PNF and Movement, 2020; 18(1): 23-34
https://doi.org/10.21598/JKPNFA.2020.18.1.23
Print ISSN: 2508-6227
Online ISSN: 2508-6472

Original Article

Open Access

The Effects of Action Observation Combined with Modified Constraint-induced Movement Therapy on Upper-extremity Function of Subacute Stroke Patients with Moderate Impairment
-A Single-blinded Randomized Controlled Trial-

Dae-Hyouk Bang, P.T., Ph.D · Soon-Hyun Lee, P.T., Ph.D[1]†

Department of Physical Therapy, Wonkwang University

[1]Department of Physical Therapy, National Traffic Injury Rehabilitation Hospital

Received: November 4, 2019 / Revised: November 24, 2019 / Accepted: November 26, 2019

ⓒ 2020 Journal of Korea Proprioceptive Neuromuscular Facilitation Association
This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (http://creativecommons.org/licenses/by-nc/3.0) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

| Abstract |

Purpose: To explore the effects of action observation combined with modified constraint-induced movement therapy on upper-extremity function and the activities of daily living in subacute stroke patients.

Methods: Twenty-four subacute stroke patients were randomly assigned to the experimental group or the control group (n = 12 each). Both groups received therapy based on motor learning concepts, including repetitive and task-specific practice. The experimental group watched video clips for 10 minutes related to tasks performed during modified constraint-induced movement therapy while the control group watched videos unrelated to upper-extremity movement. These programs were performed for 40 minutes a day five times a week for four weeks. Their scores on the Fugl–Meyer assessment of upper extremities (FMA-UE), the action research arm test (ARAT), a motor activity log (amount of use [AOU] and quality of movement [QOM]), and the modified Barthel index (MBI) were recorded.

Results: In both groups, all variables were significantly different between the pre-test and post-test periods ($p < 0.05$). The post-test variables were significantly different within each group ($p < 0.05$). In the experimental group, the changes between pre-test and post-test scores in the FMA-UE (14.39 ± 4.31 versus 6.31 ± 4.63), the ARAT (16.00 ± 4.73 versus 11.46 ± 3.73), MAL-AOU (1.57 ± 0.15 versus 1.18 ± 0.28), and MBI (27.54 ± 4.65 versus 18.08 ± 8.52) were significantly higher than those of the control group ($p < 0.05$).

Conclusion: These findings suggest that action observation combined with modified constraint-induced movement therapy may be a beneficial rehabilitation option to improve upper-extremity function in subacute stroke patients with moderate impairment.

†Corresponding Author : Soon-Hyun Lee (pnf_sh@naver.com)

Key Words: Action observation, Modified constraint-induced movement therapy, Upper-extremity function, Stroke

Ⅰ. Introduction

Strokes are commonly followed the loss of upper-extremity function (Sale et al., 2012). Constant neurologic deficits may cause long-term limitations in functional activity and participation (Doussoulin et al., 2018). Post-stroke upper-extremity dysfunction is typically characterized by weak and slow, and a lack of coordination and control (Bang, 2016; Kos et al., 2016). The impairment of upper-extremity function is considered the major problem in patients with post-stroke hemiparesis, restricting the activities of daily living (ADLs) and independent life (Bang et al., 2018; Etoom et al., 2016). Using the paretic side in repetitive, intensive and concentrated exercise while progressively increasing the speed or difficulty of the exercise can improve upper-extremity function (Bang, 2016; Bang et al., 2015; Buesch et al., 2010) Bang et al., 2015; Buesch et al., 2010). Recent systematic reviews, suggest that modified constraint-induced movement therapy (mCIMT) is more effective than other interventions at improving upper-extremity motor performance and function (Etoom et al., 2016; Shi et al., 2011).

mCIMT is a modified and complementary version of the constraint-induced movement therapy (CIMT) that makes it easier to implement long-term restraints, since stroke patients may not wish to participate in the long-term restraining of a limb (Baldwin et al., 2018). mCIMT includes: (1) wearing a restraining device (e.g., a mitts or splints) on the less-affected limb to disable it from daily-activity use, (2) intensive and repetitive task-oriented training, and (3) behavioral interventions aimed at transferring gains made in clinical settings to real-world situations (Bang et al., 2018; Page et al., 2004) Page et al., 2004).

