (COVID-19) pandemic and investigated

the efficacy of RAT on motor function and activities of daily living. Both groups demonstrated improvement in primary and secondary outcomes after the interventions. Compared with EUET, RAT performed non-inferiorly in reducing upper extremity impairment and superiorly in reducing lower extremity impairment after the 3-week interventions.

Robotic training has emerged as an alternative to conventional therapy. These results highlighted that RAT may be a substitution treatment without loss of efficacy. In addition and importantly, the increment of FMA-UE score in the RAT group ( $6.98$  points, 95% CI  $5.55$ – $8.42$ ) was greater than 10% of the total score, achieved the minimal clinically important difference, and advanced patients to the next stage of motor recovery (20). These findings could be ascribed to the relearning theories and synergistic effects of RAT and spontaneous recovery, or better motivation while participating in robotic training (21).

Numerous studies have shown benefits of various robotic devices for improving function of the paretic arm after stroke. These devices intensify the therapy with repetition and intensive training, deliver feedback, provide assistance as needed and quantify the individual's movement performance (22), which the FLEXO-Arm1 robot may similarly yield. The FLEXO-Arm1 robot provides an accurate measurement of physical properties and good training with constant speed, precise control and prolonged endurance (23) that are inability by therapists. These are the main drivers of valid



**Fig. 2.** Changes in secondary outcomes during the 3-week study compared with baseline. Data are least-square means at each time-point. During the 3-week period, changes in all posttreatment secondary outcomes were significant differences within the group while changes in post-treatment Fugl-Meyer of the lower extremity (FMA-LE) were significant differences between-group. RAT: robot-assisted training; EUET: enhanced upper extremity therapy; FMA-UE: Fugl-Meyer of the upper extremity; MBI, Modified Barthel index.

**Table IV.** Changes in secondary outcomes compared with baseline

Outcomes	RAT		EUET		Difference	
	Mid-treatment Mean $\pm$ SD	Post-treatment Mean $\pm$ SD	Mid-treatment Mean $\pm$ SD	Post-treatment Mean $\pm$ SD	<i>p</i> -value (mid-treatment)	<i>p</i> -value (post-treatment)
FMA-UE	3.04 $\pm$ 4.56	6.90 $\pm$ 7.16*	2.31 $\pm$ 2.90	5.41 $\pm$ 5.12*	0.635	0.463
Proximal	1.71 $\pm$ 2.77	3.62 $\pm$ 4.05*	1.51 $\pm$ 1.87	3.33 $\pm$ 3.23*	0.381	0.428
FMA-LE	1.36 $\pm$ 2.04	3.35 $\pm$ 3.00*	0.94 $\pm$ 1.67	2.21 $\pm$ 2.54*	0.220	0.006**
MBI	4.19 $\pm$ 5.33	10.81 $\pm$ 9.98*	4.31 $\pm$ 6.42	9.99 $\pm$ 10.72*	0.941	0.616

RAT: robot-assisted training; EUET: enhanced upper extremity therapy; SD: standard deviation; FMA-UE: Fugl-Meyer of upper extremity; FMA-LE: Fugl-Meyer of lower extremity; MBI: Modified Barthel Index.

\*Statistically significant within group.

\*\*Statistically significant between groups ( $p < 0.05$ ).

rehabilitation interventions after stroke. Moreover, The FLEXO-Arm1 robot it confers training with high flexibility and adaptability by overcoming the shortcomings of a torque algorithm alone. Compared with EUET, RAT is superior when performing repetitive training and implements human-computer interaction focusing on task-oriented games (24). These factors promote the effectiveness of RAT.

To date, evidence for the translation of FMA-UE enhancement to improvement in activities of daily living and growth in real-world arm usage is insufficient and inconclusive. The Cochrane review by Mehrholz et al. (11) has reported that RAT improves activities of daily living, while systematic reviews and meta-analysis (25) showed no benefits in upper extremity capacity compared with usual care or no treatment. Even though the difference in MBI between groups was not statistically significant in the current study, the improvements in MBI in both groups achieved the minimal clinically important difference (26). It is well known that MBI measures the individual's performance on 10 activities of daily living, rather than measuring the dexterity of the upper paretic extremity properly (27). In addition, measurements of the functional level cannot distinguish motor recovery level from the use of alternative compensating strategies. However, with the rapid development of robot technology, studies (28, 29) using different robot designs (e.g. hybrid training with functional activity and bilateral training) have disclosed functional improvements. Hence, future protocols may consider the addition of transition to task-oriented training after RAT to promote motor activity. New developments in robotic innovations and capabilities with more specific motor functions are expected.

