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Case Study

Robotic rehabilitation of the paralyzed upper limb for a stroke patient using the single-joint hybrid assistive limb: a case study assessed by accelerometer on the wrist

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Abstract. [Purpose] Recent studies have reported the effectiveness of robotic rehabilitation of paralyzed upper limbs in stroke patients. For example, the Single-Joint Hybrid Assistive Limb has been shown to improve upper limb impairments. However, limited data are available on the effectiveness of robotic rehabilitation of the upper limb with regards to daily living. In this case study, an accelerometer was adopted to examine whether rehabilitation using the Single-Joint Hybrid Assistive Limb improved upper limb activity during daily living in a stroke patient. [Participant and Methods] The participant was a 69-year-old male diagnosed with stroke and left hemiparesis. The Single-Joint Hybrid Assistive Limb was applied to the participant's elbow on the paralyzed side. The participant wore an accelerometer on each wrist to measure the activities of the upper limbs. Clinical tests of the paralyzed upper limb were also performed. [Results] The activity of the paralytic limb was significantly higher after Single-Joint Hybrid Assistive Limb intervention than before the intervention. On the other hand, none of the results of the clinical tests changed beyond a clinically important difference. [Conclusion] The Single-Joint Hybrid Assistive Limb could be useful for promoting active use of a paralyzed upper limb in daily living. In addition, an accelerometer could be especially useful for evaluating the effects of robotic rehabilitation.

Key words: Stroke, Single-Joint Hybrid Assistive Limb (HAL-SJ), Accelerometer

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INTRODUCTION

Hemiparesis is a sequela that can substantially influence the lives of patients with stroke. For these patients, exercise therapy can improve not only the impairment but also the patients' daily activities and quality of life[1, 2]. Recent studies have reported the effectiveness of robotic rehabilitation of paralyzed upper limbs in patients with stroke[3–7]. For example, Saita et al. demonstrated that the Single-Joint Hybrid Assistive Limb (HAL-SJ; HAL-FS01, CYBERDYNE, Inc., Tsukuba,

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Japan) improved upper limb impairment in stroke patients[7]. However, these studies evaluated the upper limb function in a testing situation, such as by using Fugl-Meyer assessment or the Action Research Arm Test. Few data are available about the effectiveness of robotic rehabilitation for the upper limb for activities of daily living.

Recently, some studies reported that an accelerometer provides an effective method for assessing arm activity in daily living for patients with stroke[8]. Thus, accelerometer may be useful for evaluating the effectiveness of robotic rehabilitation for daily activities. In this case study, accelerometer was used to examine whether robotic rehabilitation using the HAL-SJ improved upper limb activity in daily living in a patient with stroke.

PARTICIPANT AND METHODS

The participant was a 69-year-old man who was right handed and was diagnosed with a stroke with left hemiparesis. He was hospitalized and took part in this study 3 months after the onset of stroke. His Functional Independence Measure score was 109 and the median Manual Muscle Testing score for his left upper limb was classified as “Fair.” He did not exhibit any obvious higher brain dysfunction.

The participant provided written informed consent prior to the study. All the procedures were performed in accordance with the principles of the Declaration of Helsinki, and the study protocol was approved by the institutional ethics committee of Ibaraki Prefectural University of Health Sciences (approval number 797).

The HAL-SJ was used for this study. It is a wearable robot that assists with joint motion by detecting bioelectrical signals from the surface of the muscle. This device has been used by stroke patients with paralyzed upper limbs[7]. In this study, the HAL-SJ was applied to the participant’s elbow on the paralytic side (Fig. 1).

The study comprised 3 phases over 6 weeks: 2 weeks of the pre-intervention phase, 2 weeks of HAL-SJ intervention phase, and 2 weeks of post-intervention phase (Fig. 2). During the HAL-SJ intervention phase, the participant received 10 sessions of HAL-SJ training, which included at least 200 extension and flexion movements of the elbow joint per session, as previously reported[7]. The participant received conventional physical therapy (PT), occupational therapy (OT), and speech therapy (ST) throughout the three phases.

Throughout the 6-week study period, an Actiwatch Spectrum (AWS) accelerometer (Philips Respironics, Inc., USA) was worn on each wrist to measure the activity of his upper limbs. These detected acceleration along three axes, recording at 1-min intervals. To focus on movement of the participant’s spontaneous living environment, the data acquired at the times the

Fig. 1. HAL-SJ intervention to the participant’s elbow on the paralytic side.