Previously studies have suggested that mCIMT are useful for upper extremity movement and hand function improvement (Yoon et al., 2014, Seok et al., 2016). Yoon et al. (2014) conducted CIMT for two weeks, six hours a day, using the mirror therapy. Seok et al. (2016) conducted one hour of CIMT per day for two weeks using two programs provided in the visual feedback program (E-link). In addition, Yoon et al. (2014) and Seok et al. (2016) were conducted in three groups. In these trials, unaffected upper limbs were restrained for Short-term, even when participants were not taking other therapy. However, no study may has evaluated the effects of mCIMT combined with AO (AO+mCIMT) for upper-extremity functions and ADLs in subacute stroke. In this study, it is necessary to find out that effect of AO+mCIMT in long term for upper extremity functions and ADLs in stroke.

Action observation (AO), a neuroscience-based approach, promises to improve paretic upper-extremity movement in stroke patients (Cheng, 2018). During AO, specific brain areas are activated by observing the behavior of other people (Bang et al., 2013). This mechanism involves cognitive-action, such as understanding movement, imitation learning, motor learning, and forming motor memory (Iacoboni, 2005). The neurological mechanisms underlying the effects of AO are based on mirror neuron systems (MNSs); When actions that are directly observed are performed, similar brain regions are activated in the inferior parietal lobe, premotor cortex, and superior frontal gyrus (di Pellegrino et al., 1992; Grezes & Decety, 2001) Grezes & Decety, 2001). AO has direct influence on the primary motor cortex and muscle activity, thus supporting the idea that

AO can prime movement execution by activating common neural processes (Fadiga et al., 1995). Observing video clips of intact upper-extremity movement is a key element of AO, as it has been proposed that the observation of correct organized movement patterns facilitates enhanced motor control and motor learning (Cheng, 2018). However, patients with neurological deficits usually observe their awkward upper-extremity movement (goal-directed tasks like reaching). Thus, it is important to understand how the sensorimotor system is modulated by the observation of graceful and awkward goal-directed upper-extremity movement (Cheng, 2018). AO combined with the traditional interventions have resulted in the improvement of re-learning a functional task (Franceschini et al., 2010). However, most studies conducted to date have only evaluated the effects of AO or mCIMT. To our knowledge, no study may has evaluated the effects of mCIMT combined with AO on upper-extremity function in subacute stroke patients with moderate impairment.

In this study, we applied AO+mCIMT where subacute stroke patients performed the intensive treatments for 4 weeks. Conventional CIMT is proven to improve the gross motor function, but its effectiveness for the fine motor functions remains obscure. these results could suggest that the CIMT is insufficient for perfectly performing the task-oriented exercises with complex and delicate training on the affected wrist and hand (Yoon et al., 2014)

We examined the effects of AO+mCIMT on the upper-extremity function and ADLs of subacute stroke patients with moderate impairment using a randomized controlled trial (RCT). We hypothesized that study participant who received AO+mCIMT would demonstrate more improved outcomes than patients who received CIMT alone.

Ⅱ. Methods

1. Participants

A total of 24 patients were fully aware of the study details, were collaborative and willing to participate in the current study, and submitted a written informed consent. The participants were recruited from the inpatient rehabilitation center of Wonkwang University Medical Center in Ik-San, Republic of Korea. A general neurological examination was performed to identify eligible participants.

The inclusion criteria included: (1) experiencing a stroke between 1 to 6 months before the study, (2) the ability to actively extend at least 10° at the metacarpophalangeal and interphalangeal joints and 20° at the wrist, (3) sufficient cognition to participate in training (mini-mental status examination scores of ≥ 24)(Folstein et al., 1975) Folstein et al., 1975), (4) considerable nonuse of the affected limb (an amount of use [MAL-AOU] score of <2.5 on the motor activity log [MAL])(Taub et al., 1999), (5) no excessive spasticity (defined as a grade of ≥3 on the modified Ashworth scale)(Bohannon & Smith, 1987), and (6) not participating in any experimental rehabilitation or drug studies. The exclusion criteria included: (1) any comorbidity or disability, other than a stroke, that precluded upper-extremity training, and (2) any uncontrolled health condition for which exercise was contraindicated. Study participation was voluntary and patients were fully understanding of the study's contents. This study was approved by the research and ethics committee of Wonkwang University Medical Center, Ik-San.

2. Experimental design

We used a single-blinded, clinical pilot study with a pre-post experimental design. Participants were randomized into two groups (directly after the test) by a physical therapist not involved in the study. Participation in the study was voluntary and participants fully understood the contents of this study. All participants were informed about the tests and the use of the results, and were asked to sign a written statement in which they formally consented to the inclusion of the study. All of the enrolled participants were randomized into two groups by a physiotherapist not involved in the study. The randomization was performed by selection of an opaque closed envelope from envelopes in which the group assignment in which the group assignment was written. It was given to the physiotherapist in sealed numbered envelopes. Intervention was conducted by a physical therapist with 10 years clinical experience. The assessor, who was blinded and did not participate in this study, was experienced and well-qualified for tests used.

