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Original Article

Effects of Action Observational Training on Cerebral Hemodynamic Changes of Stroke Survivors: A fTCD Study

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Abstract. [Purpose] The purpose of this study was to investigate the effect of Action Observational Training (AOT) on cerebral hemodynamic changes, including cerebral blood flow velocity (CBFV) and cerebral blood flow volume (CBFvol) in healthy subjects and stroke survivors. [Subjects] This study had a cross-sectional design. Seven healthy subjects and six patients with a first-time stroke participated in this study. [Methods] All subjects were educated about AOT, and we measured their systolic peak velocity (Vs), mean flow velocity (Vm), pulsatility index (PI), and resistance index (RI) in the middle cerebral artery (MCA), the anterior cerebral artery (ACA), and the posterior cerebral artery (PCA), before and after performance of AOT, using Functional Transcranial Doppler (fTCD) with a 2-MHz probe. [Results] Both healthy subjects and stroke survivors showed significant improvements of Vs and Vm in MCA, ACA and PCA after AOT. [Conclusion] Our findings indicate that AOT increases CBFV in healthy subjects and stroke survivors, because the brain requires more blood in order to meet the metabolic demand of the brain during AOT.

Key words: Action observational training, Cerebral blood flow, Functional transcranial Doppler (fTCD)

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INTRODUCTION

Therapeutic applications that engage the mirror system during stroke rehabilitation, including action observation, motor imagery and imitation, have been suggested as treatments for improvement of objective-programming[1)]. Motor imagery training (MIT) is the process of acquiring indirect motor-sensory experience without overt motor output by providing internal action[2)], and AOT is the method which facilitates activation of cortical areas through simulation and execution of the observed actions[3)]. Training such as a mental practice follows the novel paradigm of motor learning by involving rehearsal of neural pathways related to more dextrous and correct motor control[4)]. The mirror-neuron system in the motor cortex may be operated not only by real action but also by imagined or observed actions[5)], and it plays an essential role in both understanding the action, and imitations that are necessary for survival[6)]. Because it is related to an observation-execution matching system, the mirror neuron system can also be activated by both specific goal-directed behavior and observation of the same behavior[7)]. Observation-execution matching directly links performed actions with recognition of observed actions[8)].

Cerebral function and metabolism are strongly associated with cerebral blood flow (CBF), because an increase of metabolic demand in the brain will lead to an increase of blood flow[9)]. Functional Transcranial Doppler (fTCD), can be easily performed, and it has become an important alternative for quantification of CBF changes accompanying cerebral activity in the circulation of the human brain[10)]. fTCD is an ultrasound instrument that can noninvasively determine the cerebral blood flow velocity (CBFV) in the middle cerebral artery (MCA), the anterior cerebral artery (ACA), and the posterior cerebral artery (PCA) and the common carotid arteries[11)], and it can evaluate changes in CBFV during performance of mental tasks[12)]. It has been used in various psychophysiological studies involving cognitive tasks to compare CBFV during cognitive activities[13)].

The purpose of this study was to investigate the effect of AOT on cerebral hemodynamic changes, including CBFV, in healthy people and stroke survivors.

SUBJECTS AND METHODS

This study had a cross-sectional design. Seven healthy subjects without pre-existing neurological or orthopedic disorders and six patients with first-time stroke were included in this study which was conducted at K hospital. Patients with stroke met the following inclusion criteria: stroke onset within one year, scores on the Mini-Mental State Examination-Korean (MMSE-K) ranging from 24 to 30, unimpaired visual and somatosensory functions, and the ability to maintain a sitting position in a chair for lon-

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Table 1. The comparison of cerebral hemodynamic changes (n=13)

