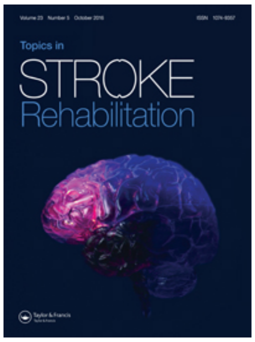

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Effects of action observation therapy on hand dexterity and EEG-based cortical activation patterns in patients with post-stroke hemiparesis

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Background: Previous reports have suggested that action observation training (AOT) is beneficial in enhancing the early learning of new motor tasks; however, EEG-based investigation has received little attention for AOT.
Objective: The purpose of this study was to illustrate the effects of AOT on hand dexterity and cortical activation in patients with post-stroke hemiparesis.
Method: Twenty patients with post-stroke hemiparesis were randomly divided into either the experimental group (EG) or control group (CG), with 10 patients in each group. Prior to the execution of motor tasks (carrying wooden blocks from one box to another), subjects in the EG and CG observed a video clip displaying the execution of the same motor task and pictures showing landscapes, respectively. Outcome measures included the box and block test (BBT) to evaluate hand dexterity and EEG-based brain mapping to detect changes in cortical activation.
Results: The BBT scores (EG: 20.50 ± 6.62 at pre-test and 24.40 ± 5.42 at post-test; CG: 20.20 ± 6.12 at pre-test and 20.60 ± 7.17 at post-test) revealed significant main effects for the time and group and significant time-by-group interactions ($p < 0.05$). For the subjects in the EG, topographical representations obtained with the EEG-based brain mapping system were different in each session of the AOT and remarkable changes occurred from the 2nd session of AOT. Furthermore, the middle frontal gyrus was less active at post-test than at pre-test.
Conclusions: These findings support that AOT may be beneficial in altering cortical activation patterns and hand dexterity.

Keywords: Action observation training, Hand dexterity, Cortical activation, Electroencephalography, Stroke

Introduction

Coordinated movements of the upper limbs are necessary for the successful execution of everyday activities.[1] However, after stroke, the nonuse of the hemiplegic side contributes to decreased strength and muscle shortening in the affected upper limb, and sometimes, a painful condition can develop and lead to increased spasticity.[2] These problems induce functional impairments in the upper limb, particularly in its dexterity, and may impede the execution of routine daily activities. Therefore, clinicians conduct various trials to identify better strategies for improving upper limb function during stroke rehabilitation.[3]

Various therapeutic protocols such as the constraint-induced movement therapy and task-oriented training have been developed for effective rehabilitation of stroke patients. Benefits of these therapies have also been recognized in clinical use for facilitating the intensive use of the affected upper limb.[4] However, such benefits may be inadequate for patients with stroke at a low functional level, because their movement abilities cannot provide a solid basis for intensive training to improve hand function.[5] In addition, poor motor functions limit the learning of experience-dependent motor skills during the rehabilitation process. In stroke rehabilitation, this might be one of the greatest dilemmas for most clinicians; therefore, they are searching for optimal therapeutic solutions to maximize functional recovery.[3]

Priming approaches including motor imagery training, action observation training (AOT), repetitive transcranial magnetic stimulation, and transcranial direct current stimulation are novel techniques that might help patients to overcome these limitations.[6] These procedures aim to increase the excitability of the impaired sensorimotor

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system and thus facilitate cortical reorganization. In particular, motor imagery training and AOT have many benefits in clinical use such as safety and low cost, and additionally, no specific equipment is necessary during the training. A recent study with randomized controlled design reported that compared with the motor imagery training, AOT is more beneficial in enhancing the early learning of new motor tasks.[7]

AOT is defined as a training process that involves observing specific actions performed by others, and subsequently imitating these actions prior to physical training, with the benefits of repetitively practicing the observed actions.[8] Previous studies have shown that observing the execution of motor tasks during AOT can activate the frontoparietal circuits and thus prepare and control target-oriented actions depending on visual and somesthetic inputs.[1] These circuits are activated equally during action observation and execution; therefore, they are known as the mirror neuron system.[9] Researchers investigating the function of mirror neuron system proposed that it plays an important role in understanding the meaning of actions and in meditating the process of action execution.[10] In addition, Krams et al.[10] found that mirror neuron system was activated during the process of preparation for imitating the intended action. Observers can match the action representation based on the activation of mirror neuron system and the features of the observed action. This observation–execution matching process is considered an important mechanism for the recognition and understanding of actions. It provides fundamental knowledge to allow successful application of AOT related to functional recovery of the upper limb and hand in patients with post-stroke hemiparesis.

