Original Article

Upper limb robotic rehabilitation for chronic stroke survivors: a single-group preliminary study

Ki Hun Cho, PhD, PT[1], Mi-Ran Hong, OT[2], Won-Kyung Song, PhD[2]*

[1] Department of Physical Therapy, Korea National University of Transportation, Republic of Korea
[2] Department of Rehabilitative and Assistive Technology, National Rehabilitation Research Institute,
National Rehabilitation Center: 58 Samgaksan-ro, Gangbuk-gu, Seoul 01022, Republic of Korea

Abstract. [Purpose] This study aimed to assess whether robotic rehabilitation can improve upper limb function, activities of daily living performance, and kinematic performance of chronic stroke survivors. [Subjects and Methods] Participants were 21 chronic stroke survivors (19 men; 60.8 years; Mini-Mental State Examination score: 28; onset duration: 10.2 years). Training exercises were performed with a Whole Arm Manipulator and a 120-inch projective display to provide visual and auditory feedback. Once the training began, red and grey balls appeared on the projective display, and participants performed reaching movements, in the assist-as-needed mode, toward 6 directional targets in a 3-dimensional space. All participants received training for 40 minutes per day, thrice per week, for 6 weeks. Main outcome measures were upper limb function (Fugl-Meyer Assessment, Action Research Arm Test, and Box and Blocks Test scores), activities of daily living performance (Modified Barthel Index), and kinematic performance (movement velocity) in 6 directions. [Results] After 6 weeks, significant improvement was observed in upper limb function, activities of daily living performance, and kinematic performance. [Conclusion] This study demonstrated the positive effects of robotic rehabilitation on upper limb function, activities of daily living performance, and kinematic performance in chronic stroke survivors.
Key words: Robot, Stroke, Upper limb

INTRODUCTION

Stroke survivors sustain functional disabilities that affect activities of daily living, and most of them experience difficulties with the upper extremity. Most daily activities are associated with use of the upper extremity, and the recovery of upper limb function is the primary goal in stroke rehabilitation[1]. In recent years, many potential rehabilitative interventions, such as feedback training, task-oriented training, constraint-induced movement therapy, virtual reality, and brain stimulation, have been used to restore upper extremity function[2, 3].

Especially, according to the published guideline for adult stroke rehabilitation[4], robot assisted training is useful for recovery of upper extremity function of stroke survivors. Thus, in the clinical setting, robotic device is being used to enhance upper extremity function of stroke survivors.

In the field of stroke rehabilitation, robotic devices used to enhance upper extremity function are classified into various types of treatment protocols, such as passive, active assist, and active, based on how force is directed to the paretic arm[2, 5]. With these features, robotic devices allow users to participate in interactive training and motor relearning via high-intensity, repetitive, and frequent tasks. Per previous studies, treatment protocols should be selected based on the compensatory strategies for the clinical features and the basic concept of motor learning in robot-assisted training in stroke[4, 6]. The assist-as-needed protocol is more effective because it adaptively provides assistance as necessary based on the subject's performance; this provides the basis for its effective use in rehabilitation[7, 8].

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*Corresponding author. Won-Kyung Song (E-mail: wksong@nrc.go.kr; wonksong@gmail.com)

However, studies on the clinical usefulness of assist-as-needed robot-aided training for the recovery of upper limb function in stroke survivors have been lacking. Thus, this study aimed to assess whether upper limb robotic rehabilitation with an assist-as-needed protocol can improve upper limb function, activities of daily living performance, and kinematic performance in chronic stroke survivors.

We hypothesized that survivors with chronic stroke would show improvements in upper limb functional movement, activities of daily living performance, and kinematic performance after 6 weeks of upper limb robotic rehabilitation with the assist-as-needed protocol. The overall goal of this study was to provide a reference point for a subsequent randomized, controlled trial.

SUBJECTS AND METHODS

Twenty-seven subjects with chronic stroke were considered for inclusion in this study. After screening, 6 subjects were excluded, and the remaining 21 were included as participants (19 men, average age 60.8 years, Mini-Mental State Examination score: 28, onset duration: 10.2 years). Inclusion criteria were (1) hemiparesis from a single stroke that occurred at least 6 months ago, (2) sufficient cognition to follow simple instructions and understand the content and purpose of the study (Korean version of the Mini-Mental State Examination score: ≥24 points), (3) absence of a musculoskeletal condition that could affect one's ability to sit safely, and (4) absence of hemispatial neglect. Exclusion criteria were (1) participation in other studies or rehabilitation programs, (2) shoulder subluxation or pain in the upper limbs, or (3) spasticity (modified Ashworth Scale score: >2)[7].

