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The Comparison between the Effect of Action Observation and that of Bimanual Movement in Chronic Hemiplegia

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Abstract

Background: Various interventions have been investigated for the purpose of regaining the limited ADL of chronic stroke hemiplegia. However the application of intervention depending on motor function is still unclear.

Objective: To investigate the effectiveness of Action Observation (AO) and Bimanual Movement (BM) depending on the severity of motor paralysis in chronic hemiplegia.

Methods: Cross over trial was undertaken with 29 participants. Before the trial, all participants were scored on Brunnstrom Recovery Stage (BRS) and classified into three groups (severe, moderate and mild). Paretic finger extension / flexion were performed in AO, BM and control (CON) condition. Primary outcome measure was the Range of finger Movement (ROM). Secondary outcome measures were smoothness of paretic finger movement and muscle activity of the extensor digitorum muscle (ED) and flexor digitorum superficialis muscle (FDS) in the paretic arm. Two way ANOVA was used to analyze the results.

Results: Significantly difference was found for the ROM between AO and CON condition in mild group, furthermore significantly difference was found for the ROM between BM and CON condition in moderate group. Although statistically trend, difference was found for the smoothness between AO and CON condition in mild group.

Conclusions: AO has the potential to facilitate motor learning by not only enhancing muscle power output but also improving motor control in mild hemiplegia. BM has beneficial effects to support generating the movement for moderate hemiplegia. Our findings might provide support for promoting the recovery of motor paralysis by selection of intervention in stroke rehabilitation.

Keywords: Stroke; Rehabilitation; Action Observation; Bimanual Movement

List of abbreviations: ADL: Activities of Daily Living; BRS: Brunnstrom Recovery Stage; CI: Coactivation Index; CIE: Coactivation Index of Flexion; CIF: Coactivation Index of Extension; CIMT: Constraint Induced Movement Therapy; CST: Corticospinal Tract; fMRI: Functional Magnetic Resonance Imaging; IEMG: Integrated Electromyogram; IHI: Interhemispheric Inhibition; MN: Mirror Neuron; NJE: Normalized Jerk of Extention; NJF: Normalized Jerk of Flexion; ROE: Range of Extension; ROF: Range of Flexion; SIAS: Stroke Impairment Assessment Set; TMS: Transcranial Magnetic Stimulation

Introduction

Motor paralysis is known as the most frequent symptom in stroke patients, and activities of daily living (ADL) of stroke patients are limited due to motor paralysis. Spontaneous recovery is occurred in a few months from onset, however most stroke patients do not completely recover from motor paralysis after six months from onset [1,2]. Therefore, various intervention methods have been investigated for the purpose of regaining the limited ADL of chronic stroke hemiplegic patients.

Action observation (AO) is known as the one of various interventions for improving upper limb motor function of chronic hemiplegia. Borges *et al.* reported that AO is beneficial in improving upper limb motor function and dependence in ADL in people with stroke [3]. The neural basis of AO is the Mirror Neurons (MN) that are active not only at own movement but also at observing other's movement [4-7]. In Functional Magnetic Resonance Imaging (fMRI) study, the activity of MN increased when exercise with observing other's movement than without observing [8,9]. Imitation, in which MN is also involved, is known to reduce interhemispheric inhibition, resulting in activation of the primary motor cortex that causes the observed movement [10]. In addition, the MN activity of capoeira dancer increased when observing capoeira movements than observing ballet movements [11]. These results indicate that AO may be suitable intervention to make movement more skillful. Considering the unskillful movement in mild hemiplegia, AO may have a potential to facilitate learning of skillful movement in mild paretic upper limb.

Bimanual movement (BM) is also known as an effective intervention for chronic hemiplegia. Previous studies reported that the generation of paretic upper limb movement is facilitated by simultaneous movement of non-paretic upper limb [12,13]. Neural coupling effects triggered through intact neural pathways linking both of hemisphere may be the basis for improvement in BM [14,15]. In fMRI study, it is reported that motor related brain areas are more active during BM than that of unilateral movement [16]. Furthermore, in Transcranial Magnetic Stimulation (TMS) studies, it is reported that the motor cortex excitability facilitated by not only contralateral hand movement that also ipsilateral hand movement [17,18]. These results indicate that BM may be an intervention to promote the generation of paretic hand movement by enhancing the activity of motor related brain area. Considering the difficulty to generate paretic hand movement in severe hemiplegia, BM may be suitable intervention for generating paretic hand movement in severe hemiplegia.