3. Training interventions

The experiment began 1 day post randomization. For both groups, interventions progressed during regularly scheduled therapy sessions, and all other routine interdisciplinary stroke rehabilitation proceeded as usual. Each training protocol involved 20 sessions (40 min/day, 5 times/week, for 4 weeks). For the study's duration, all participants also received a conventional rehabilitation program that involved occupational treatment (1 hour/day) and physical treatment (2 hours/day); the duration and intensity was the same for both groups.

Participants in the AO+mCIMT group were asked to watch videos, in the knowledge that they would attempt to perform the same movement tasks after watching. During AO, the AO+mCIMT group were seated 60 cm away from a monitor and asked to assume a comfortable posture. The videos were specially produced for AO and ran for nine minutes. The video was divided into three phases according to play speed (normal, 50% of the normal, and normal). Each video involved the same tasks, performed by a healthy woman, and provided three views simultaneously (front, side, and top). After watching these tasks, the AO+mCIMT group attempted the same movements using their paretic hand. The protocol included the full video played for the AO+mCIMT group, break to organize their thoughts (one minute), practice using the task-oriented training via mCIMT (30 minutes). The total duration of each training session was 40 minutes. In addition, while the AO+mCIMT group watch the videos, the therapist provided verbal feedback for training consistency and synchronization to the observed movements, such as elbow flexion during reaching and grasping, thereby improving the efficiency of AO.

The CG assumed the same posture as the AO+mCIMT group and watched nature videos unrelated to upper-extremity movement. The videos consisted of nature, such as forests, seas, and mountains. After watching a video for 9 minutes, the CG had 1 minute to organize their thoughts, after which they performed the same task-oriented training via mCIMT as the AO+mCIMT group for 30 minutes.

Training was provided at the rehabilitation clinic for both groups. The training was based on motor learning concepts, including repetitive and task-specific practice (Sirtori et al., 2009). Both groups were asked to perform tasks only with their more-paretic arm while their less-paretic arm was restrained in a mitt. Tasks included turning a faucet on/off, picking up a cup and drinking from it, picking up a hairbrush and brushing hair, cleaning a table with a towel, and other activities similar to those performed on a daily basis (Franceschini et al., 2010).

Task complexity was gradually increased using the behavioral technique of shaping. During the 4-week period, participants' less-paretic hands and wrists were placed in mitts with self-adhesive straps, every weekday for 5 hours during a period identified as the time of frequent arm use. In addition, self-exercise programs were provided to participants and caregivers at the end of the treatment.

4. Outcome measures

1) Fugl-Meyer assessment of upper-extremities (FMA-UE)

The FMA-UE is a standard in-laboratory quantitative assessment test used to assess post-stroke motor function in the shoulder, elbow, forearm, wrist and hand after (Fugl-Meyer et al., 1975). Subjects were asked to perform different movements best as possible. The FMA-UE is considered reliable and valid (Alonso-Alonso et al., 2007).

2) Action research arm test (ARAT)

The ARAT was used to assess changes in upper-extremity function (Lyle, 1981). This is a 19-item test divided into 4 categories (grasp, grip, pinch, and gross movement), with each item scored on a 4-point ordinal scale (0: cannot perform test, 1: partially performs test, 2: completes test but takes an abnormally long time or has great difficulty, 3: normally performs test) for a total possible score of 57. The ARAT has high intra-rater and retest reliability and validity (Lyle, 1981)

3) Motor activity log (MAL)

The MAL was administered as a semi-structured interview that assessed the subject's subjective report on 30 common daily tasks. It consisted of two assessment subscales that rated the more affected upper extremities: an amount of use (MAL-AOU) and quality of movement (MAL-QOM) scales. They were six-point rating scales (0: no use of the more affected extremity to 5: normal use) (Taub et al., 1999).

4) Modified Barthel index (MBI)

The MBI was comprised of 10 items: dependent or independent feeding, bathing, grooming or dressing; toilet use; mobility on level surfaces (immobile, wheelchair use, or walking with help or independent); and bowel and bladder continence or incontinence. Higher scores indicated the greater functional autonomy. The reliability and validity of the MBI is considered high (Nazzal et al., 2001)

5. Data and statistical analysis

All collected data were analyzed using Statistical Package for the Social Sciences (SPSS Inc., USA) version 18.0. The 24 participants' demographic and clinical characteristics were analyzed for homogeneity between groups. Differences between categorical variables were analyzed using the chi-square and independent t-tests. Independent t-tests were used to compare differences between group means. Paired t-tests were used to compare within group means. Effect sizes were calculated using the difference between the means of the AO+mCIMT and CG divided by the averaged standard deviation at baseline (Cohen, 1988). The statistical level of significance was set at 0.05 for all analyses.

