

# Comparison of the effects of and usability of active and active-assistive rehabilitation robots for the upper extremity function among patients with stroke: a single-blinded randomized controlled pilot study

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## Research

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## **Abstract**

## **Background**

Robotic rehabilitation of stroke survivors with upper extremity dysfunction yields different outcomes depending on the robot type. Considering that excessive dependence on assistive force provided by robots may interfere with the patient's active learning and participation, we hypothesized that the use of an active-assistive robot does not lead to a more meaningful difference with respect to upper extremity rehabilitation than the use of an active robot. Accordingly, we aimed to evaluate the differences in the clinical and kinematic outcomes between active and active-assistive robotic rehabilitation among stroke survivors.

## **Methods**

In this single-blinded randomized controlled trial, we assigned 20 stroke survivors with upper extremity dysfunction (Medical Research Council scale score, 3 or 4) to the active (ACT) and active-assistive (ACAS) robotic rehabilitation groups in a 1:1 ratio and administered 20 sessions of 30-minute robotic intervention (5 days/week, 4 weeks). The primary (Wolf Motor Function Test [WMFT]-score and -time: measures activity), and secondary (Fugl-Meyer Assessment [FMA] and Stroke Impact Scale [SIS] scores: measure impairment and participation, respectively; kinematic outcomes) outcome measures were determined at baseline, after 2 and 4 weeks of the intervention, and 4 weeks after the end of the intervention. Furthermore, we evaluated the usability of the robotic devices by conducting interviews with the patients, therapists, and physiatrists.

## **Results**

In both the groups, the WMFT-score and -time improved over the course of the intervention. Time had a significant effect on the WMFT-score and -time, FMA-UE, FMA-prox, and SIS-strength; group × time interaction had a significant effect on SIS-function and SIS-social participation (all,  $p < 0.05$ ). The ACT group showed better improvement in participation and smoothness than the ACAS group. In contrast, the ACAS group exhibited better improvement in mean speed.

## **Conclusions**

There were no differences between the two groups regarding the impairment and activity domains. However, the ACT robots were more beneficial than ACAS robots regarding participation and smoothness. Considering the high cost and complexity of ACAS robots, ACT robots may be more suitable for robotic rehabilitation in stroke survivors who can perform voluntary movement.

# Trial registration:

The trial was registered retrospectively on 14 March 2018 at ClinicalTrials.gov (NCT03465267).

## Introduction

Approximately 30–66% of stroke survivors suffer from upper extremity dysfunction, which leads to impairment of activities of daily living (ADL) and social participation.[1] Various interventions have been applied for upper extremity rehabilitation, and robotic rehabilitation has been recently popularized.[2–4]

Robotic rehabilitation has potential advantages regarding high repetition of specific tasks and interactivity, leading to active participation with less burden on therapists.[2, 5] Recent systematic reviews have suggested the beneficial effects of robotic rehabilitation on upper extremity dysfunction among patients with stroke.[4, 6] Veerbeek et al. described that robotic rehabilitation is more beneficial for the improvement of the motor control and strength of a paretic arm, but not for that of ADL, than is conventional therapy.[6] Furthermore, Mehrholz et al. demonstrated that robotic rehabilitation has more beneficial effects on ADL as well as on arm function and muscle strength than does conventional therapy. [4] However, these conclusions should be considered cautiously because the robots that were included in these reviews are heterogeneous, that is, 28 and 24 different rehabilitation robots were included in the systemic reviews by Veerbeek et al. and Mehrholz et al., respectively. We recently showed that the use of end-effector and exoskeleton rehabilitation robots led to significant functional outcome differences stemming from the distinct characteristics of robots; this indicates that the differential effects might result from the type of rehabilitation robot used.[7] Nonetheless, there is a lack of studies that examined the differential effects according to the characteristics of robots. If the discrepant effects during upper extremity rehabilitation are understood according to the characteristics of robots, more suitable robotic rehabilitation may be applied and provided to each patient.

Representatively, robotic devices can be classified as active and active-assistive robotic devices according to the training modality, that is, an active robot does not provide assistive force, while an active-assistive robot supplies assistive force when the participant could not make active movements. [8, 9] Robotic active assistance is thought to be beneficial for participants without voluntary movement because they can be trained with ideal path or speed. Nonetheless, active assistance using manipulation for upper limb rehabilitation is too complex to be adopted with ease because the upper extremities are composed of several joints and different muscles, which allow movements with multiple degrees of freedom. Moreover, musculoskeletal problems associated with stroke such as spasticity, contractures, deformity, or hemiplegic shoulder pain make the application of robotic assistance more difficult. Additionally, excessive dependence on assistive force might interfere with active learning and participation for participants who can perform voluntary movement. Therefore, we hypothesized that an active-assistive robot does not make a meaningful difference in terms of upper extremity rehabilitation relative to that made by an active robot. Thus, we aimed to explore whether there is a difference in clinical and kinematic outcomes between active and active-assistive robots during robot-assisted upper extremity

rehabilitation of patients with stroke showing a Medical Research Council (MRC) scale score of 3 or 4 for the paretic proximal upper limb. In addition, we assessed usability of robotic assistance. To our knowledge, this is the first clinical trial to directly compare rehabilitative effects between active and active-assistive robots.

## Methods

### Study design

This was a single-blinded, randomized controlled trial conducted at a rehabilitation hospital. Participants were randomly assigned to the active-assistive robotic intervention (using active-assistive exoskeletal robot with assistive force; ACAS) group or active robotic intervention (using active exoskeletal robot without assistive force; ACT) group in a 1:1 allocation ratio. Random allocation was conducted by using consecutive sealed opaque envelopes indicating group allocation, which were placed in a plastic container in numerical order. Each group completed 20 sessions of 30-minute robotic intervention, 5 days a week, for 4 weeks, conducted by an experienced research physical therapist in a research intervention room. Additionally, both groups received 30 minutes of conventional therapy for the affected upper limb, 5 days a week, for 4 weeks. The study was approved by the institutional review boards of a hospital, and all participants provided written informed consent before enrollment. Our study was registered retrospectively with ClinicalTrials.gov (NCT03465267).