A single-group, pre-test and post-test design was used. The 21 participants were briefed on the experimental procedure, and written informed consent was obtained from all participants prior to the experiment. Ethical approval for inclusion of human subjects was obtained from the relevant committee of the National Rehabilitation Center Institutional Review Board (No.: NRC-2015-05-035) before conducting the experiment.

All participants underwent the training program thrice per week for 6 weeks. A single training session lasted 40 minutes and was supervised by the same assistants. All participants completed the training sessions and were assessed for functional movement with the Fugl-Meyer Assessment (FMA), Action Research Arm Test (ARAT), and Box and Blocks Test (BBT) and for activities of daily living performance with the modified Barthel Index (MBI). In addition, upper extremity kinematic performance was measured using movement velocity for upper limb reaching during upper limb robotic rehabilitation. Measurements for functional movement, activities of daily living performance, and kinematic performance were performed at 2 time points: at baseline and after the intervention.

Movement velocity was recorded while the participant reached from the hand point to the target point and returned to the hand point. Participants had to execute movements to reach different targets placed in ipsilateral, central, and contralateral positions. Data were transferred to MATLAB software (Mathworks, Inc., Nattick, MA, USA) for further analysis.

The training program was conducted on a testbed. The setting of the testbed followed that of previous studies[5, 9]. The testbed consisted of one Whole Arm Manipulator (WAM) (Barrett Technology, Inc., Newton, MA, USA) and one projective display device. The WAM arm with a gimbal was set at 7° of freedom for the shoulder, elbow, and wrist joints during the training sessions. The participant held the handle of the gimbal while performing the point-to-point movements. WAM provides a highly back-drivable motion that helps the user reach the desired sphere using point-to-point movements. Additionally, WAM can assist arm movement when providing either weight support or assistive force to complete point-to-point movements. WAM adaptively provides as much assistance as necessary, that is, the assist-as-needed mode, based on the subject's reaching performance. A subtle assist-as-needed force, i.e., 2 N, is applied when the participant does not move the arm for more than 2 seconds. For example, WAM compensates for a robotic arm body weight while the subject moves the arm independently. However, when subjects experience difficulty in moving their arm, WAM provides an additional force to reach the desired target. Specifically, when participants do not move their arm independently, the small additional guidance force helps them move their arm again. A 120-inch projective display placed in front of the testbed was used to provide suitable visual and auditory feedback to the user. Participants performed the robot-assisted reach training exercises while wearing the WAM arm and sitting on a chair. In addition, participants wore a trunk-fixed belt to minimize compensatory movement and the likelihood of emergency situations.

Once the training began, red and grey balls appeared on the projective display, and participants performed reaching movements toward targets in 3-dimensional space in 6 directions (i.e., targets 1–6). The red ball was linked to the participant's upper limb movements, and auditory feedback was provided when the red and grey balls matched. One task consisted of 3 phases: moving toward the target, manipulating the target, and returning from the target. The ding-dong sound is played when WAM reaches to the target. While performing the training exercises, the velocities from the starting point to the target point and from the target point to the starting point were recorded. To prevent accidents due to fatigue, an assistant stood nearby, and emergency stop devices were installed. Rest breaks during training sessions were allowed if requested but were not included in the overall exercise time.

Data analysis was performed using IBM SPSS (version 21.0; IBM Corp., Armonk, NY, USA). The Shapiro-Wilk test was used to confirm the normality of all outcome variables. All variables (functional movement, activities of daily living performance, and upper extremity kinematic performance in 6 directions) were normally distributed; therefore, paired t-tests

were used to determine whether differences existed between comparisons. All outcomes are expressed as mean values and standard deviations. Statistical significance was accepted at p<0.05.

RESULTS

A summary of the general characteristics of the 21 participants who met the inclusion criteria is provided in Table 1. After 6 weeks of training, significant improvement was observed in upper limb function (FMA: from 47.90 to 51.52, BBT: from 15.00 to 16.85, and ARAT: from 37.52 to 41.14; all: p<0.05) and activities of daily living performance (MBI: 94.95 to 96.38, p<0.05) (Table 2).