Based on the premise that AO enhances MN's activity to facilitate motor learning of paretic hand movement and BM induce neural coupling effects between both upper limbs to facilitate generation of paretic hand movement, we hypothesized that application for stroke rehabilitation would be differ between AO and BM depending on the severity of motor paralysis. In this study, as a preliminary study, we aimed to compare the kinematic parameter of paretic hand during AO and that of BM for clarifying the application at these interventions.

Material and Methods

Participants

Participants were recruited from among chronic stroke patients attended in Tohoku University Hospital between May 2015 and March 2019. An inclusion criteria was stroke patients who had suffered first ever stroke over 6 months from on set. An exclusion criterion was aphasia, pain during motor tasks and other neurological history. Twenty-nine stroke patients (mean ± S.D. age 56 ± 9 years, range 35 - 70 years, 7 female, 7 dominant-hand affected) participated in this study. After fully informed consent, written consent was obtained from all patients in accordance with the Declaration of Helsinki and ethics provisions at Tohoku University Graduate School of Medicine.

Design

This was a cross sectional study designed as a cross over trial under three different conditions. All participants performed motor task under each conditions. To exclude the influence of order effects, the order of conditions were counterbalanced among participants.

Behavioral testing

All participants were scored on Brunnstrom Recovery Stage (BRS) [19] for finger and Stroke Impairment Assessment Set (SIAS) [20]. It is reported that these assessments has validity to assess the impairment in hemiplegia [21,22]. Miyamoto *et al.* reported that hemiplegia with BRS for finger score I, II and III are requiring assistance for ADL, and hemiplegia with BRS finger score V and VI are requiring light partial assistance or independent for ADL [23]. Therefore, in the present study, participants were classified into 3 groups: the severe group, BRS for finger score I, II and III; the moderate group, BRS for finger score IV; and the mild group, BRS for finger score V and VI.

Motor Task

Participants sat on a comfortable chair and the paretic upper limbs were fixed with self-made fixtures so that only the movement of the fingers could be done. Instruction was to perform ten times flexion and extension movements of paretic fingers with switching these movements according to metronome sounds. In control (CON) condition, motor task was just performed. In AO condition, participants performed motor task observing the flexion-extension finger movements performed by healthy people from the first person's viewpoint via head mount display (HMZ T-2, SONY, Japan). In BM condition, motor task was performed with non-paretic hand simultaneously.

Measurement

Electrogoniometer (Single Axis Goniometer Type F 35, Biometrics Ltd, UK) was attached to the second metacarpophalangeal (MP) joint in paretic side to measure the kinematic data. The electrogoniometer signal was collected using an analog to digital converter (Power lab 16/35; AD Instruments, Japan) and appropriate software (Lab chart 7; AD Instruments, Japan). The signal was recorded at 1KHz with low-pass filter (cutoff frequency 5Hz). Surface electrodes (SX230 EMG Sensor, Biometrics Ltd, UK) were used to measure muscle activity. Electromyography (EMG) data were collected from the extensor digitorum muscle (ED) and flexor digitorum superficialis muscle (FDS) in the paretic arm. EMG signals were amplified and recorded at 1 kHz with a bandpass filter between 20 and 450 Hz.

Data analysis

The angle of second MP joint during motor task in each condition was measured. The angle data in the second to tenth section was used for analysis because it was difficult to control the initial position of paretic finger among patients due to spasticity. The degree of finger movement from the maximum extension angle to the maximum flexion angle was calculated as the range of flexion (ROF) and the average value in each phase was used for statistics. The degree of finger movement from the maximum flexion angle to the maximum extension angle was calculated as the range of flexion (ROE) and the average value in each phase was used for statistics.