## Participants

The study enrolled 20 patients with upper extremity dysfunction owing to stroke who were admitted in a rehabilitation hospital between March 2017 and December 2017. The inclusion criteria were: (1) age of > 19 years; (2) presence of hemiplegia owing to ischemic or hemorrhagic stroke; (3) stroke duration of > 3 months; (4) hemiplegic shoulder and elbow flexion/extension with a Medical Research Council scale score of 3 or 4 for muscle strength; (5) affected upper extremity Fugl-Meyer Assessment score (FMA) of 21–50; (6) shoulder and elbow flexor spasticity with Modified Ashworth Scale score of  $\leq 1+$ ; (7) cognitive function of the level that facilitates the understanding and obeying of instructions of this study; and (8) absence of a limit of range of motion of the shoulder and elbow joint, as determined by the neutral zero method. The exclusion criteria were as follows: (1) history of surgical treatment of the affected upper extremity; (2) musculoskeletal problem of the upper extremity such as fracture, contracture, and shoulder subluxation of more than two finger breadth; and (3) cybersickness, that is, occurrence of nausea or vomiting while seeing a screen.

## Intervention

### Active-assistive robotic intervention group

In the ACAS group, we administered intervention using an Armeo® Power (Hocoma Inc, Zurich, Switzerland) (Fig. 1A), which is a three-dimensional exoskeletal active-assistive robot used for upper extremity rehabilitation. Actuators actively assist affected arm movement as established extent, on top of arm weight support offsetting the device weight. Participants were trained with game-based virtual reality environment with focus on proximal upper limb movement.

## Active robot intervention group

In the ACT group, we used an Armeo® Spring robot, (Hocoma Inc, Zurich, Switzerland) (Fig. 1B), which is an exoskeletal active robot for three-dimensional upper extremity rehabilitation. The Armeo® Spring provides gravity compensation, offsetting the device and participant's upper extremity with the help of a spring but not with robotic actuators. Participants were trained under the same virtual reality environment as were those included in the ACAS group.

## Outcome Measure

We evaluated FMA to measure impairment, Wolf Motor Function Test (WMFT) to measure activity, Stroke Impact Scale (SIS) to measure participation, according to the International Classification of Functioning, Disability, and Health (ICF) concept. [10] To determine more detailed kinematic outcomes, smoothness and mean speed were measured. Outcome measures were checked at baseline (T0), after 2 (T1) and 4 weeks of the intervention (T2), and 4 weeks after the end of the intervention (T3).

## Primary Outcome

The primary outcome measure was WMFT, which quantifies the upper extremity functional activity using 15 functional tasks.[11] WMFT-score is rated on a 6-point scale, with the score ranging from zero to five; thus, the total score ranges from 0–75. WMFT-time is the sum of the time required to perform all 15 tasks. The higher the WMFT-score or the shorter the WMFT-time, the better the motor activity.

## Secondary Outcomes

Secondary outcome measures were FMA score, SIS score, and kinematic data. FMA score, which ranges from 0 to 100, is a quantitative indicator of motor impairment following stroke, with a higher scores reflecting a lower impairment. [12] We used FMA-UE (shoulder, elbow, forearm, wrist, and hand; 33 items, 0–66) and FMA-prox (shoulder, elbow, and forearm; 18 items, 0–36). SIS version 3.0, which is a stroke-specific, self-reported questionnaire, has been applied as a health-related quality of life measurement tool to assess participation. [13, 14] We measured eight domains of SIS (strength, hand function, ADLs and instrumental ADLs (ADLs/IADLs), mobility, communication, emotion, memory and thinking, and social participation); the score of each domain ranges from 0 to 100; the higher the score the better the health

status. In the present study, four domains (strength, physical, ADLs/IADLs, and social participation) that are more relevant to proximal upper extremity function were selected for secondary outcome assessment. We also determined SIS-overall (sum of scores of all eight domains) and SIS-function (sum of scores of ADLs/IADLs and social participation).

With regard to kinematic analysis for detailed information about impairment, we recorded the position of affected upper extremity using the trakSTAR™ system (Ascension Technology Corp, USA), which measures the movement of an electromagnetic sensor tracing 6 degrees of freedom (x, y, and z axes) at 80 Hz of sampling rate during each reaching movement. In the present study, the sensor was attached at the distal phalanx of the middle finger with double-sided tape, and the wire was fixed to the skin with bandage; the reference transmitter was located behind the participant (Fig. 2). Each patient was asked to sit in a chair in front of a table, the height of which was adjusted such that the elbow is flexed at an approximate angle of 90° in the sagittal plane; however, the distance of the table from the participant was maintained such that comfortable reaching is ensured. Participants practiced the reaching task three times to be familiarized with the experimental setup, which is described as follows. Buttons (base button and three target buttons) were positioned according to each participant's affected arm length (from the distal end of the middle finger to the acromion). Three target buttons were set on a vertical wooden plate in front of the participant at the height of the participant's xiphoid process and at a distance of 75% of the arm length in three different positions on the transverse plane (ipsilateral, central, and contralateral). The central button was installed in front of the midline, and two other buttons (ipsilateral and contralateral button) were placed in the ipsilateral and contralateral position at an angle of 45° from the central button. Base button was placed on the table in front of the midline at 25% of the measured arm length. Subsequently, participants were asked to reach from the base button to one of the three different target buttons, subsequently bringing back the upper limb to the base button at their own comfortable speed. Those movements were repeated nine times (three times to reach each target button in a randomized order) with 1 min of rest between each movement. Patients were instructed to limit trunk movements without a trunk restraint.

Subsequently, two kinematic performance indices were computed on the basis of the position data during reaching: spectral arc length (SAL) and mean speed (MSP). SAL is a dimensionless measure reflecting the smoothness, which was calculated using the arc length of the Fourier magnitude spectrum of a movement speed profile. [15] A higher SAL value indicates a smoother and thus a better movement.[16] It is also known as an important marker reflecting motor recovery of patients with stroke. [17] MSP was calculated by dividing the distance of actual trajectory by the time required for reaching from the base button to each target button.

## Usability Study

We assessed the usability of the patients with stroke with on the basis of individual interview at the end of the intervention. Usability was also determined on the basis of interviews conducted by the research

physical therapists, who were in charge of the robotic intervention, and physiatrists, who observed the robotic rehabilitation at the end of the present study.