Recently, advanced brain imaging technologies allowed the extensive use of EEG for investigating the mirror neuron system. Its activation can be identified by measuring the mu (μ) rhythm, which is a brain activity pattern in the motor area of the cortex with a frequency of 8–13 Hz.[11] When subjects execute or observe actions, the mu rhythm reduces.[12,13] EEG has a high temporal resolution, but a low spatial resolution. To overcome this limitation of EEG, new techniques have been developed to identify the specific locations of neural activation based on EEG data.[14] Additionally, a recent study described a system for the real-time observation of cortical rhythm activation based on EEG data.[15] However, to our knowledge, EEG-based investigations of mirror neuron system activation and its involvement in the functional recovery of the upper limb and hand have received little attention, especially for AOT. Therefore, this study aimed to illustrate the effects of AOT on hand dexterity and EEG-based cortical activation in patients with post-stroke hemiparesis.

Methods

Subjects

Twenty subjects with chronic stroke volunteered for this study, and they were randomly allocated to either the experimental group (EG) or the control group (CG) with 10 subjects in each group. Inclusion criteria were as follows: (1)>6 months since stroke onset; (2) no other neurological and orthopedic impairments; (3) no cognitive impairment (>24 points in mini-mental state examination—Korean version [MMSE-K]);[16] and (4) ability to grasp a small cube (2.5 cm × 2.5 cm × 2.5 cm). All subjects were provided with the detailed description of the experimental procedure, which included explanation of the safety of the procedure, and subjects signed a written consent form.

Clinical test for hand dexterity

The box and block test (BBT) assesses gross manual dexterity to determine the functional level of the upper limb in patients with disabilities, and it is frequently used in clinical settings for evaluating the hand function of children and adults. The tool consists of 50 blocks (2.5 cm × 2.5 cm × 2.5 cm) in a wooden box (53.7 cm × 8.5 cm × 27.4 cm) split into two equal-sized compartments with a divider. Subjects were asked to put as many blocks as possible, one at a time, from one compartment to the other in one minute. The score represents the number of blocks per minute. This test was reported to be highly reliable for clinical evaluations.[17]

Electroencephalography (EEG) recording and data processing

EEG was recorded and analyzed using WEEG-32 (LXE3232-RF, LAXTHA Inc., South Korea) with a sampling frequency of 256 Hz and a band-pass filter of 0.5–50 Hz, and data were saved on the main computer system after a 12-bit AD conversion. To determine cortical activation in the regions of interest during action observation, electrodes (Ag-AgCl electrodes) were positioned at 30 scalp sites (extension of the 10–20 system) (Fig. 1), and reference electrodes were placed at both mastoids. Electrolytic gel was used at each electrode site to decrease the impedance of the electrode-skin contact. After the electrodes were placed, EEG data were collected from subjects sitting in a quiet testing room and in a chair with their arms and back resting. Data processing was performed using the Telescan 3.08 program (LAXTHA Inc, South Korea).

An EEG-based brain mapping system provided topographically represented maps of the most activated

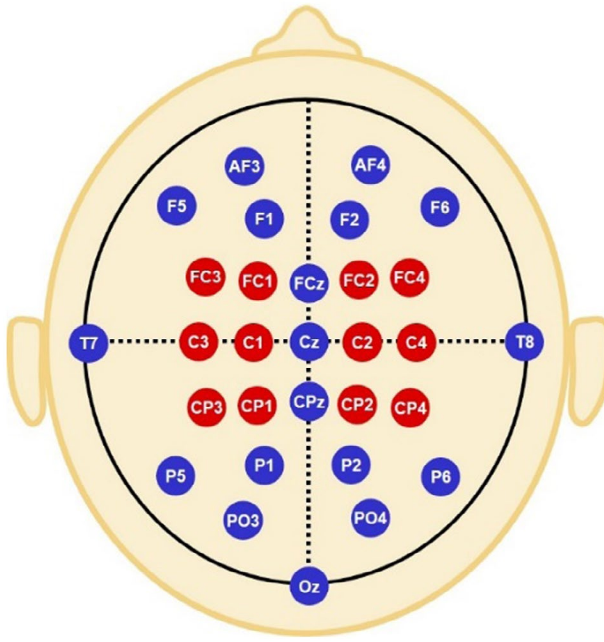

Figure 1 Sites of EEG electrodes. The red electrodes indicate the regions of interest.