			Healthy subjects (n=7)		Stroke survivors (n=6)	
			Right side	Left side	Affected side	Unaffected side
MCA	Vs	rest	83.0 (9.5)	80.6 (8.3)	72.5 (6.4)	77.5 (9.7)
		AOT	89.6 (12.3)*	89.6 (12.3)	75.8 (5.3)	82.9 (14.0)
	Vm	rest	57.3 (6.4)	57.3 (6.7)	50.7 (6.3)	54.3 (8.5)
		AOT	63.3 (9.1)*	61.6 (7.4)*	53.2 (6.9)*	57.1 (7.7)*
	PI	rest	0.75 (0.09)	0.70 (0.04)	0.74 (0.14)	0.74 (0.17)
		AOT	0.71 (0.12)	0.71 (0.12)	0.73 (0.17)	0.77 (0.15)
	RI	rest	0.52 (0.04)	0.50 (0.02)	0.51 (0.06)	0.51 (0.07)
		AOT	0.49 (0.05)	0.50 (0.02)	0.50 (0.08)	0.52 (0.06)
ACA	Vs	rest	70.3 (16.2)	79.0 (12.6)	69.5 (16.6)	80.0 (35.3)
		AOT	73.1 (17.1)*	84.9 (13.8)*	73.0 (17.3)*	82.9 (32.3)
	Vm	rest	46.6 (9.8)	54.4 (10.4)	47.5 (13.0)	54.0 (19.8)
		AOT	49.0 (10.5)*	59.0 (11.7)*	50.3 (13.5)*	58.9 (24.8)
	PI	rest	0.83 (0.14)	0.79 (0.14)	0.79 (0.11)	0.74 (0.19)
		AOT	0.80 (0.12)	0.73 (0.13)*	0.77 (0.15)	0.72 (0.18)
	RI	rest	0.55 (0.05)	0.53 (0.06)	0.53 (0.04)	0.50 (0.08)
		AOT	0.53 (0.04)	0.50 (0.05)	0.52 (0.06)	0.50 (0.08)
PCA	Vs	rest	39.9 (5.3)	34.1 (5.6)	35.0 (7.9)	34.5 (4.9)
		AOT	41.6 (4.4)	37.7 (5.1)*	38.5 (4.9)	37.8 (4.3)*
	Vm	rest	27.9 (3.7)	24.6 (4.4)	25.5 (3.8)	24.3 (3.5)
		AOT	29.4 (3.6)	27.3 (4.3)*	27.2 (4.8)	26.8 (3.6)*
	PI	rest	0.73 (0.07)	0.68 (0.06)	0.73 (0.14)	0.72 (0.07)
		AOT	0.72 (0.09)	0.68 (0.11)	0.72 (0.14)	0.71 (0.09)
	RI	rest	0.50 (0.03)	0.48 (0.02)	0.50 (0.07)	0.50 (0.03)
		AOT	0.50 (0.04)	0.48 (0.05)	0.50 (0.06)	0.50 (0.04)

Values are mean (SD). MCA, middle cerebral artery; ACA, anterior cerebral artery; PCA, posterior cerebral artery; Vs, systolic peak velocity; Vm, mean flow velocity; PI, pulsatility index; RI, resistance index; AOT, Action Observational Training; Significant difference between rest and AOT *$p<0.05$.

ger than 30 minutes. The exclusion criteria were: bi-lateral stroke or history of stroke involving the contralateral side, musculoskeletal disorder, including muscle contracture or limitation of joint motion, and history of seizure. General characteristics of the healthy subjects group were: a mean age of 47.0 ± 6.0 years, a mean height of 158.0 ± 6.2 cm, and a mean weight of 57.4 ± 8.6 kg. Subjects in the stroke survivors group had: a mean age of 56.5 ± 11.8 years, a mean height of 164.0 ± 8.2 cm, a mean weight of 72.2 ± 9.9 kg, and duration since stroke onset of 6.7 ± 0.8 months; types of stroke were infarction in 4, and hemorrhage in 2 subjects. There were no significant differences between the groups. This study was approved by the Committee of Ethics of Sahmyook University. The objective of the study and its requirements were explained to all participants before conduct of the experiment, and all participants signed a written informed consent form.

All participants had a five-minute rest period before the fTCD test, during which they sat comfortably in a chair with their arms placed on a table. Then, they were asked to carefully observe 18 different video sequences containing functional movements that are required in their daily lives for 3 minutes. Each sequence became increasingly difficult (starting with turning off a water tap, followed by more complex movements such as tying shoelaces, etc.). The examiner required that all participants imitate the motor activities soon after the three minute-observation of the video sequences.

Measurement of bilateral insonation of MCA, ACA, and PCA were performed using fTDC (PMD-150, TRANSCRANIAL DOPPLER SYSTEM, SPENCER, USA) with a 2-MHz probe secured in place using a head frame in a quiet laboratory. After participants were in the supine position, detailed instructions were given before performance of measurements. The examiner measured systolic peak velocity (Vs), mean flow velocity (Vm), pulsatility index (PI), and resistance index (RI) in MCA, ACA, and PCA before and after performance of AOT. All measurements were repeated three times in a random order.

The SPSS 18.0 program was used to perform of statistical analyses. The Shapiro-Wilk test was used to determine the distribution of the general properties and outcome measures of the subjects. The paired t-test was used to compare cerebral hemodynamic values between the pre-test and the post-test within each group, and the independent t-test was performed to compare the changes between the two groups. Results were accepted as statistically significant at $p<0.05$.