## Statistical analysis

We analyzed the participants who completed outcome measurements at T2 at the least. When the results of T3 were not measured, the last observation carried forward method was used; thus, missed outcomes at T3 were filled in with those determined at T2. For the comparison of baseline characteristics between two groups, Fisher's exact test and Mann-Whitney U test were applied for categorical variables and continuous variables, respectively. Repeated measures of analysis of variance (RM-ANOVA) were conducted using the group (ACAS or ACT) and time (T0, T1, or T2) to compare the effect of each intervention across time, and time × group interactions were assessed. Greenhouse-Geisser corrections were applied when the violation of sphericity occurred. Additionally, Mann-Whitney U test was performed for the intergroup comparison of kinematic data. A p-value of <0.05 was considered statistically significant. All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.

## Results

A total of 20 patients with stroke participated in the present study from January 1, 2017, to December 31, 2017, and ten participants each were allocated to the ACAS or ACT groups (Fig. 3). One participant of the ACT group dropped out because he was transferred to another hospital without any adverse event; thus, data on 19 participants (10 ACAS group, 9 ACT group) who completed outcome measurements at T2 at the least were analyzed (Table 1).

Table 1  
Baseline characteristics of the participants

	ACAS group (n = 10)	ACT group (n = 9)	p-value
Age	54.9 ± 10.7	53.9 ± 16.7	0.842‡
Time after stroke onset (month)	11.8 ± 11.0	9.6 ± 4.5	0.905‡
Stroke type (infarction/hemorrhage)	5/5	4/5	1.000*
Hemiplegic side, right	6	5	1.000*
Sex, male	8	8	1.000*
FMA-prox	20.6 ± 5.0	22.2 ± 6.2	0.497‡
FMA-UE	28.2 ± 10.9	30.2 ± 9.7	0.549‡

Values are presented as the mean ± standard deviation or number.

\*Fisher's exact test, ‡Mann-Whitney U test

ACT: active; ACAS: active-assistive; FMA-prox: Fugl-Meyer Assessment-proximal (shoulder, elbow, and forearm; 18 items, 0–36); FMA-UE: Fugl-Meyer Assessment-upper extremity (shoulder, elbow, forearm, wrist, and hand; 33 items, 0–66)

## Primary Outcome

Both the groups showed similar tendencies, that is, WMFT-score improved over the course of 4 weeks of the intervention and declined after its completion, whereas WMFT-time continued to improve over time (Fig. 4). There was a significant effect of time on both WMFT-score ( $F = 19.754$ ,  $p < .001$ ) and WMFT-time ( $F = 7.369$ ,  $p = 0.002$ ); however, there was no significant effect of group × time interaction on WMFT-score ( $F = 0.700$ ,  $p = 0.504$ ) and WMFT-time ( $F = 0.802$ ,  $p = 0.457$ ).

## Secondary Outcome

There was a significant effect of time on both FMA-UE ( $F = 6.615$ ,  $p = 0.004$ ) and FMA-prox ( $F = 9.746$ ,  $p < .001$ ) without that of group × time interaction on FMA-UE ( $F = 0.856$ ,  $p = 0.434$ ) and FMA-prox ( $F = 0.388$ ,  $p = 0.682$ ) (Fig. 4). Furthermore, group × time interaction had a significant effect on SIS-function ( $F = 4.965$ ,  $p = 0.013$ ) and SIS-social participation ( $F = 6.388$ ,  $p = 0.004$ ), with more improvements in the ACT group than in the ACAS group, but not on SIS scores (Table 2). Similarly, time had a significant effect on SIS-strength ( $F = 6.622$ ,  $p = 0.004$ ), but not on SIS-overall ( $F = 2.277$ ,  $p = 0.118$ ), SIS-function ( $F = 0.642$ ,  $p =$

0.532), SIS-physical ( $F = 1.909$ ,  $p = 0.164$ ), SIS-ADL/IADLs ( $F = 0.429$ ,  $p = 0.655$ ), and SIS-participation ( $F = 0.298$ ,  $p = 0.744$ ).

Table 2  
Comparison of the performance between the ACAS and ACT groups at T0, T1 and T2

Variable	ACAS group (n = 10)			ACT group (n = 9)			Time * Group	
	T0	T1	T2	T0	T1	T2	F	p-value
SIS-overall	55.6 ± 12.2	57.9 ± 13.8	59.3 ± 14.1	59.0 ± 13.2	61.8 ± 14.3	63.7 ± 12.7	0.031	0.970
SIS-function	62.1 ± 16.7	56.0 ± 17.0	55.7 ± 15.6	59.5 ± 21.6	65.2 ± 20.8	71.5 ± 18.5	4.965	0.013
SIS-physical	37.3 ± 11.4	42.1 ± 12.6	44.9 ± 14.7	52.8 ± 14.8	49.3 ± 11.6	53.7 ± 16.0	1.765	0.187
SIS-strength	15.3 ± 13.7	23.0 ± 16.3	30.0 ± 18.6	32.1 ± 13.0	34.0 ± 20.9	44.4 ± 19.0	0.301	0.742
SIS-ADL/IADLs	62.6 ± 17.5	59.2 ± 18.8	63.4 ± 16.6	65.7 ± 20.3	67.2 ± 18.5	69.2 ± 24.0	0.261	0.772
SIS-social participation	61.5 ± 26.7	52.8 ± 30.3	47.9 ± 28.9	53.3 ± 24.8	63.1 ± 26.2	73.8 ± 24.4	6.388	0.004

ACT: active; ACAS: active-assistive; SIS: Stroke Impact Scale; IADLs: instrumental ADLs; ADLs: activities of daily living

Kinematic data from eight participants of the ACAS group and seven participants of the ACT group were available because of signal loss during the experiment (Figs. 5, 6) (Supplementary table). Group × time interaction had no significant effect on SAL and MSP across the target buttons, but time had significant effects on SAL-central ( $F = 9.589$ ,  $p = 0.001$ ), MSP-contralateral ( $F = 12.707$ ,  $p < .001$ ), MSP-central ( $F = 14.681$ ,  $p < .001$ ), and MSP-ipsilateral ( $F = 7.323$ ,  $p = 0.003$ ). The ACT group showed a better improvement than did the ACAS group with regard to SAL-ipsilateral from 2 to 8 weeks ( $p = 0.029$ ) and from 4 to 8 weeks ( $p = 0.014$ ) and with regard to SAL-central from 4 to 8 weeks ( $p = 0.029$ ). On the contrary, the ACAS group showed a better progression of MSP-central than did the ACT group from 0 to 4 weeks ( $p = 0.021$ ).