regions of the brain, and the mapping comprised pre-processing and real-time processing. For the pre-processing of EEG measurements, an inverse operator was used at the locations where anatomical information was reflected.[18] During action observation, alterations in cortical electrical activities were determined with computation of the event-related spectral perturbation (ERSP), which indicates the average change in spectral power, namely the event-related desynchronization and synchronization. Analysis of the ERSP was performed with EEGLAB (http://sccn.ucsd.edu/eeglab/). The μ frequency band (8–12 Hz) was recorded and analyzed offline to construct the brain map representing cortical activation during action observation. EEG data for preparing the topographical power maps were obtained from the middle of the time interval (20 s duration) to exclude any noisy signals that might be present in the first and last 5 s of the 30-s action observation. Then, topographical power maps were displayed on a computer monitor for the direct observation of spatial cortical perturbations in various brain regions. After averaging the procession of onset cues for each electrode, the power values of the μ band were recorded in a range of 0–5 s and were displayed according to a predefined color map.

Experimental procedures

Subjects were randomly divided either into the EG to observe a video clip showing the execution of a motor task or into the CG to observe a video clip showing pictures of landscapes, with 10 subjects in each group. Subjects were randomly assigned to a group based on the outcome of flipping a coin. Namely, subjects who got heads were assigned to the EG, while subjects who got tails were assigned to the CG.

Subjects in the EG watched the execution of a motor task (action observation); their video clip showed the action of placing wooden blocks from one side of the box to another using the right and left hands for 30 s. This task is same with a process of the BBT. The video clip was created as a two-dimensional scene. On the other hand, subjects of the CG observed an auto slideshow of landscape pictures changing every 5 s for 1 min. For the observation of video clip, the subjects of both groups were asked to sit in the chair with their arms and back resting, and watched a 40-inch monitor positioned at a distance of 1.5 m in front of the chair. After observing the video clips for 1 min, each subject performed the motor task, which consisted of placing wooden blocks from one box to another for 3 min.

For functional measurement, subjects of both groups carried out the BBT before and after the five intervention sessions. Furthermore, the EEG data of subjects in the EG were collected in each session, while they were observing the video clip. This demonstration was performed for five sessions with 10-min rest intervals between the sessions (Fig. 2). Sequential executions of the observed action after AOT were not monitoring with EEG. During training sessions, consecutive execution of observed action indicates that subjects intended to sequentially execute the observed actions after observing the video clip.

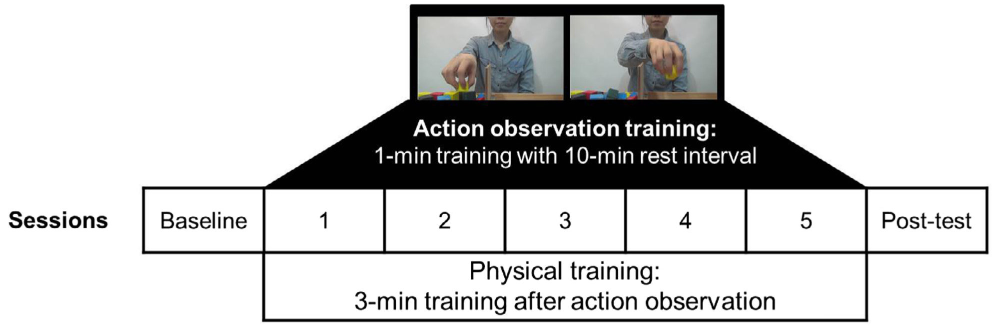

Figure 2 Experimental paradigm of action observation training for subjects in the experimental group. Baseline and post-test assessments were performed before starting the training, and again after six sessions of the training, with no sequential execution of motor tasks.

Data analysis

Statistical analysis was performed with the Statistical Package for the Social Sciences 17.0 for Windows, and data were expressed as mean ± standard deviation (SD). The independent t-test was used to reveal whether there is a significant difference in age, onset duration, and MMSE-K score between the EG and CG. Additionally, a 2 × 2 analysis of variance (ANOVA) with 1 within-subject factor (time: before and after intervention) and 1 between-subject factor (group: EG and CG) was used to reveal the main effects and the difference in the BBT score between the two groups. Significance level was set at $p < 0.05$.

Results

Initially, 22 subjects volunteered for this study; however, the data of two subjects (1 in each group) were excluded from the final analysis because they did not participate in full sessions during the intervention. Figure 3 shows a flowchart of this study. General characteristics of the subjects are summarized in Table 1. Age (t = 0.083, p = 0.935), onset duration (t = 0.139, p = 0.891), and MMSE-K score (t = −0.275, p = 0.786) were not significantly different between the groups.