The smoothness of finger movement was evaluated by jerk analysis of the finger angle [24]. To normalize for different movement duration and range, the jerk divided by range/duration and extracting the square root. The normalized jerk (NJ) formula as:

$$\sqrt{\left(\frac{1}{2} * \int_{T_{start}}^{T_{end}} \text{jerk}(t)dt * \text{duration} / \text{range} \right)}$$

where T_{start} and T_{end} represent the start and end times of the movement, jerk is the third derivative of angle, duration is the movement execution time ($T_{start} - T_{end}$) and range represent a degree from minimum angle to the maximum angle. The average value in each phase was used for statistics as NJ of extension (NJE) and NJ of flexion (NJF).

The muscle activity of ED and FDS during motion task was measured. EMG signals ware processed under root mean square (RMS) using a sliding 50 ms window. Integrated EMG (IEMG) was calculated during the section which from one second before to the time at maximum flexion/extension performed. To investigate the effect of each condition on muscle activity, the ratio of agonist IEMG and antagonist IEMG at extension/flexion phase ware calculated [25]. The average value of ratio in each phase was used for statistics as Co-contraction Index of extension (CIE) and Co-contraction Index of flexion (CIF).

Statistical Analysis

A post hoc power analysis was performed to confirm sufficient power to identify significant interaction in primary outcome measures (ROE, ROF) and secondary outcome measures (NJE, NJF, CIE and CIF). We calculated statistical power using sample size (N = 29), 0.05 α error significance level, and effect size calculated from results.

A mixed ANOVA was performed on ROE, ROF, NJE, NJF, CIE and CIF comprising within-subjects factors of conditions (CON, AO and BM) and between-subjects factors of severity (severe, moderate and mild). Post hoc testing was performed with the Bonferroni correction. A significant interaction of "condition × severity" would mean that the performance of motor task differs significantly between groups. Statistical analysis were performed with SPSS for Windows (SPSS version 25.0; IBM, USA), and G*Power version 3.1. All data are presented as the mean ± the standard error of the mean. In this study, p value of < 0.05 was considered statistically significant.

Results

A number of participants were 14 patients in the severe group, 9 patients in the moderate group and 6 patients in the mild group. Characteristics of each groups are presented in Table 1. No adverse event associated with all conditions was encountered.

	severe Group (n=17)	**moderate Group (n=6)**	**mild Group (n=6)**
Male / Female	15 / 2	5 / 1	4 / 2
Mean age (SD)	59 (7.3)	59 (14.3)	49 (17.6)
Mean of months after the onset (SD)	57 (42.4)	63 (48.5)	35 (35.3)
Dominant hand (right / left)	17 / 0	6 / 0	6 / 0
Hemiplegic side (right / left)	8 / 9	4 / 2	4 / 2
Damaged regions (cortical / Subcortical)	3 / 14	0 / 6	1 / 5
MCA	3	0	1
Putamen	12	4	3
Internal capsule	1	0	0
Corona radiate	0	1	1
Thalamus	1	1	1
Mean SIAS score (Median)	46 (48)	51 (45)	59 (35)

SIAS: Stroke Impairment Assessment Set

Table 1: Characteristics of the participants

Post hoc power analysis revealed that the significant "condition × severity" effect at primary outcome measure showed a moderate effect size (>0.50) and power greater than 0.80 (Table 2).

Outcome Measures	Power	Effect Size
Primary outcome measure		
Range of finger movement		
Range of extension	1.00	0.58
Range of flexion	0.99	0.57
Secondary outcome measure		
Smoothness of finger movement		
Normalized jerk of extension	0.99	0.52
Normalized jerk of flexion	0.73	0.26
Muscle activity		
Co-contraction Index of extension	0.71	0.25
Co-contraction Index of flexion	0.70	0.25

[a]Power analysis for within-between interaction

Table 2: Post Hoc Power Analysis[a]