Ⅲ. Results

There were 29 people found eligible for the study during screening, out of which five (AO+mCIMT: 2, CG: 3) declined to participate in the study due to the absence of regular participation in the intervention sessions or

Table 1. Homogeneity test for General characteristics

	AO+mCIMT (n=12)	mCIMT (n=12)	P-value
Sex (n)			
Men	5	6	0.68
Women	7	6	
Side of stroke (n)			
Right	3	5	0.35
Left	9	7	
Stroke type (n)			
Infarction	9	8	0.65
Hemorrhage	3	4	
Age (years),	62.09±6.66[a]	61.00±8.22	0.74
Onset duration (months)	3.17±1.03	3.83±1.03	0.13
MMSE (scores)	26.40±1.35	25.70±1.25	0.25
MAS (grade)	2.11±0.78	1.67±0.87	0.27
MAL (scores)			
AOU	1.58±0.19	1.57±0.26	0.77
QOM	1.71±0.16	1.77±0.23	0.61

[a]mean ± standard deviation
AO: action observation, mCIMT: modified constraint-induced movement therapy, MMSE: mini-mental state examination, MAS: modified Ashworth scale, MAL: motor activity log, AOU: amount of use, QOM: quality of movement.

Table 2. Within-group and between-group comparisons for the outcome measures

	AO+mCIMT group (n=12)		mCIMT group (n=12)		*t*	Effect sizes	between groups P-values
	Pre-test	Post-test	Pre-test	Post-test			
FMA-UE	40.54±2.60[a]	54.92±3.77*†	40.46±3.36	46.77±2.98*	0.23	2.54	0.00(5.40-1091)
ARAT	27.85±4.95	43.85±4.81*†	28.23±4.48	39.65±4.55*	2.26	0.98	0.03(0.36-7.95)
MAL							
AOU	1.58±0.19	3.09±0.29*†	1.57±0.29	2.77±0.12*	2.97	1.39	0.01(0.09-0.55)
QOM	1.71±0.15	3.38±0.34*†	1.77±0.24	2.95±0.16*	3.30	2.20	0.01(0.15-0.71)
MBI	52.92±4.56	80.46±3.31*†	54.92±5.92	73.00±5.08*	4.44	2.01	0.00(3.99-1093)

[a]means±SD, *Significant difference within groups, †Significant difference between groups
AO: action observation, mCIMT: modified constraint-induced movement therapy,
CI: confidence interval, FMA-UE: Fugl-Meyer assessment upper extremity part,
ARAT: action research arm test, MAL: motor activity log, AOU: amount of use,
QOM: quality of movement, MBI: modified Barthel index
Effect sizes of Cohen: 0.15 = small, 0.4 = medium, 0.75 = large, 1.1= very large, 1.45 = huge effect size