Figure 4 shows the BBT scores of the EG and CG. At pre-test, the BBT score of the EG was 20.50 ± 6.62, and at post-test, the score increased to 24.40 ± 5.42. The BBT score of the CG was 20.20 ± 6.12 at pre-test, and 20.60 ± 7.17 at post-test. The significant main effects in the BBT score were for time ($F_{1,18}$ = 15.803, p = 0.001) and group ($F_{1,18}$ = 235.024, p = 0.000), and significant time-by-group interactions were found in the BBT score ($F_{1,18}$ = 10.470, p = 0.005).

Topographical representation created by the brain mapping system was different after each session of the AOT. At pre-tests, cortical activation was uniform in the regions of interest; however, remarkable changes were found from the 2nd session of the AOT, with less cortical activation was observed at post-test. Before AOT, cortical activation was visible in the superior frontal gyrus, middle frontal gyrus, inferior frontal gyrus, precentral gyrus, postcentral gyrus, and inferior parietal cortex. However, the middle frontal gyrus was not activated after AOT (Fig. 5 and Table 2).

Table 1 General characteristics of the subjects

	EG (n_1 = 10)	CG (n_2 = 10)
Gender (male/female)	4/6	5/5
Age (years)	60.00 ± 9.36	59.70 ± 6.58
Paretic side (right/left)	4/6	5/5
Stroke (hemorrhage/infarction)	5/5	4/6
Onset duration (months)	15.30 ± 6.77[a]	14.90 ± 6.05
MMSE-K (score)	25.00 ± 1.63	25.20 ± 1.62

[a]Mean ± SD. EG: experimental group, CG: control group, MMSE-K: mini-mental state examination—Korean version.

Discussion

In general, stroke rehabilitation focuses on restoring the abilities that enable independent execution of everyday activities without difficulties, and the recovery of upper limb function is necessary to achieve this goal.[19] The goal of our study was to investigate the effects of AOT on patients with post-stroke hemiparesis, and our findings support that action observation therapy might help in functional recovery, as favorable changes were found in hand dexterity and in EEG-based cortical activation patterns.

Task-specific trainings, which focus on the repeated practice of functional activities, improve the hand function of patients with post-stroke hemiparesis.[20] Additionally, during the training, the repetitive use of the hand induces plastic changes in the neural networks of the brain, which contribute to the improvement of hand function.[6] In addition to physical training, the use of AOT may be a favorable option for extending the repertoire of movements and to relearn motor skills.[21,22]