The angle of second MP

Averaged ROE and ROF at each condition are shown in Figure 1. In ROE, mixed ANOVA revealed significant main effect ($F_{(2, 52)} = 4.344$, $p = 0.018$) and interaction ($F_{(4, 52)} = 4.998$, $p = 0.002$). Post hoc testing revealed significant difference between BM and CON ($p = 0.000$) and a trend toward significant difference between BM and AO in moderate group ($p = 0.085$). Furthermore, in mild group, post hoc testing revealed significant difference between AO and CON ($p = 0.004$). In ROF, mixed ANOVA revealed significant main effect ($F_{(2, 52)} = 4.153$, $p = 0.021$) and interaction ($F_{(4, 52)} = 6.229$, $p = 0.000$). Post hoc testing revealed significant difference between BM and other conditions in moderate group (vs CON: $p = 0.025$, vs AO: $p = 0.045$). Furthermore, in mild, post hoc testing revealed significant difference between AO and CON ($p = 0.000$), and a trend toward significant difference between AO and BM ($p = 0.052$).

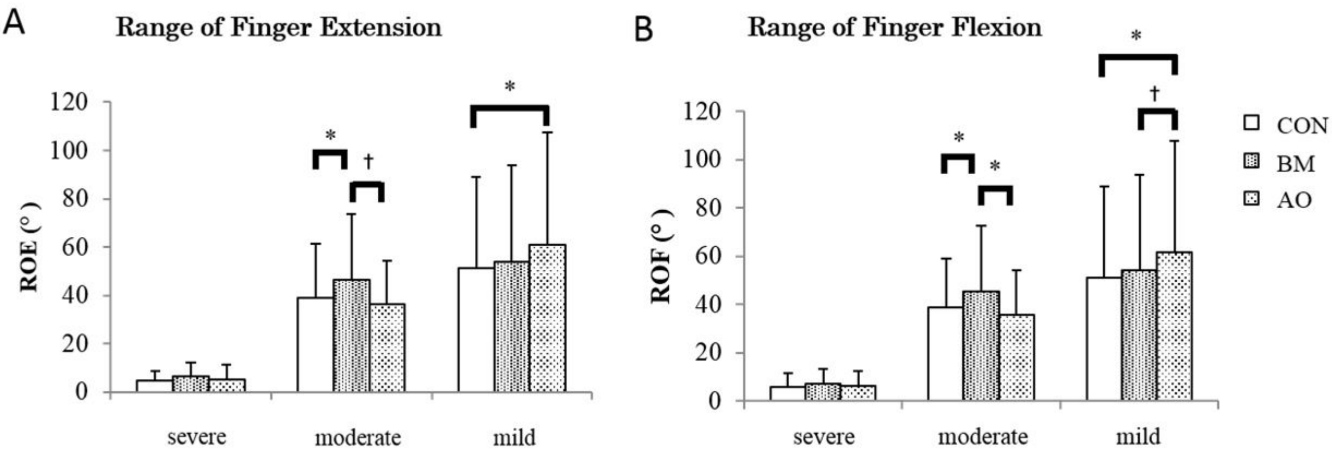

Figure 1: This illustrates the ROE **(A)** and ROF **(B)** in three conditions for each severity of motor paralysis, showing the average and the standard deviation. A total 29 patients were included (severe; 17 patients, moderate; 6 patients, mild; 6 patients). * $p < 0.05$; † $p < 0.1$.

The smoothness of finger movement

Averaged NJE and NJF at each condition are shown in Figure 2. In NJE, mixed ANOVA revealed significant difference in interaction ($F_{(4, 52)} = 2.999$, $p = 0.027$). Post hoc testing revealed a trend toward significant difference between AO and CON in moderate ($p = 0.070$) and severe group ($p = 0.059$). In ROF, mixed ANOVA revealed no significant difference in main effect ($F_{(2, 52)} = 0.568$, $p = 0.570$) and interaction ($F_{(4, 52)} = 0.554$, $p = 0.697$).