Significant improvement in kinematic performance (movement velocity) was observed in all directions (target 1: from 0.29 to 0.47 m/s, target 2: from 0.22 to 0.38 m/s, target 3: from 0.21 to 0.36 m/s, target 4: from 0.26 to 0.43 m/s, target 5: from 0.14 to 0.33 m/s, and target 6: from 0.16 to 0.32 m/s; all: p<0.05) (Table 2).

DISCUSSION

Stroke is a main cause of functional impairment, and >50% of stroke survivors experience functional difficulties with their upper extremity[10]. Moreover, stroke is a risk factor associated with chronic impairment of upper limb function, and improvement in upper limb ability is known to provide stroke survivors opportunities to participate in the community again[11, 12]. Reportedly, most recovery from stroke occurs within the first 3 months, and only minor additional improvement occurs after 6 months following onset[13]. Thus, studies on the rehabilitation training method for motor recovery in chronic stroke survivors are necessary. Specifically, exercise for people with chronic stroke can correspond to the rehabilitation concept[14], i.e., not only reaching functional levels but also maintaining functional levels.

Table 1. General characteristics of the subjects (N=21)

	n (%) or Mean ± SD
Gender (male/female)	19/2 (90.5/9.5)
Etiology (infarction/hemorrhage)	15/6 (71.4/28.6)
Paretic side (right/left)	12/9 (57.1/42.9)
MAS-UE (0/1/1+/2)	5/9/3/4
Brunnstrom stage_UE (3/4/5/6)	2/3/14/2
MRC-EE (4/5)	5/16
Age (years)	60.85 (8.26)
Time since stroke (years)	10.23 (6.43)
Height (cm)/weight (kg)	167.27 (9.06)/71.25 (8.92)
MMSE (scores)	28.09 (2.44)

MAS-UE: Modified Ashworth Scale for Upper Extremity; MRC-EE: Medical Research Council Scale for muscle strength on Elbow Extensor; MMSE: Mini-Mental State Examination.

Table 2. Changes of the upper limb function, activities of daily living and kinematic performance (N=21)

Variables		Pre test	Post test	t	p
Upper limb function (points)	FMA-UE	47.90 (11.02)	51.52 (11.29)	−6.007	0.000
	BBT	15.00 (10.20)	16.85 (11.81)	−2.540	0.020
	ARAT	37.52 (16.94)	41.14 (15.54)	−2.617	0.016
ADL performance (points)	MBI	94.95 (3.78)	96.38 (3.69)	−2.118	0.047
Kinematic performance (mm/sec)	MV for target 1	0.29 (0.13)	0.47 (0.16)	−7.054	0.000
	MV for target 2	0.22 (0.09)	0.38 (0.12)	−7.443	0.000
	MV for target 3	0.21 (0.08)	0.36 (0.12)	−7.529	0.000
	MV for target 4	0.26 (0.11)	0.43 (0.16)	−6.183	0.000
	MV for target 5	0.14 (0.06)	0.33 (0.10)	−9.530	0.000
	MV for target 6	0.16 (0.06)	0.32 (0.10)	−8.115	0.000

Values are expressed as mean (SD).
FMA-UE: Fugl-Meyer Assessment for Upper Extremity; BBT: Box and Blocks Test; ARAT: Action Research Arm Test; MBI: Modified Barthel Index; MV: Movement Velocity.

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Recently, in a clinical setting for stroke rehabilitation, an adaptive provision of assistive force (the assist-as-needed paradigm) was emphasized as an essential factor for successful stroke rehabilitation[7, 15]. Through the present study, we confirmed the positive effects of upper limb robotic rehabilitation with an assist-as-needed protocol on upper limb functional movement, activities of daily living performance, and kinematic performance in chronic stroke survivors.

Considering that participants were chronic stroke survivors with a long onset period (10.2 years), the results of our study are noteworthy. However, because only a single-group analysis was performed without a control group, we could not conclude with certainty that the improvement in functional movement was because of upper limb robotic rehabilitation with the assist-as-needed protocol. Thus, a randomized, controlled trial is required in the future. In addition, this study included only high-functioning stroke survivors. Some chronic stroke survivors have weak movement function and might find upper limb movement with WAM difficult owing to the heavy weight and high inertia of WAM. Therefore, the results of this study cannot be generalized to all stroke survivors.

In conclusion, this study demonstrated the positive effects of upper limb robotic rehabilitation on upper limb functional movement, activities of daily living performance, and kinematic performance in chronic stroke survivors. Albeit limited by design, this study highlights that assist-as-needed robot-aided upper extremity exercise can be effective in chronic stroke survivors.

Conflict of interest

The authors declare no conflict of interest.

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