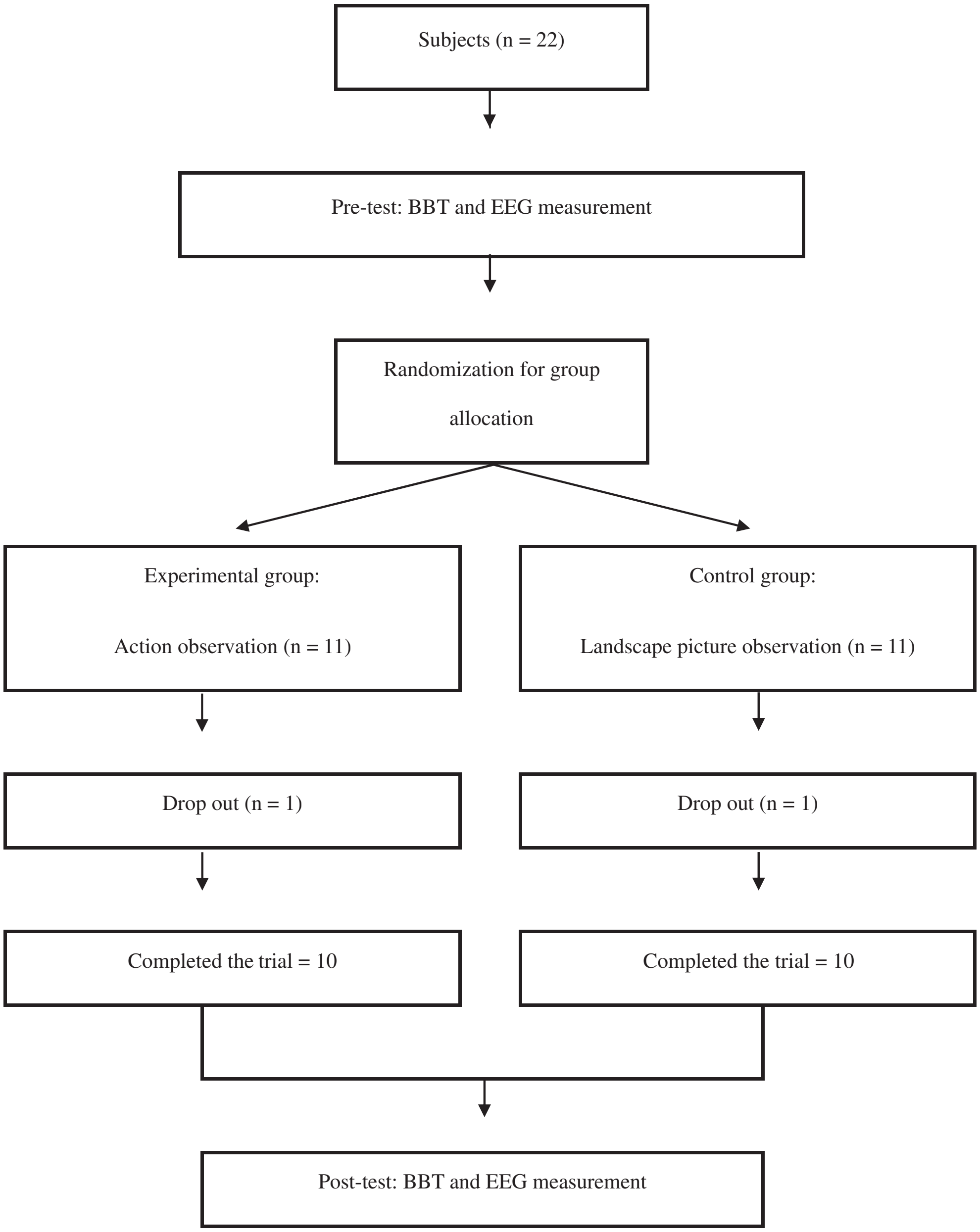

Figure 3 Flowchart for this study. BBT (box and block test) was performed for both groups; however, EEG (electroencephalography) data were obtained from the experimental group only.

After AOT, the motor improvement is most likely to be associated with increased cortical activation in the network including the bilateral ventral premotor area, inferior parietal area, supplementary motor area, contralateral supramarginal gyrus, and bilateral superior temporal gyrus.[23–25] In general, ventral premotor and inferior parietal areas are considered as the mirror neuron system, which is commonly known as a critical area in motor learning and action observation-associated functional recovery.[26] The mirror neuron system becomes more active upon observing actions, suggesting that specific motor experiences of the observer induce neural reorganization in patients with post-stroke hemiparesis.[27] Our EEG-based findings may be fundamental to support the clinical feasibility of AOT in stroke rehabilitation, since favorable changes were observed in cortical activation patterns associated with functional recovery. Since it is probably not possible to detect fine differences in brain activation using EEG data, in our study, we chose the EEG-based brain mapping system, which benefits from a high spatial resolution, to identify the brain areas activated during AOT.[18] Furthermore, electrodes collecting the EEG data were placed on brain regions of the mirror neuron system, based on the findings of a previous study.[28]

As shown in our findings, the activation of specific regions, such as the superior frontal gyrus, inferior frontal

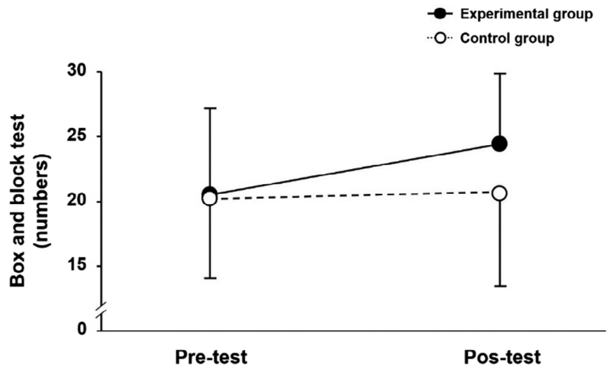

Figure 4 BBT scores in the experimental and control groups.