## Usability Study

The usability, in terms of robotic active assistance, mechanical aspects of robot, experience during robotic rehabilitation, and benefits of robotic rehabilitation, was summarized as pros and cons, separately for both the groups in Table 3. Some patients felt that the robotic active assistance was beneficial for their training, as it afforded patient coordination and desirable movement pattern without aggravated compensatory movements of the trunk. However, active assistance was sometimes discordant to the

patients' intended movement. The mechanical complexity and high inertia stemming from the manipulator, which provide active-assistive force, make the robotic training more difficult. On the contrary, participants of the ACT group tried to invest more effort to move the limb than did those of the ACAS group, which led to a sense of achievement, fulfillment, and motivation among participants because they could accomplish the tasks without external assistance.

**Table 3.** Usability test for each intervention from the patients with stroke, physiatrists, and therapists.

ACAS

ACT

## **Patients with stroke**

## Pros

Assistive force-as-needed function of the ACAS robot facilitated the strengthening of the upper limb and increased smoothness of movement. The spontaneous and voluntary control of the robot seems to be linked to functional improvement in ADL. The voluntary control of the robot without any

The voluntary control of the robot without any external assistance leads to a feeling of achievement.

Cons

Assistive force sometimes gave the Assistive force-as-needed function might allow resistance for the intended voluntary more optimal movement or the movement that movement. was not possible without any assistance.

was not possible without any assistance.

The robotic exoskeleton was too heavy and bulky hampering arm movement.

### **Physiatrists and therapists**

## Pros

ACAS robot seems to be better for introducing "ideal smooth and efficient" upper limb movement. More efforts were required from the participants; thus, self-motivated voluntary training was fulfilled.

Cons

Assistive force sometimes was not coordinated in terms of timing and context of the virtual environment.

Compensatory movements were aggravated, such as abnormal posture or overuse of trunk instead of limb use, because of no assistance

The assistive force caused conflict with the spasticity of participants.

The inertia caused by manipulator was too high for the patients, paradoxically hampering upper limb movement.

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## Discussion

We demonstrated that the ACAS and ACT rehabilitation robots had distinct effects on different domains among patients with chronic stroke showing an MRC scale score of 3 or 4 for the affected proximal upper extremity muscle strength. In terms of the impairment and activity domains, there were no differences between the two groups. On the contrary, for the participation domain, the ACT rehabilitation robot showed more beneficial effects than did the ACAS rehabilitation robot on SIS-function and SIS-social participation. Kinematic analysis demonstrated that the ACT group showed better lasting effects on smoothness, while the ACAS group showed immediate effects on speed.

On the basis of our finding, we could say that our results represent the effects of active-assistance during robotic rehabilitation, because other factors of each group, such as the dose (time), task (three-dimensional task), software platform (game-based virtual reality environment), and mechanical structure (exoskeleton type), were comparable. There have been few studies focusing on robotic rehabilitation using assistive force. A previous study compared active-assistive robotic reaching training and non-robotic free-reaching training.[18] In terms of clinical outcomes, no between-group differences were found. On the contrary, kinematic analysis demonstrated that active-assistive robot training improves the smoothness but not the range of motion and straightness, indicating the subtle effects of active-assistive robot. A recent study compared the effects of robotic path assistance and/or weight support on upper extremity kinematics among patients with stroke.[19] They showed that path assistance led to a faster movement in the high functioning group and that a combination of path assistance and weight support led to a smaller error in the low functioning group. However, path assistance was not superior to weight support alone with regard to upper extremity kinematics of especially the lower functioning group, when considering a trade-off between speed and error.

Collectively, results of the previous studies and the current study indicate that ACAS and ACT rehabilitation robots showed no difference in their effects on clinical measures of parameters including impairment and activity, but they have distinct kinematic effects. There might be several explanations for these findings. First, our study population had an ability to move their affected arm without necessarily requiring external assistance although some patients of the ACT group said that robotic active assistance might be more helpful for their training intensity and quality. Second, the active-assistive function was not excellent enough to alleviate the fundamental issues of the upper limb function; therefore, other impairment or activity cannot be attributed to its effects.[20] Robotic assistance was not well coordinated with the motion of participants, thus impeding the intended voluntary movement in some patients, especially among those with spasticity. In a similar vein, the therapists who participated in this study emphasized that the alignment of axis is important to minimize those conflicts. Third, a higher inertia

owing to the weight of the manipulator that supplied assistance, hampered the patient's movement, thereby offsetting the effect of the assistance. Fourth, the kinematic analysis had detected distinct feature that were not explained by clinical scale scores.[21]

Notably, the ACT rehabilitation robot showed more beneficial effects with respect to SIS-function and SIS-social participation than did the ACAS rehabilitation robot. Active assistance could induce "motor slacking" of participants, which is a tendency to minimize metabolic and movement-related costs, thereby preventing active participation and simultaneously developing dependence on the robot.[22] Motor slacking also possibly affects motivation, attention, effort, and active engagement, which are related to motor cortex excitability and motor plasticity. [20, 23] Robotic assistance of the ACAS group decrease the loads on the participants' motor systems, which impedes the learning of the fundamentals essential for performing the task.[20] On the contrary, the ACT group might experience more achievement, resulting in the improvement of participation, as reflected by SIS, but not that of impairment and activity, as reflected by FMA and WMFT. Similar results were found by a previous study that used a self-powered robot, which manipulated the participants' affected arm using their unaffected arm and induced a higher degree of muscle activation in the affected arm than did externally powered robots, indicating the role of active participation.[22] In addition, those active engagements might induce learning and lasting effects, as shown by the lasting effects of smoothness after intervention in the ACT group.