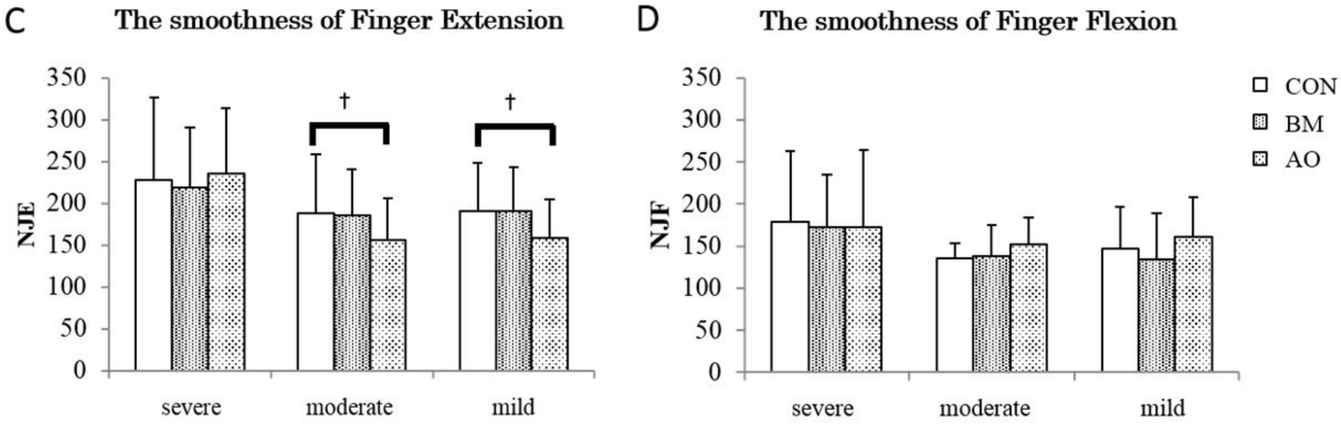

Figure 2: This illustrates the NJE **(C)** and NJF **(D)** in three conditions for each severity of motor paralysis, showing the average and the standard deviation. A total 29 patients were included (severe; 17 patients, moderate; 6 patients, mild; 6 patients). † $p < 0.1$.

The muscle activity

Averaged CIE and CIF at each condition are shown in Figure 3. In CIE, mixed ANOVA revealed no significant difference in main effect ($F_{(2, 52)} = 1.445$, $p = 0.245$) and interaction ($F_{(4, 52)} = 1.181$, $p = 0.330$). In ROF, mixed ANOVA revealed significant difference in interaction ($F_{(4, 52)} = 3.749$, $p = 0.009$). Post hoc testing revealed significant difference between AO and CON in severe group ($p = 0.040$).

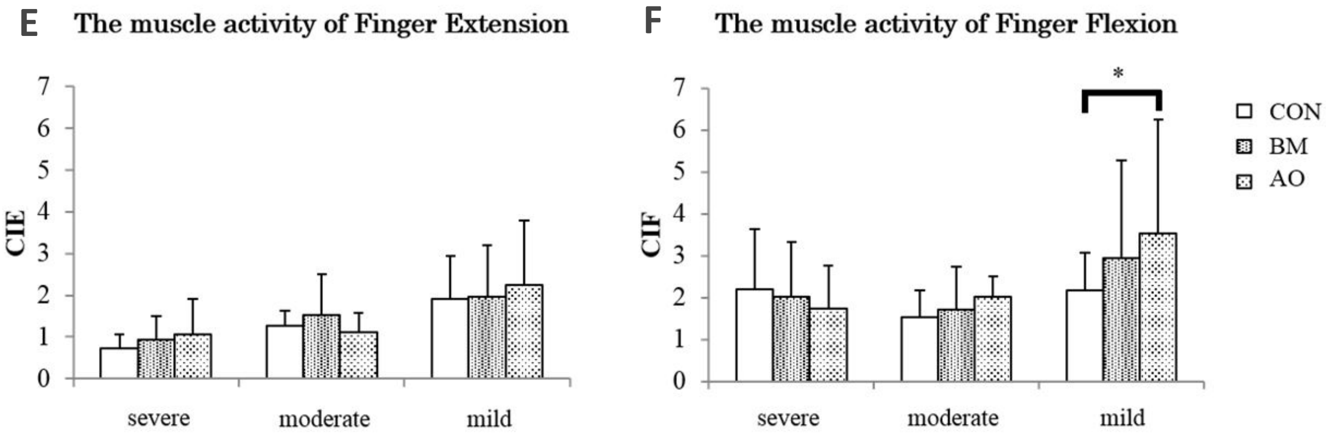

Figure 3: This illustrates the CIE **(E)** and CIF **(F)** in three conditions for each severity of motor paralysis, showing the average and the standard deviation. A total 29 patients were included (severe; 17 patients, moderate; 6 patients, mild; 6 patients). * $p < 0.05$