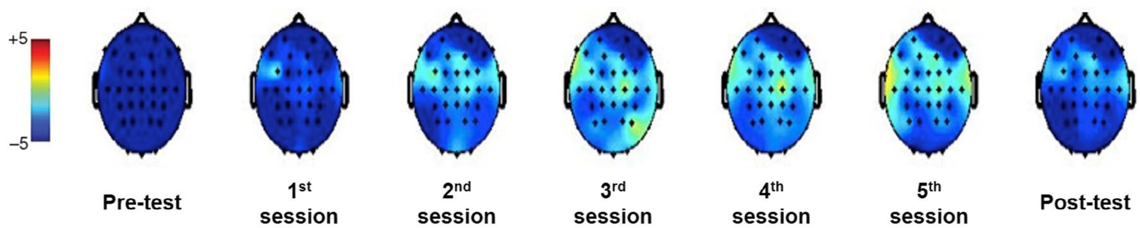

Figure 5 Overview of topographical representations created by the EEG-based brain mapping system, suggesting the cortical activation patterns change during action observation. These representations indicate a group average of the EEG signals.

Table 2 Activated regions of the mirror neuron system before and after action observation

Pre-test	Post-test
Superior frontal gyrus (BA[a] 6, 9)	Superior frontal gyrus (BA 6, 9)
Middle frontal gyrus (BA 46)	Inferior frontal gyrus (BA 45)
Inferior frontal gyrus (BA 45)	Precentral gyrus (BA 4)
Precentral gyrus (BA 4)	Postcentral gyrus (BA 1, 2, 3)
Postcentral gyrus (BA 1, 2, 3)	Inferior parietal cortex (BA 7, 40)

[a]BA: Brodmann area.

gyrus, precentral gyrus, postcentral gyrus, and inferior parietal cortex, was observed following AOT, while the middle frontal gyrus was less active despite its activation before AOT. Park et al.[29] found that the prefrontal area of the brain was less active after task training. Their findings support that short-term intensive training may facilitate the learning of tasks, and the superfluous activation of the brain is reduced with the decrease in cognitive efforts associated with performing the tasks. This indicates the increased efficiency of cerebral control in processing neuromuscular information and executing motor tasks. Similarly, our findings revealed the selective activation of mirror neuron system after AOT, but the middle frontal gyrus was less active. In an fMRI study by Buccino et al.,[23] the observation of novel actions prior to performing them induced cortical activation in the inferior parietal lobule, opercular part of the frontal lobe, and ventral premotor cortex. Similarly to their results, our findings showed different cortical activation patterns in subjects of the EG, but cortical activation was maintained in the bilateral regions of the inferior frontal gyrus and inferior parietal cortex. Although the inferior parietal cortex is activated upon performing or observing the same hand actions, the repetitive practice of observed actions contributes to the decrease of excess cortical activation.[30]

An important implication of our findings is that AOT might contribute to imitating individual motor actions, and it may be a basic procedure to practice the actions repeatedly.[31] Imitation of observed actions is regarded as a cognitive task, which requires relatively less effort to execute actions. During observation and imagination of actions, the neural networks of cortical regions related to movement execution can benefit from the increased efficiency of synaptic transmission, thus contributing to functional recovery.[32] In the fMRI study of Iacoboni et al.,[33] certain cortical regions became active during movement, and their activation increased upon imitating the action performed by another person. In particular, cortical activation was found in the opercular region of the left inferior frontal cortex and the rostral-most region of the right superior parietal lobule. Neural networks responsible for motor imitation contain numerous brain regions, and selectively activate the areas responsible for processing sensory signals. This mechanism supports the role of mirror neuron system, which allows the involvement of motor systems in the imagination and execution of observed actions, and reinforces the recovery of functional impairments after stroke. Currently, scientists focus on the similarities of basic neural circuits related to the imitation of actions and on mirror neuron system activated by action observation.[34]

In this study, AOT was used to perform motor tasks sequentially. Namely, patients with post-stroke hemiparesis observed an action in order to imitate it, which quickly prepares the motor system for following instructions, and makes the sequential performance of actions more successful.[35] Previous studies reported that AOT is beneficial for creating motor memories.[36,37] A study by Celnik et al.[38] reported that the incorporation of action observation into motor training can reinforce the encoding process of motor memory in the primary motor cortex, leading to the modulation of motor cortex excitability depending on the muscular involvement during the training task. Reinforcement of the motor learning process may originate from the activation of the neural system that matches the properties of action observation with those of action execution.[39]

In addition to the favorable effects of AOT, such as the activation of mirror neuron system and motor function, we acknowledge that our experiment has several limitations, which can be improved in further studies. First, this study used only the small number of subjects; therefore, it is difficult to extend our results beyond our group. Second, the main goal of this study was to detect short-term effects after AOT, assuming this therapy changes the mirror neuron system and facilitates functional improvement. Therefore, it was not possible to reveal the long-term effects of AOT. Finally, movement quality during task execution could not be analyzed due to the absence of quantitative kinematic measurements. Therefore, it may be difficult to make a definite conclusion from our findings.