There are four limitations to this study. First, for the ACT group, we used a robot that supports the limb with gravity compensation. Nonetheless, most rehabilitation robots provide weight support of the limb to eliminate gravity effects; thus, our comparison represents the effects of active assistance during robotic rehabilitation and provides guidance for the development or application of active assistance of rehabilitation robot. Second, the present study included patients with stroke showing an MRC scale score of 3 or 4 for the proximal upper limb strength, and therefore, the results may not be similarly applicable to other populations. For patients with limited muscle strength, active-assistive robotic training is necessary. Third, the number of participants may be insufficient to draw a definite conclusion. In addition, a power analysis was not performed to calculate the required participant number because this was a pilot study. Fourth, intervention dose was not sufficient to induce motor learning, as indicated by the decline of many outcomes after 4 weeks of treatment. Thus, further studies with a larger study population and a higher dose of intervention are needed.

## Conclusion

Our findings suggested that the active-assistive robot did not provide a significantly higher advantage than did the active robot with regard to improvement of impairment and activity. It had a rather lower effects on participation, although there were differences with regard to kinematic results. Moreover, considering the complex nature and high price of active-assistive robots, active robots could provide sufficient robotic rehabilitation for patients with stroke showing voluntary motor control of the upper limbs.

## **Abbreviations**

ADL, Activities of daily living

FMA, Fugl-Meyer Assessment

MRC, Medical Research Council

SAL, Spectral arc length

SIS, Stroke Impact Scale

WMFT, Wolf Motor Function Test

ACAS, Active-assistive

ACT, Active

## **Declarations**

Ethics approval and consent to participate

The study was approved by the institutional review boards of National Rehabilitation Center in South Korea (NRC-2017-01-007) and conducted in accordance with the Declaration of Helsinki. All participants provided written informed consent before enrollment. Our study was registered retrospectively with ClinicalTrials.gov (NCT03465267).

Consent for publication

Consent for publication is acquired by all the authors.

Availability of data and materials

The dataset used in the present study is available from the corresponding author on reasonable request.

Competing interests

The authors report no conflicts of interest.

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Authors' contributions

JHP implemented analysis and interpretation of data and wrote and edited the manuscript. GP and HYK participated to the study design, data collection and analysis. JYL and YH conducted the research and data collection. DH and SK participated to data analysis and interpretation. JHS contributed to the study design, prepared the research protocol, interpreted the data, and wrote and edited the manuscript. All authors have read and approved the final manuscript.

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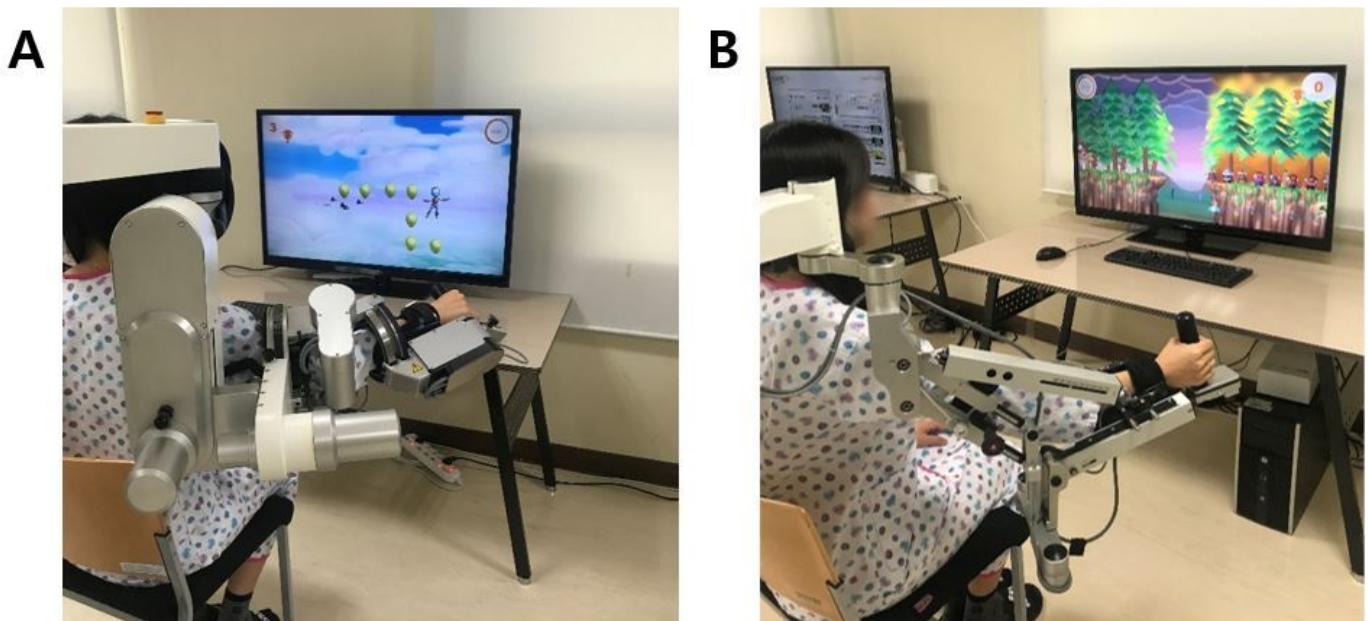
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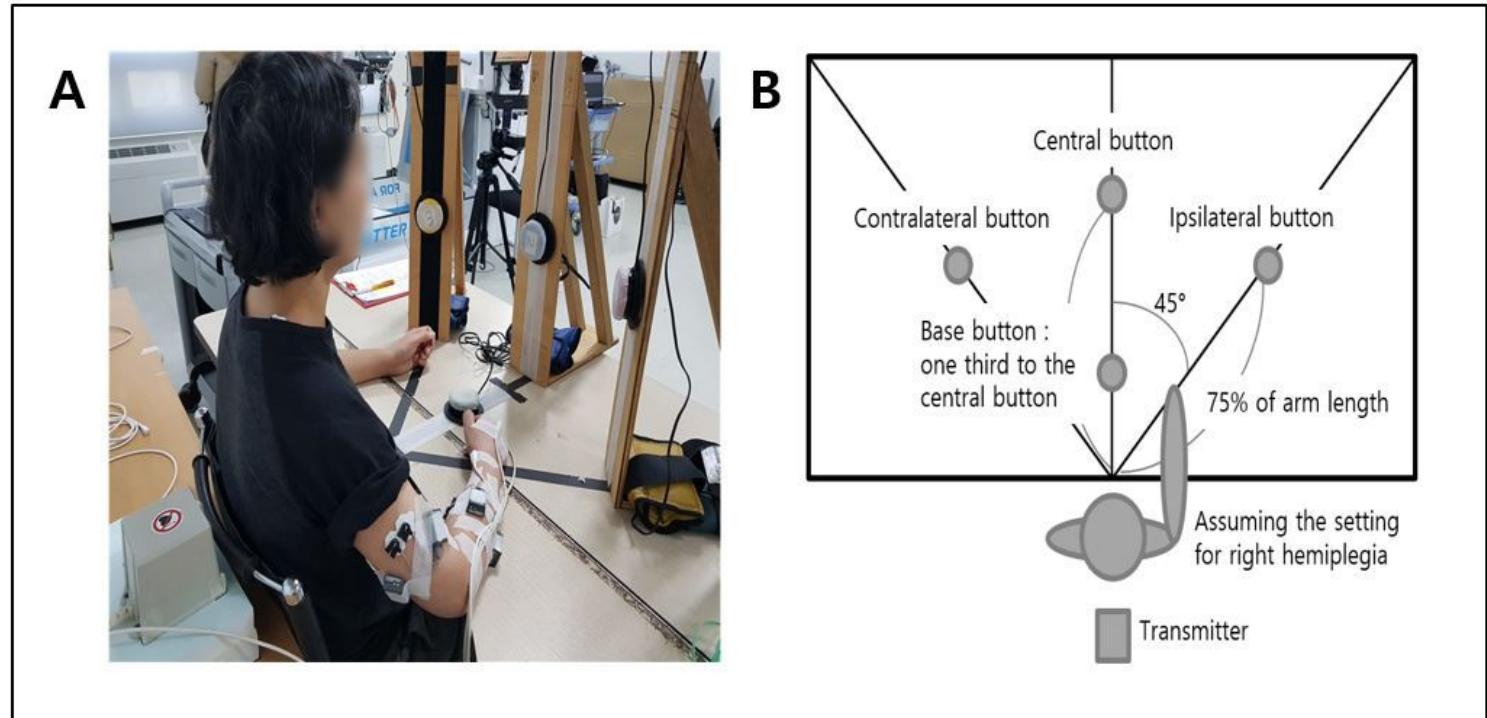
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## Figures