The effects of upper extremity training are not restricted to the arm, and also seem to reduce lower extremity impairment. As specified in the Introduction, previous studies have shown that somatosensory networks involved in coordination patterns remain partially preserved after stroke, and post-stroke rehabilitation specifically targeting upper extremity movements can also improve lower extremity motor-function (30). Pooled data from the current study unexpect-

edly showed a pronounced mean change difference in FMA-LE (difference, 1.28 points; 95% CI 0.44–2.12) between groups. Coincidentally, adaptation of the lower extremity has been validated in an earlier study by the discovery that improvement in the upper extremity redressed the hemiplegic gait of stroke individuals (4). However, several explanations may account for this discrepancy. First, proper limb posture is proposed as the core notion of the novel integration concept for upper and lower extremities (31), thus the current study reconsidered the study scenarios. The images clearly displayed the difference in the lower extremity position during training between groups (Figs S1 and S2). Individuals in the RAT group were asked sitting with proper limb posture unconsciously, which could contribute to adaptive changes in lower extremity. Furthermore, the task-oriented games offered by robot might be another point of discussion, since repairment of the lower extremity appears to be more relevant with cognitive function than upper extremity (32). RAT could be believed as an administering dual-task (motor and cognitive) training embedded with video feedback games. The cognitive feedback results in a higher level of active participation of subjects, measured by muscle activity (33). The integration between cognitive and motor functions contributes to the recovery and learning process (34). However, it cannot be concluded that cognition is the explanation for this finding.

Notably, the difference in FMA-LE between groups, although statistically significant, was probably not of clinical significance, since the mean change in FMA-LE in RAT (3.37 points; CI 2.77–3.97) and EUET (2.09 points; 95% CI 1.49–2.69) groups failed to achieve the minimal clinically important difference (35). Nevertheless, it cannot be discounted that the dose of intervention is a significant factor related to efficacy. The intervention dose (time, duration and frequency of treatment sessions) of the current study protocol adheres to the lower recommended limit of the robotic intervention (28), which offers training in sessions lasting from 30 min to 1.5 h, with 3–5 sessions per week for 3–8 weeks. In this case the possible greater efficacy of RAT on lower extremity recovery cannot be ruled out. Furthermore, the lower

extremity may have greater potential (36) and a faster rate (37) of neurological recovery than the upper extremity for patients with simultaneous lower and upper extremity motor impairments. Based on this, it is understandable that the non-inferiority of upper extremity and superiority of lower extremity between groups appears simultaneously. Ultimately, however, this explanation is purely speculative, and further research is needed.

Several aspects should be considered for future research. Large-scale longitudinal clinical and cohort trials should facilitate the determination of optimal conditions and evolution of interlimb coupling in stroke survivors. Further studies are additionally necessary to explore whether an increase in dose of robotic training would reduce lower-extremity impairment to achieve the minimal clinically important difference. In addition, it is imperative to employ multiple measurements (such as 10-m walk test, three-dimensional gait analysis, Timed Up and Go test and Berg balance scale) to evaluate lower extremity and neuroimaging data to analyse activation of the corresponding brain regions.

This randomized and evaluator-blinded study should minimize most of the common biases. Nevertheless, the current study has several limitations. A major limitation of the current study is that individuals were not stratified by phase after stroke onset based on level of impairment or intactness of the corticospinal tract system. The disparate recovery potential of different phases and impairment levels might have influenced the observed efficacy of RAT compared with EUET, but does not call into question the interpretation of non-inferiority. From this point of view, the use of robotic training in clinical application is highly anticipated. Another limitation is that the current study provides evidence for immediate functional improvements following the intervention, but no follow-up assessments were conducted. While immediate function change is important and may be seen as the first step in the process of sustainable function change agenda, it is likely that additional follow-up or supplemental interventions are necessary for long-term improvement. It is also that the effects are sustainable. Finally, the study was not powered to answer the question of cost-effectiveness and therapist attitudes toward RAT. Future studies with long-term follow-up are needed to stratify the effects of RAT on different phases and impairment levels with economic evaluation (cost-effectiveness, utility of benefit analysis).

## CONCLUSION

This study demonstrated that RAT is non-inferior but not better to EUET in reducing upper extremity impair-

ment in stroke survivors, and found that RAT maybe superior in promoting lower extremity recovery than EUET. However, the mechanism causing this difference between groups in the lower extremity is unclear, but may be related to the robot. This intriguing observation raises novel insights for RAT in future studies.

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Data supporting the findings of this study are available from the corresponding author on reasonable request.

This study involving human participants was reviewed and approved by the ethics committee of Shanghai Jing'an District Central Hospital. Patients provided written informed consent to participate in this study. Written informed consent was also obtained from individuals for publication of any potentially identifiable images or data included in this article.

*The authors have no conflicts of interest to declare.*

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