

Cortical activation pattern during shoulder simple versus vibration exercises: a functional near infrared spectroscopy study

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Abstract

To date, the cortical effect of exercise has not been fully elucidated. Using the functional near infrared spectroscopy, we attempted to compare the cortical effect between shoulder vibration exercise and shoulder simple exercise. Eight healthy subjects were recruited for this study. Two different exercise tasks (shoulder vibration exercise using the flexible pole and shoulder simple exercise) were performed using a block paradigm. We measured the values of oxygenated hemoglobin in the four regions of interest: the primary sensory-motor cortex (SM1 total, arm somatotopy, and leg and trunk somatotopy), the premotor cortex, the supplementary motor area, and the prefrontal cortex. During shoulder vibration exercise and shoulder simple exercise, cortical activation was observed in SM1 (total, arm somatotopy, and leg and trunk somatotopy), premotor cortex, supplementary motor area, and prefrontal cortex. Higher oxygenated hemoglobin values were also observed in the areas of arm somatotopy of SM1 compared with those of other regions of interest. However, no significant difference in the arm somatotopy of SM1 was observed between the two exercises. By contrast, in the leg and trunk somatotopy of SM1, shoulder vibration exercise led to a significantly higher oxy-hemoglobin value than shoulder simple exercise. These two exercises may result in cortical activation effects for the motor areas relevant to the shoulder exercise, especially in the arm somatotopy of SM1. However, shoulder vibration exercise has an additional cortical activation effect for the leg and trunk somatotopy of SM1.

Key Words: nerve regeneration; functional near infrared spectroscopy; cortical activation; shoulder vibration exercise; flexible pole; neural regeneration

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Introduction

It is well known that exercise is necessary for good health (North et al., 1990; Salmon, 2001; Dziedzic et al., 2008; Siddiqui et al., 2010; Fagard, 2011; Weinstein et al., 2013). In general, exercise provides positive physiological effects, such as increased cardiorespiratory fitness and enhanced musculoskeletal function (Dziedzic et al., 2008; Fagard, 2011; Weinstein et al., 2013). In particular, exercise provides positive psychological effects in terms of self-esteem, mood, and relieving stress (North et al., 1990; Salmon, 2001). In addition, many functional neuroimaging studies have reported that various exercises had an effect in the induction of cortical activation (Luft et al., 2002; Park et al., 2008; Perrey, 2008; Tashiro et al., 2008; Kim et al., 2011; Leff et al., 2011); however, this has not been clearly elucidated so far.

There are several kinds of exercises, including, but not limited to, anaerobic exercise, aerobic exercise, stretching exercise, and strengthening exercise (Siddiqui et al., 2010). Strengthening exercise is a type of anaerobic exercise that involves the use of resistance to induce muscular contraction, which can increase motor unit recruitment, synchronization, and muscle fiber size (Knuttgren, 2007; Siddiqui et al., 2010).

It has been performed using various resistance devices, such as elastic tubing, weighted ball, isokinetic machine, dumbbell and so on (Stratton et al., 2004). Recently, a flexible pole, such as the Bodyblade (Hymanson Inc, Playa del Rey, CA, USA), has been commonly used in strengthening exercises. The purpose of such a device is to hold and shake it to create a vibration that leads to reciprocal muscle contraction to maintain the vibration (Lister et al., 2007; Moreside et al., 2007). Therefore, it has been widely used in physical therapy, sports training, and fitness enhancement (Anders et al., 2008; Leao Almeida et al., 2011). Many studies have reported that exercise using this device has an effect on increasing muscle power, strength, and endurance (Lister et al., 2007; Moreside et al., 2007; Anders et al., 2008; Parry et al., 2012). However, little is known about the cortical effect of this exercise.

To date, there have been many functional neuroimaging studies reporting on the cortical activation pattern induced by various exercises (Luft et al., 2002; Park et al., 2008; Perrey, 2008; Tashiro et al., 2008; Kim et al., 2011; Leff et al., 2011). Most of these studies were conducted using functional MRI or positron emission topography (Luft et al., 2002; Park et al., 2008; Tashiro et al., 2008; Kim et al., 2011). However,

these techniques are sensitive to motion artifact and cannot be used for large movement tasks. By contrast, the functional near infrared spectroscopy (fNIRS), which measures the intensity of scattered near-infrared light to calculate the changes in the concentrations of oxygenated hemoglobin (HbO) and deoxygenated hemoglobin (HbR) in the cerebral cortex, has a unique advantage in the execution of large movements due to less motion artifact (Miyai et al., 2001; Strangman et al., 2002, 2006; Perrey, 2008; Holtzer et al., 2011; Karim et al., 2012; Kurz et al., 2012).

In the current study, using fNIRS, we attempted to investigate the cortical activation pattern between the shoulder vibration exercise (SVE) using the flexible pole and shoulder simple exercise (SSE).