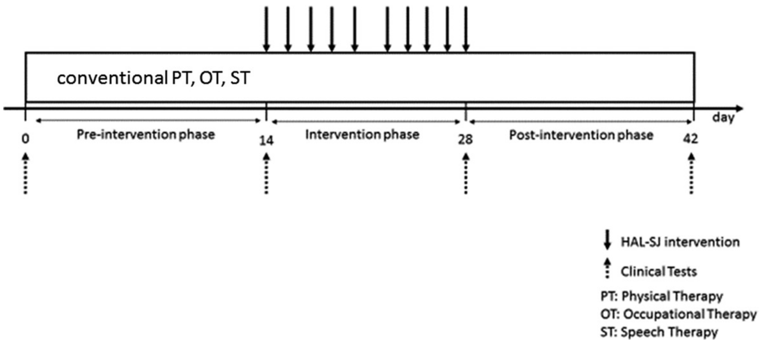

Fig. 2. Study design. The study comprised 3 phases over 6 weeks: 2 weeks of the pre-intervention phase, 2 weeks of HAL-SJ intervention phase, and 2 weeks of post-intervention phase.

participant received PT, OT, and ST were excluded. A period of rest ordered by the participant's doctor was also excluded.

From the AWS data, the activity of the most active 10-hour periods in each day (M10) was used for analysis. The AWS detects the acceleration over 0.5 G, and M10 represents the mean counts/hour of the most active 10-hour period in one day. M10 is a standard parameter that reflects rest–activity patterns on consecutive days in the participant's living environment[9–13].

For statistical analysis, we preliminarily compared M10 between the first and second halves of the pre-intervention phase using a t-test to confirm that the participant's recovery had already reached a plateau with conventional PT, OT, and ST. After that, the differences in M10 among the three study phases were analyzed with repeated-measures analysis of variance followed by post hoc testing using Dunnett's honestly significant difference test. SPSS version 21.0 for Windows (SPSS Inc., Chicago, IL, USA) was used for the statistical analysis, and the level of significance was set at $p<0.05$.

Clinical tests of the upper limb were performed at baseline and after 2, 4, and 6 weeks (Fig. 2). The participant was evaluated using Fugl-Meyer Assessment-Upper Extremity (FMA-UE), the Action Research Arm Test (ARAT), and the Motor Activity Log (MAL), which comprises the Amount of Use (MAL-AOU) and Quality of Movement (MAL-QOL) scales.

Results of the clinical tests at each time point were examined for any change greater than the clinically important difference (CID), i.e., the difference regarded as clinically meaningful for health professionals and patients. The CID score for ARAT is 3.0 points, for FMA-UE is within the range 4.25–7.25 points, and for MAL-AOU is 0.52 points[14, 15]. The CID for MAL-QOM has not yet been established. As an example, a change in the ARAT score of 2 points would be considered unmeaningful, whereas a change of 4 points would be meaningful.

RESULTS

Table 1 shows the mean M10 values measured by AWS for the paralyzed upper left limb during the first and second halves of the pre-intervention phase (3,812 ± 1,220 and 3,529 ± 611, respectively). There was no significant difference between the two halves of pre-intervention phase ($p=0.59$), suggesting that recovery with the conventional therapy had reached a plateau.

Table 2 shows the mean M10 values for each upper limb in each of the three study phases (pre-intervention, intervention, and post-intervention). For the paralyzed left upper limb, the mean M10 scores were 3,670 ± 938, 2,864 ± 786, and 5,165 ± 2,292, respectively. There was no significant difference in scores between the pre-intervention and intervention phases, but the mean score at the post-intervention phase was significantly higher than that for the pre-intervention phase ($p=0.035$).

For the intact right upper limb, the mean M10 scores were 11,197 ± 1,870, 10,907 ± 1,438, and 12,995 ± 2,879, respectively, with no significant differences ($p=0.052$).

Table 3 shows the results of the clinical tests of the paralyzed upper limb at the four time points. None of the results changed beyond the CIDs.