Discussion

The present study, we compared the effects of AO and BM in chronic hemiplegia. As a result, we found that the effects of these interventions differ depending on the severity of motor paralysis. The motor function of mild paralysis was improved by performing AO, and the motor function of moderate paralysis was improved by performing BM. These results offer evidence that selecting the interventions according to the severity of motor paralysis promote the functional recovery of the paralyzed limb.

The results showed that AO has significant main effect on the range of paretic finger movement, and multiple comparisons revealed that the range was increased by performing AO more than that of CON in mild group. In addition, a trend that the range was increased by performing AO more than that of BM in the mild group was found. The trend was consistent with the tendency for AO to increase the range in the mild group. Previous studies reported that the activity of mirror neurons at the damaged hemisphere is enhanced by AO [26,27] and function of paretic limb is improved by combining physical therapy and AO [28,29]. In the present study, paretic finger movement would have been facilitated by enhanced mirror neurons at AO condition in mild paralysis group. Improvement of the muscle activity ratio and improvement, although statistically trend, of the smoothness of paretic finger movement in mild paralysis group suggest that AO has the potential to facilitate motor learning by not only enhancing muscle power output but also improving motor control in chronic mild hemiplegia. However, AO did not work in the moderate and severe groups in the present study. Previous studies reported that mirror neuron activity is increased by observing movements that have been experienced in the daily life [9,30]. Severe and moderate paralysis patients do not use paretic hands in activity of daily life, and flexion-extension of the paretic finger used as motor task in the present study could not be performed adequately by them. Therefore there is a possibility that the activity of mirror neurons does not occur in severe and moderate groups. The present studies suggest that AO is effective intervention for mild paralysis hemiplegia more than severe and moderate one.

The results showed that BM has significant main effect on the range of paretic finger movement during the motor task, and multiple comparison revealed that the range was increased by performing BM more than that of control conditions in moderate group. In addition, a trend that the range was increased by performing BM more than that of AO in the moderate group was found. The trend was consistent with the tendency for BM to increase the range in the moderate group. Previous studies using fMRI reported that the activities of motor related areas such as primary motor cortex, premotor cortex and supplementary motor area in the damaged hemisphere are enhanced by performing BM more than that of unilateral movement [31,32]. Furthermore, in TMS studies, the excitability of primary motor cortex neurons in the damaged hemisphere are enhanced by movement of non-paralysis limb [33,34]. In the present study, the activity of motor related area would have been enhanced by performing BM, and the enhancement would have facilitated paretic finger movement in moderate paralysis group. However, BM did not improve the motor function of severe and mild paralysis group in the present study. Previous studies suggested that the BM mediate imbalanced Interhemispheric Interaction (IHI) [35] and the imbalanced IHI relate to motor dysfunction of paretic limb in chronic stroke [36]. In the present study, BM would not have worked at mild paralysis with balanced interhemispheric interaction. On the other hand, corticospinal tracts (CST) of severe motor paralysis patients are severely injered [37,38] and they have poor potential to recovery from motor paralysis [39]. In the present study, even if BM enhance cortical activity, muscle power output of severe paralysis with damaged CST would not have improved. The present studies suggest that BM is effective as an intervention for moderate paralysis more than severe and mild one.

However, this study has some limitation. First, the damaged regions of each patient were varied in the present study. The difference of damaged regions may have influenced the effects of AO and BM. Second, the affected sides of patient were also varied in the present study. Motor control of dominant hand is different from that of non-dominant hand [40], therefore the effects of AO and BM may differ between the affected dominant hand and the affected non-dominant hand.

Conclusion

In conclusion, this study offers preliminary evidence at selection of intervention for improving paretic hand function in chronic hemiplegia. In particular, AO may suitable intervention to improve smoothness of paretic limb movement for mild hemiplegia, and BM may suitable intervention to support generating the movement for moderate hemiplegia.

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