Participants and Methods

Participants

Eight healthy participants (five males, three females; mean age 29.13 ± 2.70 years, range 26–33 years) with no history of neurological, physical, or psychiatric illness were recruited for this study. All subjects understood the purpose of the study and provided written, informed consent prior to participation. The study protocol was conducted in accordance with the principles of the *Declaration of Helsinki* and approved by the Institutional Review Board of Yeungnam University Hospital (YUMC 2014-01-425).

Shoulder exercise

All subjects were asked to sit comfortably in a chair in an upright position during the experiment. Two different exercise tasks were performed using a block paradigm (three cycles: resting [20 seconds]-exercise task [20 seconds]-resting [20 seconds]-exercise task [20 seconds]-resting [20 seconds]-exercise task [20 seconds]); SVE: after receiving brief instructions and participating in a practice session to ensure familiarity in using the flexible pole [Bodyblade® Classic (length: 48 in weight: 1.5 lb), Bodyblade, Los Angeles, CA, USA], subjects were asked to vibrate the pole. They were instructed to vibrate the pole in an antero-posterior direction while holding the flexible pole with the right shoulder at a 90° flexion. SSE: flexion-extension movements of the right shoulder were performed at a frequency of 0.5 Hz under the guidance of a metronome (Figure 1). Each exercise task was repeated twice and the sequence of the tasks was randomly assigned.

Functional NIRS

The fNIRS system (FOIRE-3000; Shimadzu, Kyoto, Japan), with continuous wave laser diodes with wavelengths of 780, 805, and 830 nm, was used to record the cortical activity at a sampling rate of 10 Hz; we employed a 49-channel system with 30 optodes (15 light sources and 15 detectors). Based on the modified Beer-Lambert law, we acquired the values for HbO (Baker et al., 2014), following changes in the levels of cortical concentration (Cope and Delpy, 1988). The international 10/20 system, with Cz (cranial vertex) located beneath the 25th channel, was used to position the optodes. A stand-alone application was used for spatial registration of

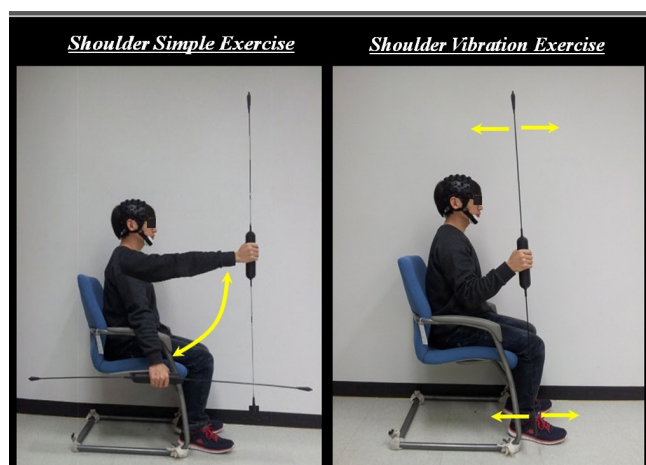


Figure 1 Sagittal view for the shoulder simple (left) and vibration exercises (right).

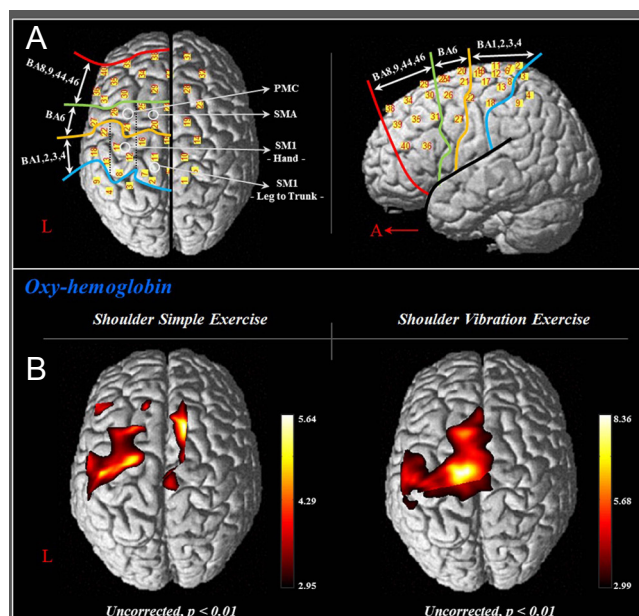


Figure 2 Region of interest and results of functional near infrared spectroscopy (fNIRS) during shoulder simple versus vibration exercises in healthy participants.