DISCUSSION

The aim of this study was to evaluate whether the use of HAL-SJ improved the amount of activity in daily living of the paralyzed upper limb of a patient with stroke. The comparison of activity between the two halves of the pre-intervention

Table 1. M10 values for the paralyzed upper limb during the two halves of the pre-intervention phase

		First half of the pre-intervention phase (N=7)		Second half of the pre-intervention phase (N=7)		p value
		Mean	SD	Mean	SD	
M10 (Counts/hour)	Left upper limb	3,812	1,220	3,529	611	0.59

M10: The activity of the most active 10-hour periods in each day.
p value is for t-test between the two halves of the pre-intervention phase. No significant difference was observed.

Table 2. M10 values for the participant's paralyzed upper limb (left) and intact upper limb (right) of the pre-intervention, intervention, and post-intervention phases

		Pre-intervention phase (N=14)		Intervention phase (N=14)		Post-intervention phase (N=9)		p value
		Mean	SD	Mean	SD	Mean	SD	
M10 (Counts/hour)	Paralyzed upper limb (left)	3,670	938 *	2,864	786	5,165	2,292 *	0.035
	Intact upper limb (right)	11,197	1,870	10,907	1,438	12,295	2,879	0.052

M10: The activity of the most active 10-hour periods in each day.
p value is for the Dunnett's honestly significant difference test among phases.
For the paralyzed upper limb, significant difference was observed between pre- and post-intervention phases.

Table 3. Scores of clinical tests

			Day 0	Day 14	Day 28	Day 42
Clinical tests	FMA-UE	Total score	32	36	34	34
		Proximal score	16	20	18	19
		Distal score	16	16	16	15
	ARAT		9	9	8	11
	MAL	AOU	0	0.43	0.29	0.49
		QOM	0	0.36	0.29	0.29

FMA-UE: Fugl Meyer Assessment-Upper Extremity; ARAT: Action Research Arm Test; MAL: Motor Activity Log; AOU: Amount of Use; QOM: Quality of Movement.

phase indicated that the participant's recovery had already reached a plateau with conventional PT, OT, and ST at the beginning of this study. Our findings showed a significant increase in activity of the upper limb after the HAL-SJ intervention. This was the first study to use accelerometer to measure the effect of robotic rehabilitation on arm activity and to evaluate how the use of HAL-SJ improved the amount of activity of a paralyzed upper limb in daily living.

The results of the clinical tests (FMA, ARAT, and MAL) did not show any clinically important changes. This contrasted with the results of a recent study which reported that robotic rehabilitation improved clinical tests points for FMA, ARAT, and MAL[7)]. The reason for this discrepancy may be related to the intervention frequency. Our study intervention involved five sessions per week, whereas the study of Saita et al. involved 10 sessions per week. This may explain why Saita et al.'s study showed greater changes in clinical test results.

Although there were no clinically important changes in the clinical test results, our study using the accelerometer demonstrated a significant increase in the amount of activity in the paralyzed upper limb after the HAL-SJ intervention. This suggests that accelerometer is more sensitive than clinical testing for evaluating upper limb activity. We believe accelerometer could be especially useful for evaluating the effects of robotic rehabilitation.

In addition, our study also demonstrated a tendency to increase the amount of activity in the intact upper limb after the HAL-SJ intervention. Some studies have reported that HAL-SJ intervention affects activities of daily living such as dressing the upper body[16)]. In other words, HAL-SJ intervention might improve not only paralyzed upper limb activity but also intact upper limb activity. Unfortunately, past studies have reported the effectiveness of robotic rehabilitation on paralyzed upper limb function, and the effectiveness on the intact upper limbs remains to be clarified[17)]. The accelerometer might also be useful for evaluating the effectiveness on intact upper limb activities.

The limitation of our study is that it was a single-case study. A study with a larger number of patients is needed to obtain substantial results. Nevertheless, this study provides an opening for future studies.

In conclusion, this study provided new and important information on the effectiveness of rehabilitation with HAL-SJ for a stroke patient with a paralyzed upper limb. HAL-SJ could be useful for promoting the active use of a paralyzed upper limb in daily living.

Presentation at a Conference

This study was partially presented at the Second Annual Meeting of the Japanese Association of Rehabilitation Medicine in Autumn (abstract number 2-KP-9-3).

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Conflict of interest

All the authors have no conflict of interest to declare.

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