Conclusions

In stroke rehabilitation, the advanced knowledge in neuroscience provides strong evidence about the advantages of various rehabilitation approaches in a clinical setting, which gives the clinicians various opportunities for clinical reasoning and decision-making. The current study used EEG-based brain mapping to explore the effects of AOT in patients with post-stroke hemiparesis. Our findings support that AOT may be advantageous in altering cortical activation patterns and hand dexterity. These benefits are likely to be associated with cortical reorganization and the activation of the observation-execution matching system to create motor memories. Accordingly, AOT may be a beneficial option for the functional improvement of patients with post-stroke hemiparesis.

Acknowledgments

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Conflict of Interest

The authors declare that there are no conflicts of interest.

Ethical approval

Ethical approval for this study was obtained from the Institutional Review Board of Cheongju University.

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References

1 Frey SH, Fogassi L, Grafton S, Picard N, Rothwell JC, Schweighofer N, et al. Neurological principles and rehabilitation of action disorders: computation, anatomy, and physiology (CAP) model. *Neurorehabil Neural Repair*. 2011;25:6S–20S.
2 Gjelsvik BEB. *The Bobath concept in adult neurology*. Germany: Thieme; 2008.
3 Barreca S, Wolf SL, Fasoli S, Bohannon R. Treatment interventions for the paretic upper limb of stroke survivors: A critical review. *Neurorehabil Neural Repair*. 2003;17:220–226.
4 Hakkennes S, Keating JL. Constraint-induced movement therapy following stroke: A systematic review of randomised controlled trials. *Aust J Physiother*. 2005;51:221–231.
5 Taub E, Uswatte G, Morris DM. Improved motor recovery after stroke and massive cortical reorganization following constraint-induced movement therapy. *Phys Med Rehabil Clin N Am*. 2003;14:S77–S91.
6 Pomeroy V, Aglioti SM, Mark VW, McFarland D, Stinear C, Wolf SL, et al. Neurological principles and rehabilitation of action disorders: rehabilitation interventions. *Neurorehabil Neural Repair*. 2011;25:33S–43S.

7 Gonzalez-Rosa JJ, Natali F, Tettamanti A, Cursi M, Velikova S, Comi G, et al. Action observation and motor imagery in performance of complex movements: Evidence from EEG and kinematics analysis. *Behav Brain Res*. 2015;281:290–300.

8 Fabbri-Destro M, Rizzolatti G. Mirror neurons and mirror systems in monkeys and humans. *Physiology*. 2008;23:171–179.

9 Iacoboni M, Molnar-Szakacs I, Gallese V, Buccino G, Mazziotta JC, Rizzolatti G, et al. Grasping the intentions of others with one's own mirror neuron system. *PLoS Biol*. 2005;3:e79.

10 Krams M, Rushworth MFS, Deiber MP, Frackowiak RS, Passingham RE. The preparation, execution and suppression of copied movements in the human brain. *Exp Brain Res*. 1998;120:386–398.

11 Pineda JA, Allison BZ, Vankov A. What goads cigarette smokers to smoke? Neural adaptation and the mirror neuron system. *Brain Res*. 2000;1121:128–135.

12 Muthukumaraswamy SD, Johnson BW, McNair NA. Mu rhythm modulation during observation of an object-directed grasp. *Brain Res Cogn Brain Res*. 2004;19:195–201.

13 Oberman LM, Hubbard EM, McCleery JP, Altschuler EL, Ramachandran VS, Pineda JA. EEG evidence for mirror neuron dysfunction in autism spectrum disorders. *Brain Res Cogn Brain Res*. 2005;24:190–198.

14 Mosher JC, Leahy RM, Lewis PS. EEG and MEG: Forward solutions for inverse solutions. *IEEE Trans Biomed Eng*. 1999;46:245–259.

15 Lee NG, Kang SK, Lee DR, Hwang HJ, Jung JH, You JS, et al. Feasibility and test-retest reliability of an electroencephalography-based brain mapping system in children with cerebral palsy: A preliminary investigation. *Arch Phys Med Rehabil*. 2012;93:882–888.