RESULTS

Results of cerebral hemodynamic changes in MCA, ACA and PCA are shown in Table 1. In MCA, no significant difference in Vs was observed between the right side and left side of healthy subjects during the resting time (p=0.621) and after AOT (p=1.00), or between the affected side and unaffected side of stroke survivors during the resting time (p=0.270) and after AOT (p=0.224). However, in the comparison of outcome differences between before and after AOT, significant changes in Vs of the right side (p=0.001) and Vm both sides (p=0.004) were observed in healthy subjects, and in Vm on both the affected and unaffected sides (p=0.001) in stroke survivors.

In ACA, no significant difference in Vs was observed between the right side and left side of healthy subjects during the resting time (p=0.284) and after AOT (p=0.185), or during the resting time (p=0.475) and after AOT (p=0.477) between the affected side and unaffected side of stroke survivors. However, in the comparison of outcome differences between before and after AOT, significant changes were observed in Vs and Vm on the right side (p=0.033 for Vs, p=0.004 for Vm) and left side (p=0.013 for Vs, p=0.002 for Vm) of healthy subjects, and on the affected side (p=0.002 for Vs, p=0.002 for Vm) of stroke survivors.

In PCA, no significant difference in Vs or Vm was observed between the right and left side of both healthy subjects and stroke survivors. In the comparison of outcome differences between before and after AOT, significant changes were observed in Vs and Vm on the left side (p=0.007 for Vs, p=0.003 for Vm) of healthy subjects, and the unaffected side of stroke survivors (p=0.008 for Vs, p=0.002 for Vm).

In the comparison of the two groups using the independent t-test, no significant differences between the healthy subjects and stroke survivors were found in any variable.

DISCUSSION

This study demonstrated the effect of AOT on cerebral hemodynamic changes in healthy subjects and stroke survivors. Although we did not observe a significant difference in CBFV between heathy subjects and stroke survivors after AOT, the results of CBFV showed a significant increase in both groups. This finding indicates that AOT increases CBFV, since the brain requires more blood in order to meet its metabolic demand. Measurement of blood flow velocity (BFV) in the main arteries using fTCD has been accepted in a variety of studies of analysis of brain activities during performance of cognitive tasks[13]. Previous studies have investigated the relationship between cerebral hemodynamic changes and the performance of mental tasks using fTDC, and suggested that fTDC, as a non-invasive method, can provide quantitative and qualitative measures in addition to psychological parameters[12]. Motor imagery reinforces activation of the cortical and subcortical motor system during motor learning by providing quality of a motor image of a prior movement, giving rise to an experience of re-executing the movement[14]. Action observation (AO) activates motor areas of the brain, such as the ventral premotor cortex (PMv), and the inferior parietal lobule (IPL) which are related to the performance of a motor task and observation of the same action. Mirror neurons existing in these areas contribute to imitation and skill acquisition. A recent study demonstrated the effectiveness of motor training with AO on motor memory encoding, and suggested that AO can improve the effects of motor training on memory encoding protocols in older adults[15]. The results support the suggestion of another study that AOT can provide a good alternative neurorehabilitative approach to chronic stroke patients as it stimulates neural structures, including mirror neurons[16]. In this study, we used 18 different functional movements that are necessary activities of daily living (ADL) in AOT because Ewan et al. suggested that AOT, which consists of individualized and meaningful motor behaviors, including ADL, can provide a valid intervention for stroke survivors and motivate them in their activities[17]. We demonstrated an increase in blood demands in the brain after AOT. Our results are consistent with the findings reported by Ertelt et al, who investigated the effects of action observation therapy by comparing neural activations between the experimental and control groups after training using fMRI. They determined that the combined observation of daily actions with physical training improved motor functions during the four-week treatment period, and suggested that AOT had an additional influence on motor recovery after stroke by enhancing the activity in the bilateral ventral premotor cortex, bilateral superior temporal gyrus, supplementary motor area (SMA), and contralateral supramarginal gyrus[18]. A possible underlying mechanism of CBFV changes may be that AO increases the quantity of blood flow by facilitating the activation of premotor and parietal cortices, and several somatotopically organized motor circuit areas[19]. In addition, in order to understand the effect of AO, Celink et al. investigated the magnitude of motor memory formation in the primary motor cortex (M1) induced by contralateral thumb movements, and they reported that AO with physical training improved corticomotor excitability change in the muscles of the trained/observed movements[20].

The finding of this study is that AOT allows adjuvant effects, suggesting that observational training programs considering patient's new circumstances or new activities may contribute to consolidation of the positive effects of cognitive neurorehabilitation based on practice of motor tasks. However, we have not tested how long the effects of AOT on CBF persist after the intervention ceases. Future studies with longer intervention periods and larger samples of stroke survivors may result in larger improvements by determining the valuable role of AOT application.

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