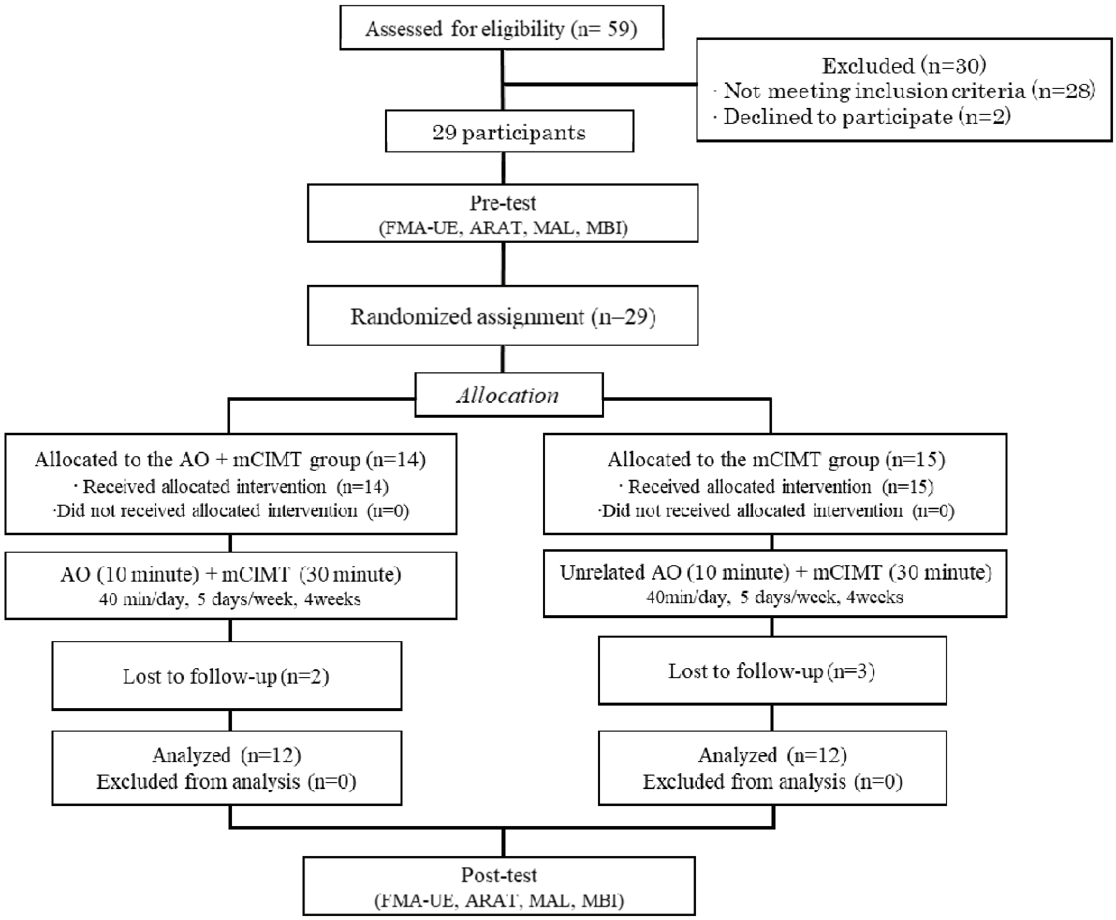

Fig. 1. Flow diagram of the study.

AO: action observation, mCIMT: modified constraint-induced movement therapy, FMA-UE: Fugl-Meyer assessment upper extremity part, ARAT: action research arm test, MAL: motor activity log, AOU: amount of use, QOM: quality of movement, MBI: modified Barthel index.

abandonment of the study. Consequently, the data of the remaining 24 individuals were used for statistical analysis (Fig. 1).

The remaining participants were enrolled (Table 1). There were no significant differences between groups at baseline there were no significant differences between groups. At baseline there were no significant differences between groups in sex, the side of stroke, stroke type, onset duration, and outcome variables, as well as in any tools that measured impairment level ($p>0.05$).

The results of the FMA-UEs, ARATs, MALs, and MBIs are provided in Table 2. In both groups, all variables were significantly different between the pre-test and post-test periods ($p<0.01$). Furthermore, the post-test values of variables were statistically different between each group ($p<0.05$).

The effect sizes (Cohen, 1988) for the FMA-UE, ARAT, MAL-AOU, MAL-QOM, and MBI were 2.54 (*d-value*), 0.98, 1.39, 2.20, and 2.01, respectively.

Ⅳ. Discussion

The loss of upper-extremity function in stroke patients has a high incidence, low treatment effect, and is typically a significant limitation to be solved urgently in neurological rehabilitation. Our results indicate that AO+mCIMT is useful in improving the motor function of the more affected upper extremities in subacute stroke patients.

In agreement with systematic review of (Wattchow et al., 2018), our data suggests that mCIMT is an effective method for improving more affected upper-extremity function. The possible mechanisms responsible for the improvement in motor and daily function's improvement in both groups after such a short therapy could be an speculated based related the studies (Aarts et al., 2011; Bang et al., 2018; Page et al., 2004; Taub et al., 1999). Firstly, overcoming learned nonuse by constraining the less affected extremities may reduce the learned nonuse phenomenon. Secondly, repetitive practice of ecologically significant tasks may lead to the increased reorganization of brain post stroke. Thirdly, setting of behavioral methods to transfer the gains occurred during the supervised training for the individual' ADLs. Increased neural activity in the motor area by intensive and repetitive practice may draws on neuroplasticity mechanisms to mediate enhanced motor control and the relearning of movements with central nervous system impairment. The results obtained may reveal that both groups showed significant improvement in terms of the FMA-UEs, ARATs, MALs, and MBIs.