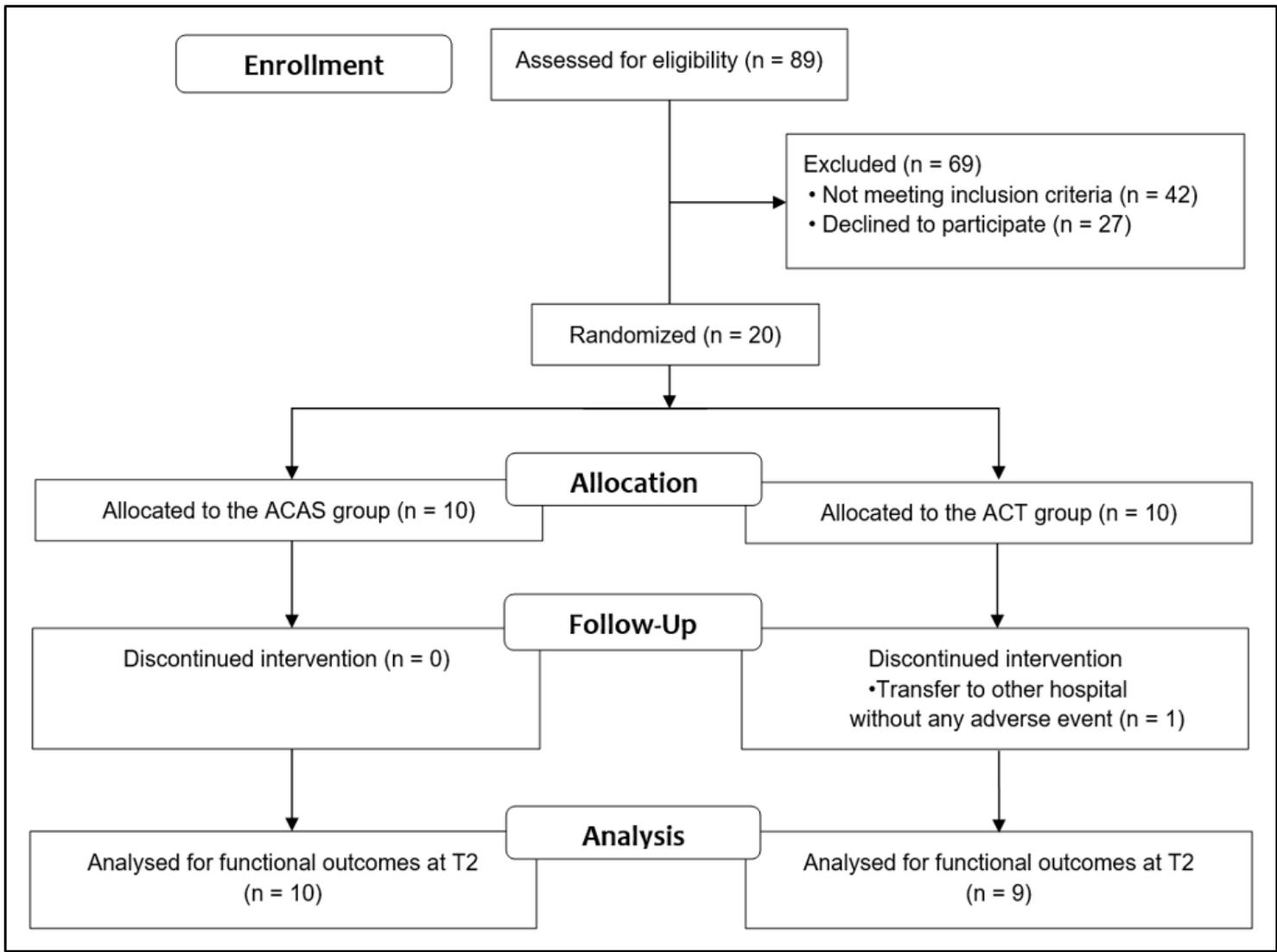
**Figure 1**

Two types of rehabilitation robots used for the robotic rehabilitation. (A) Armeo® Power for the ACAS group and (B) Armeo® Spring for the ACT group. ACAS, active-assistive; ACT, active.