16 Park JH, Kwon YC. Standardization of Korean version of the mini-mental state examination (MMSE-K) for use in the elderly. Part II. Diagnostic validity. *J Korean Neuropsychiatric Assoc*. 1989;28:508–513.

17 Cromwell FS. *Occupational therapist's manual for basic skill assessment; primary prevocational evaluation*. Fair Oaks, CA: Fair Oaks Printing; 1976.

18 Im CH, Hwang HJ, Che H, Lee S. An EEG-based real-time cortical rhythmic activity monitoring system. *Physiol Meas*. 2007;28:1101–1113.

19 Krakauer JW. Arm function after stroke: From physiology to recovery. *Semin Neurol*. 2005;25:384–395.

20 Carr JH, Shepherd RB. *Neurological rehabilitation: Optimizing motor performance*. 2nd ed. New York: Churchill Livingstone; 2010.

21 Buccino G, Riggio L. The role of the mirror neuron system in motor learning. *Kinesiology*. 2006;38:5–15.

22 Carvalho D, Teixeira S, Lucas M, Yuan TF, Chaves F, Peressutti C, et al. The mirror neuron system in post-stroke rehabilitation. *Int Arch Med*. 2013;6:41.

23 Buccino G, Binkofski F, Riggio L. The mirror neuron system and action recognition. *Brain Lang*. 2004;89:370–376.

24 Rizzolatti G, Craighero L. The mirror-neuron system. *Annu Rev Neurosci*. 2004;27:169–192.

25 Binkofski F, Buccino G. The role of ventral premotor cortex in action execution and action understanding. *J Physiol*. 2006;99:396–405.

26 Ertelt D, Small S, Solodkin A, Dettmers C, McNamara A, Binkofski F, et al. Action observation has a positive impact on rehabilitation of motor deficits after stroke. *NeuroImage*. 2007;36:T164–T173.

27 Calvo-Merino B, Glaser DE, Grèzes J, Passingham RE, Haggard P. Action observation and acquired motor skills: An fMRI study with expert dancers. *Cereb Cortex*. 2005;15:1243–1249.

28 Koessler L, Maillard L, Benhadid A, Vignal JP, Felblinger J, Vespignani H, et al. Automated cortical projection of EEG sensors: Anatomical correlation via the international 10–10 system. *NeuroImage*. 2009;46:64–72.

29 Park JW, Kim JM, Seo JH, Kim YH. Reorganization of motor network and the effect of cross education derived from unilateral coordination training: Case study. *Phys Ther Korea*. 2002;9:67–76.

30 Chong TT, Cunnington R, Williams MA, Kanwisher N, Mattingley JB. fMRI adaptation reveals mirror neurons in human inferior parietal cortex. *Curr Biol*. 2008;18:1576–1580.

31 Buccino G, Solodkin A, Small SL. Functions of the mirror neuron system: implications for neurorehabilitation. *Cog Behav Neurol*. 2006;19:55–63.

32 Cowles T, Clark A, Mares K, Peryer G, Stuck R, Pomeroy V. Observation-to-imitate plus practice could add little to physical therapy benefits within 31 days of stroke: Translational randomized controlled trial. *Neurorehabil Neural Repair*. 2013;27:173–182.

33 Iacoboni M, Woods RP, Brass M, Bekkering H, Mazziotta JC, Rizzolatti G. Cortical mechanisms of human imitation. *Science*. 1999;286:2526–2528.

34 Caspers S, Zilles K, Laird AR, Eickhoff SB. ALE meta-analysis of action observation and imitation in the human brain. *NeuroImage*. 2010;50:1148–1167.

35 Brass M, Bekkering H, Wohlschläger A, Prinz W. Compatibility between observed and executed finger movements: Comparing symbolic, spatial, and imitative cues. *Brain Cogn*. 2000;44:124–143.

36 Stefan K, Cohen LG, Duque J, Mazzocchio R, Celnik P, Sawaki L, et al. Formation of a motor memory by action observation. *J Neurosci*. 2005;25:9339–9346.

37 Celnik P, Webster B, Glasser DM, Cohen LG. Effects of action observation on physical training after stroke. *Stroke*. 2008;39:1814–1820.

38 Celnik P, Stefan K, Hummel F, Duque J, Classen J, Cohen LG. Encoding a motor memory in the older adult by action observation. *NeuroImage*. 2006;29:677–684.

39 Di Pellegrino G, Fadiga L, Fogassi L, Gallese V, Rizzolatti G. Understanding motor events: A neurophysiological study. *Exp Brain Res*. 1992;91:176–180.