Previously studies have suggested that AO and mCIMT are useful for relearning movement and motor function improvement (Bang et al., 2018; Shih et al., 2017). However, no studies are available on the combination of these training methods. Bang (2016) reported greater improvement in upper-extremity function following mCIMT and according to Shih et al. (2017) AO led to an activation of brain area. By result of FMA-UE, The AO+mCIMT group improved their more affected upper extremities' motor function more significantly than the CG. Our study was found that the FMA-UE score was higher than the minimal clinically important difference (MCID) in the AO + mCIMT group. The mean change between pre-test and post-test periods in the FMA-UE scores (14.39±4.31) of the AO+mCIMT group was more than 10 points. This change (FMA-UE scores ≥6–8 points) indicates that additional AO is associated with clinically meaningful improvements, and may be helpful in improving upper-extremity function in stroke patients (Page et al., 2012). However, the mean changes of FMA-UE scores (6.31±4.63) of the CG were not meaningful changes. The AO+mCIMT group improved more significantly in the use (MAL-AOU) and quality (MAL-QOM) of their more affected upper extremities than the CG. The mean changes in MAL-AOU (1.57±0.15) and MAL-QOM (1.73±0.28) scores in the AO+mCIMT group were more than one point. This may indicates that AO+mCIMT is clinically meaningful and may be helpful in improving upper-extremity function in subacute stroke patients (Lang et al., 2008). The mean changes in MAL-AOU (1.18±0.28) and MAL-QOM (1.07±1.18) scores in the CG were not clinically meaningful changes (below 1 point). It might be that AO+mCIMT is more beneficial than mCIMT for improving the motor function of more affected upper extremities in subacute stroke patients with moderate motor impairment.

The AO+mCIMT group reported a greater increase in motor function and the use of more affected extremities than the CG. This increased motor function and use led to the measureable improvement in upper-extremity function. It is possible that AO may provide an opportunity for patients to prepare movement and activate the motor area of the brain related to functional tasks. Furthermore, the video contents used may be beneficial. For AO, the speed of the video varied across three phases. This protocol, which involved playing a video repeatedly at different speeds, might have allowed participants with brain damage to correctly observe performing tasks with normal upper-extremity movement. Additionally, while the AO+mCIMT group were watching the videos, the therapist explained the movements presented, such as elbow flexion/extension and hand movements, in detail, thereby improving the efficiency of AO. The AO+mCIMT group were asked to think about the observed movements and to train in the same way. By looking at normal ADL-related movement, patients may be provided an additional opportunity to adapt to tasks while watching the video. Such effects may be helpful in performing familiar tasks during mCIMT, thereby enhancing upper-extremity motor function. Previous studies have suggested that AO is a useful method for motor function recovery and improving activity levels (Buccino et al., 2006; Pomeroy et al., 2005). Porro et al. (2007) reported the greater strengthening and movement of the fingers following AO, compared to that achieved after simple repetitive exercise. Brunner et al. (2014) reported that this improvement in motor performance may be related to the activation of the inferior temporal gyrus, thalamus, and movement-related areas, such as the premotor, supplementary, and motor cortex, during AO. Furthermore, Tia et al. (2010) reported on the mirror neuron system mechanism in areas related to movement initiation and sequencing (supplementary motor area in the medial frontal cortex), and memory (medial temporal lobe). Gonzalez-Rosa et al. (2015) reported that AO was associated with greater beta synchronization over bilateral parietal regions than motor imagery and control groups. This beta synchrony demonstrated the strongest association with kinematic errors, which were also significantly lower in the AO group than in the control group. Indeed, the activation of the cerebellum and premotor area correlated with improvement of upper-extremity function (Harmsen et al., 2014).

Our findings suggest that AO+mCIMT can be used for rehabilitating subacute stroke patients. Through watching and repetitively practicing intensive exercise, motor relearning may be promoted. For people with an impaired of central nervous system, by observing upcoming training tasks, mirror neurons that control the same actions can be activated and increase their excitability (Fu et al., 2017). Our study found that the combination of motor observation, repetitive training and intensive training strategies can effectively improve upper-extremity motor function in subacute stroke patients with moderate impairment.

Ⅴ. Conclusion

This single-blinded RCT uses clinical analyses to study post-intervention differences between AO+mCIMT and mCIMT in stroke patients with moderate impairment. This study showed that AO+mCIMT improves motor performance and upper-extremity function in subacute stroke patients. A further study with larger samples and different study design will be needed to clarify these results.