**Figure 2**

(A) Picture showing the experimental setup for kinematic measurement. (B) Illustration of placement of the base button and target buttons.

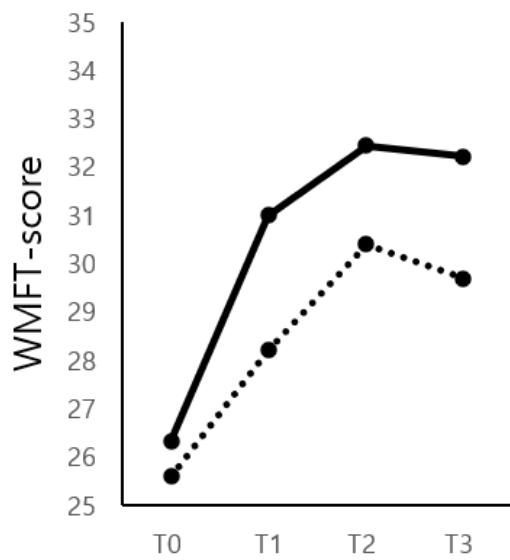


**Figure 3**

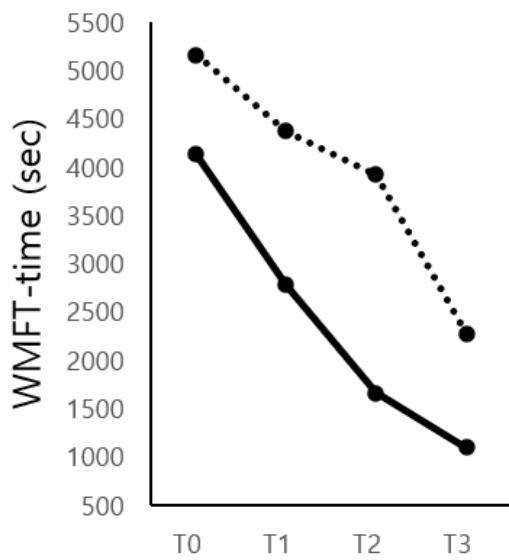
Flow chart showing the study design

····· ACAS    — ACT

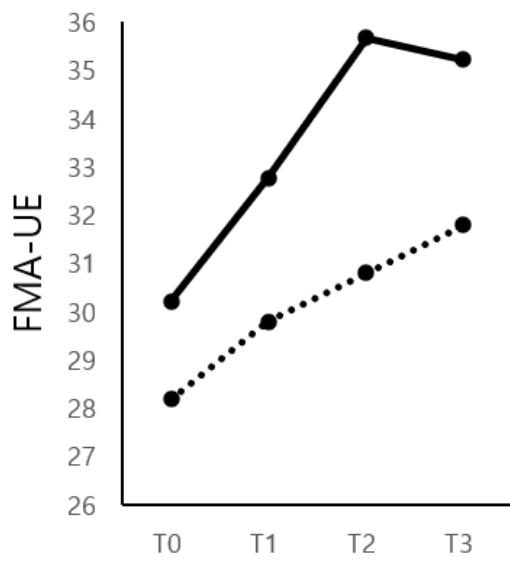
A



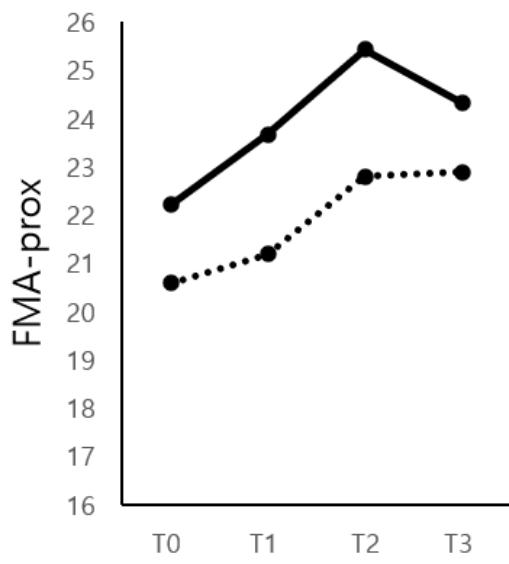
B



C

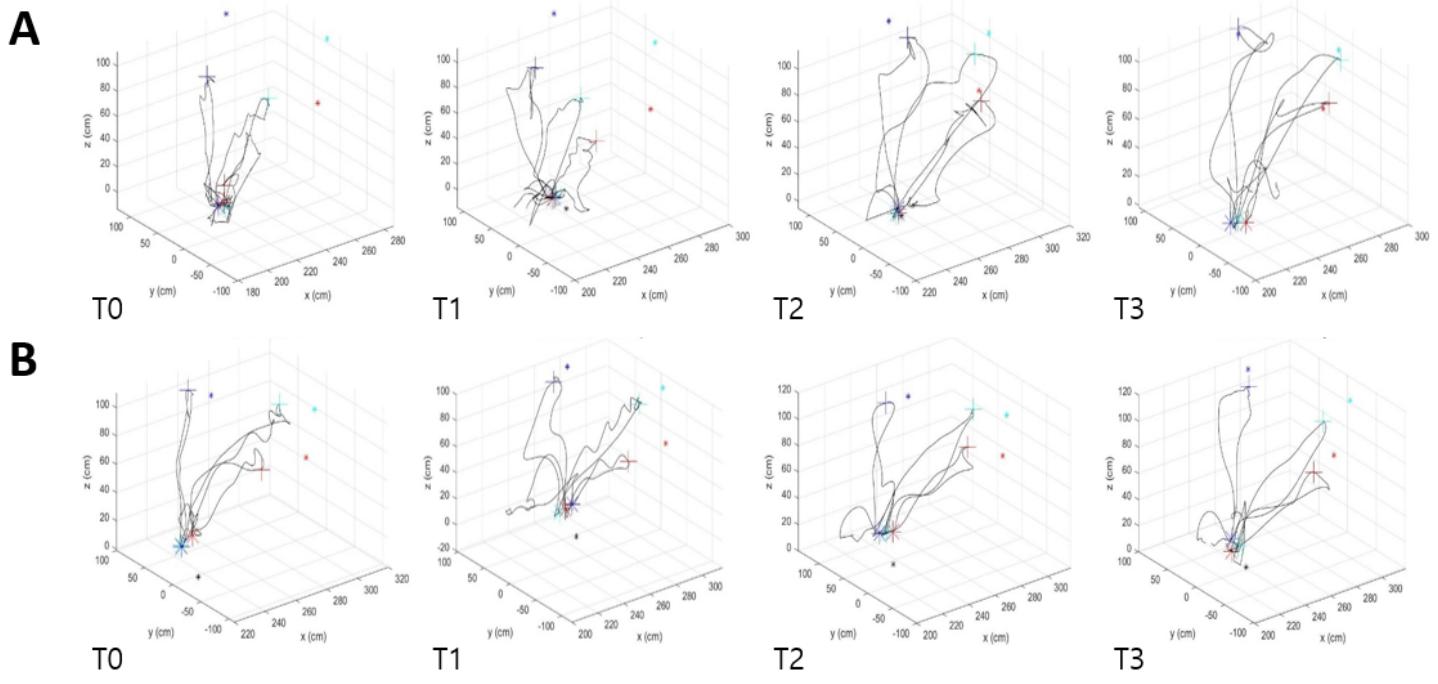


D



**Figure 4**

(A) WMFT-score, (B) WMFT-time, (C) FMA-UE, (D) FMA-prox

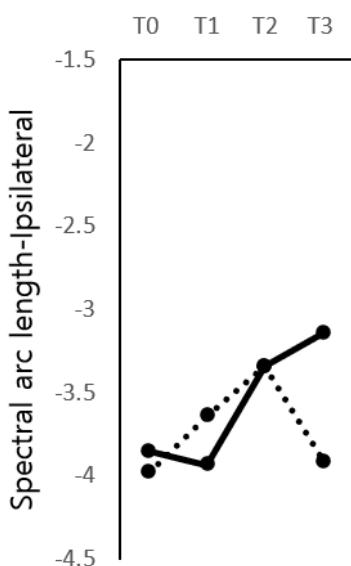