References

Aarts PB, Jongerius PH, Geerdink YA, et al. Modified constraint-induced movement therapy combined with bimanual training (mcimt-bit) in children with unilateral spastic cerebral palsy: how are improvements in arm-hand use established? *Research*

in Developmental Disabilities. 2011;32(1):271-279.
Alonso-Alonso M, Fregni F, Pascual-Leone A. Brain stimulation in poststroke rehabilitation. *Cerebrovascular Diseases*. 2007;24 Suppl 1:157-166.
Baldwin CR, Harry AJ, Power LJ, et al. Modified constraint-induced movement therapy is a feasible and potentially useful addition to the community rehabilitation tool kit after stroke: a pilot randomised control trial. *Australian Ocuupational Therapy Journal*. 2018;65:503-511.
Bang DH. Effect of modified constraint-induced movement therapy combined with auditory feedback for trunk control on upper extremity in subacute stroke patients with moderate impairment: randomized controlled pilot trial. *Journal of Stroke and Cerebrovascular Diseases*. 2016;25(7):1606-1612.
Bang DH, Shin WS, Choi HS. Effects of modified constraint-induced movement therapy with trunk restraint in early stroke patients: a single-blinded, randomized, controlled, pilot trial. *NeuroRehabilitation*. 2018;42(1):29-35.
Bang DH, Shin WS, Choi SJ. The effects of modified constraint-induced movement therapy combined with trunk restraint in subacute stroke: a double-blinded randomized controlled trial. *Clinical Rehabilitation*. 2015;29(6):561-569.
Bang DH, Shin WS, Kim SY, et al. The effects of action observational training on walking ability in chronic stroke patients: a double-blind randomized controlled trial. *Clinical Rehabilitation*. 2013;27(12):1118-1125.
Bohannon RW, Smith MB. Interrater reliability of a modified ashworth scale of muscle spasticity. *Physical Therapy*. 1987;67(2):206-207.
Brunner IC, Skouen JS, Ersland L, et al. Plasticity and response to action observation: a longitudinal fMRI study of potential mirror neurons in patients with subacute stroke. *Neurorehabilitation and Neural Repair*. 2014;28(9):874-884.
Buccino G, Solodkin A, Small SL. Functions of the mirror neuron system: implications for neurorehabilitation. *Cognitive and Behavioral Neurology*. 2006;19(1): 55-63.
Buesch FE, Schlaepfer B, de Bruin ED, et al. Constraint-induced movement therapy for children with obstetric brachial plexus palsy: two single-case series. *International Journal of Rehabilitation Research*. 2010;33(2): 187-192.
Cheng CH. Effects of observing normal and abnormal goal-directed hand movements on somatosensory cortical activation. *European Journal of Neuroscience*. 2018;47(1):48-57.
Cohen J. Stastical power analysis for the behaviorl science, 2nd ed. New York. Academic Press. 1988.
di Pellegrino G, Fadiga L, Fogassi L, et al. Understanding motor events: a neurophysiological study. *Experimental Brain Research*. 1992;91(1):176-180.
Doussoulin A, Rivas C, Rivas R, et al. Effects of modified constraint-induced movement therapy in the recovery of upper extremity function affected by a stroke: a single-blind randomized parallel trial-comparing group versus individual intervention. *International Journal of Rehabilitation Research*. 2018;41(1): 35-40.
Etoom M, Hawamdeh M, Hawamdeh Z, et al. Constraint-induced movement therapy as a rehabilitation intervention for upper extremity in stroke patients: systematic review and meta-analysis. *International Journal of Rehabilitation Research*.. 2016;39(3):197-210.
Fadiga L, Fogassi L, Pavesi G, et al. Motor facilitation during action observation: a magnetic stimulation study. *Journal of Neurophysiology*. 1995;73(6):2608-2611.
Folstein MF, Folstein SE, McHugh PR. “Mini-mental state”. A practical method for grading the cognitive state

of patients for the clinician. *Journal of Psychiatric Research*. 1975;12(3):189-198.

Franceschini M, Agosti M, Cantagallo A, et al. Mirror neurons: action observation treatment as a tool in stroke rehabilitation. *European Journal of Physical and Rehabilitation Medicine*. 2010;46(4):517-523.

Fu J, Zeng M, Shen F, et al. Effects of action observation therapy on upper extremity function, daily activities and motion evoked potential in cerebral infarction patients. *Medicine*. 2017;96(42):e8080.

Fugl-Meyer AR, Jaasko L, Leyman I, et al. The post-stroke hemiplegic patient. 1. A method for evaluation of physical performance. *Scandinavian Journal of Rehabilitation Medicine*. 1975;7(1):13-31.

Gonzalez-Rosa JJ, Natali F, Tettamanti A, et al. Action observation and motor imagery in performance of complex movements: evidence from EEG and kinematics analysis. *Behavioural Brain Research*. 2015;281(2015):290-300.

Grezes J, Decety J. Functional anatomy of execution, mental simulation, observation, and verb generation of actions: a meta-analysis. *Human Brain Mapping*. 2001;12(1):1-19.

Harmsen WJ, Bussmann JB, Selles RW, et al. A mirror therapy-based action observation protocol to improve motor learning after stroke. *Neurorehabilitation and Neural Repair*. 2015;29(6):509-516.

Iacoboni M. Neural mechanisms of imitation. *Current Opinion in Neurobiology*. 2005;15(6):632-637.

Kos D, Duportail M, Meirte J, et al. The effectiveness of a self-management occupational therapy intervention on activity performance in individuals with multiple sclerosis-related fatigue: a randomized-controlled trial. *International Journal of Rehabilitation Reserach*. 2016;39(3):255-262.

Lang CE, Edwards DF, Birkenmeier RL, et al. Estimating minimal clinically important differences of upper-extremity measures early after stroke. *Archives of Physical Medicine and Rehabilitation*. 2008; 89(9):1693-1700.

Lyle RC. A performance test for assessment of upper limb function in physical rehabilitation treatment and research. *International Journal of Rehabilitation Reserach*. 1981;4(4):483-492.

Nazzal M, Sa'adah MA, Al-Ansari D, et al. Stroke rehabilitation: application and analysis of the modified Barthel index in an arab community. *Disability Rehabilitation*. 2001;23(1):36-42.

Page SJ, Fulk GD, Boyne P. Clinically important differences for the upper-extremity fugl-meyer scale in people with minimal to moderate impairment due to chronic stroke. *Physical Therapy*. 2012;92(6):791-798.

Page SJ, Sisto S, Levine P, et al. Efficacy of modified constraint-induced movement therapy in chronic stroke: a single-blinded randomized controlled trial. *Archives of Physical Medicine and Rehabilitation*. 2004;85(1):14-18.

Pomeroy VM, Clark CA, Miller JS, et al. The potential for utilizing the "mirror neurone system" to enhance recovery of the severely affected upper limb early after stroke: a review and hypothesis. *Neuro-rehabilitation and Neural Repair*. 2005;19(1): 4-13.

Porro CA, Facchin P, Fusi S, et al. Enhancement of force after action observation: behavioural and neurophysiological studies. *Neuropsychologia*. 2007;45(13):3114-3121.

Sale P, Lombardi V, Franceschini M. Hand robotics rehabilitation: feasibility and preliminary results of a robotic treatment in patients with hemiparesis. *Stroke Research and Treatment*. 2012;2012:5.

Seok H, Lee SY, Kim J, et al. Can short-term constraint-induced movement therapy combined with visual biofeedback training improve hemiplegic upper limb function of subacute stroke patients? *Annals of Rehabilitation*

Medicine. 2016;40(6):998-1009.

Shi YX, Tian JH, Yang KH, et al. Modified constraint-induced movement therapy versus traditional rehabilitation in patients with upper-extremity dysfunction after stroke: a systematic review and meta-analysis. *Archives of Physical Medicine and Rehabilitation*. 2011;92(6):972-982.

Shih TY, Wu CY, Lin KC, et al. Effects of action observation therapy and mirror therapy after stroke on rehabilitation outcomes and neural mechanisms by meg: study protocol for a randomized controlled trial. *Trials*. 2017;18(1):459.

Sirtori V, Corbetta D, Moja L, et al. Constraint-induced movement therapy for upper extremities in stroke patients. *Cochrane Database System Review*. 2009;(4):CD004433.

Taub E, Uswatte G, Pidikiti R. Constraint-induced movement therapy: a new family of techniques with broad application to physical rehabilitation--a clinical review. *Journal of Rehabilitation Research and Development*. 1999;36(3):237-251.

Tia B, Mourey F, Ballay Y, et al. Improvement of motor performance by observational training in elderly people. *Neuroscience Letters*. 2010;480(2):138-142.

Wattchow KA, McDonnell MN, Hillier SL. Rehabilitation interventions for upper limb function in the first four weeks following stroke: a systematic review and meta-analysis of the evidence. *Archives of Physical Medicine and Rehabilitation*. 2018;99(2):367-382.

Yoon JA, Koo BI, Shin MJ, et al. Effect of constrain-induced movement therapy and mirror therapy for patients with subacute stroke. *Annals of Rehabilitation Medicine*. 2014;38(4):458-466.