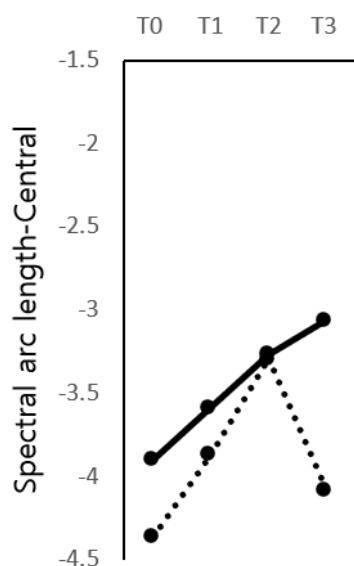
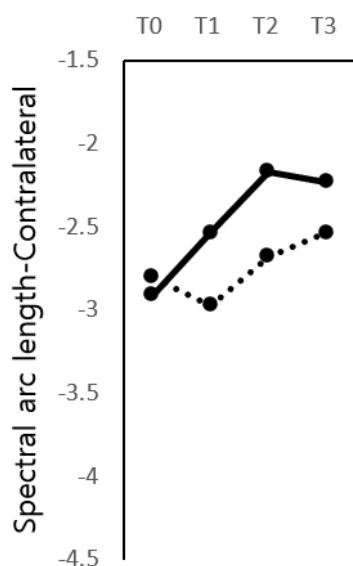


**Figure 5**

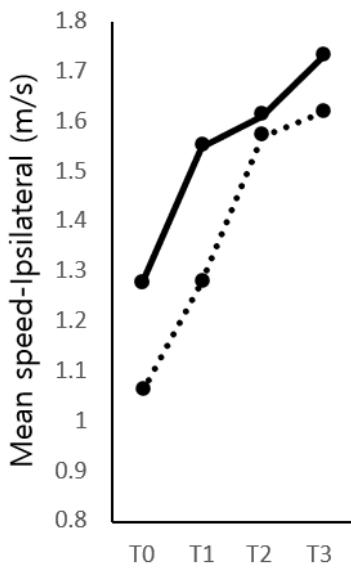
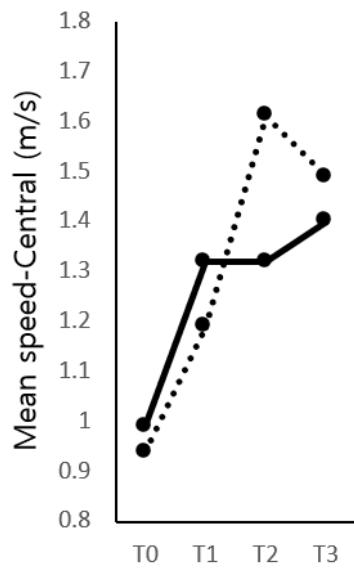
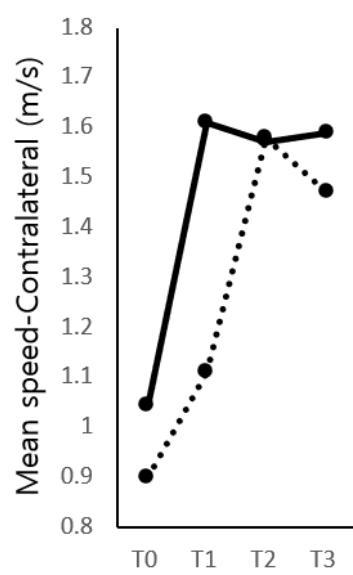
Examples of reaching trajectories across time from a patient with stroke in (A) the ACAS group and in (B) the ACT group.

..... ACAS    — ACT

**A**



**B**



**Figure 6**

(A) Spectral arc length, (B) mean speed

## Supplementary Files

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- [Supplementarytable.docx](#)