(A) Four regions of interest based on the Brodmann's area (BA) and anatomical location of the brain. The primary sensory-motor cortex (SM1): BA 1, 2, 3, and 4; the premotor cortex (PMC): BA 6 (BA 6 except for the SMA); the supplementary motor area (SMA) (anterior boundary: vertical line to the anterior commissure, posterior boundary: anterior margin of M1, medial boundary: midline between the right and left hemispheres, lateral boundary: the line 15 mm lateral from the midline between the right and left hemispheres); prefrontal cortex (PFC): BA 8, 9, 44, 45, and 46; the leg to trunk somatotopy of SM1 (medial boundary: longitudinal fissure, lateral boundary: the line that passed between the precentral knob and the electrode located in the trunk somatotopic area of the SM1); the hand somatotopy of SM1 (medial boundary: medial margin of the precentral knob, lateral boundary: lateral margin of the precentral knob). Numbers in A mean BA numbers. (B) Group-average activation map of oxygenated hemoglobin during execution of a weight-shifting control trainer using Near Infrared Spectroscopy-Statistical Parametric Mapping (uncorrected, $P < 0.01$). Each right bar (red to yellow) means intensity of brain activation. The uppercase letters L and A in figure 2 means anterior and posterior, respectively.

the acquired 49 channels on the Montreal Neurological Institute (MNI) brain based on the 25th channel on the Cz (Ye et al., 2009).

The software package, NIRS-SPM (<http://bisp.kaist.ac.kr/NIRS-SPM>) implemented in the MATLAB environment (The Mathworks, Natic, MA, USA) was used to analyze the fNIRS data. Gaussian smoothing with a full width at half maximum (FWHM) of 2 seconds was applied to correct the noise from the fNIRS system (Ye et al., 2009; Tak et al., 2011). The detrending algorithm based on wavelet-minimum description length (MDL) was used to correct signal distortions due to breathing or movement of subjects, and the general linear model (GLM) analysis with a canonical hemodynamic response curve was then performed in order to model the hypothesized HbO response under the experimental condition (Ye et al., 2009; Tak et al., 2011). For the group analysis of HbO, SPM *t*-statistic maps were computed, and HbO was considered significant at the uncorrected $P < 0.01$ (Ye et al., 2009; Li et al., 2012).

We selected four regions of interest (ROI) based on Brodmann's area (BA) and anatomical locations of brain areas: primary sensory-motor cortex (SM1) (BA 1, 2, 3, and 4), premotor cortex (PMC) (BA 6, except for the supplementary motor area [SMA]), SMA (anterior boundary: vertical line to the anterior commissure, posterior boundary: anterior margin of M1, medial boundary: midline between the right and left hemispheres, lateral boundary: the line 15 mm lateral from the midline between the right and left hemispheres), and the prefrontal cortex (PFC) (BA 8, 9, 44, 46). In addition, we divided the ROIs of SM1 into two areas: the area of the arm somatotopy (precentral knob) and the area of the leg and trunk somatotopy (medial part to the precentral knob) (**Figure 2A**) (Dassonville et al., 1998; Mayka et al., 2006; Amiez and Petrides, 2009). The values for HbO were estimated from each channel of the four ROIs during the resting phase and performance of shoulder movements. Subsequently, using NIRS-SPM, the HbO values of each ROI were acquired based on the individual GLM analysis results.

Statistical analysis

SPSS 15.0 software (SPSS, Chicago, IL, USA) was used in performance of data analysis. Data were expressed as the mean \pm standard deviation (SD). The Mann-Whitney *U* test was performed to determine the difference of HbO value in each ROI between SVE and SSE. The results were considered significant when the *P* value was < 0.05 .

Results

HbO response

In the average HbO value from the result of individual GLM analysis, cortical activation was observed in SM1 (total, arm somatotopy, and leg and trunk somatotopy), PMC, SMA, and PFC during performance of both SVE and SSE. Among these ROIs, the highest HbO values (SVE = 0.013, SSE = 0.011) were observed in the arm somatotopy of SM1 compared with those of other ROIs while performing each

exercise. However, no significant difference in the arm somatotopy of SM1 was observed between the two exercises ($P > 0.05$). By contrast, there was a significantly higher HbO value (0.011) in the leg and trunk somatotopy of SM1 for SVE than for SSE (0.006) ($P < 0.05$). However, no significant differences in HbO values in the total SM1 (SVE = 0.012, SSE = 0.008), PMC (SVE = 0.008, SSE = 0.007), SMA (SVE = 0.008, SSE = 0.005), and PFC (SVE = 0.005, SSE = 0.005) were observed between the two exercises ($P > 0.05$) (**Table 1**).

SPM *t*-statistic maps

The results from group analysis of HbO for SSE (SPM *t*-statistic maps, uncorrected, $P < 0.01$) showed a significant activation in the arm somatotopy of SM1 and PMC. Conversely, for SVE, significant activation was observed in the leg and trunk somatotopy of SM1 and SMA, as well as the arm somatotopy of SM1 and PMC (**Figure 2B**).

Discussion

Herein, we investigated the differences of cortical activation patterns between SVE and SSE. We measured the change of HbO in selected ROIs (SM1 [total, arm somatotopy, leg and trunk somatotopy], PMC, SMA, and PFC) that were assumed to have a close association with shoulder exercise. As a result, we observed greater activation in the arm somatotopy of SM1 than in the other ROIs while performing the two types of shoulder exercise. In addition, the leg and trunk somatotopy of SM1 showed a greater activation during performance of SVE than SSE. This result was in accordance with the group analysis. Therefore, both exercises have cortical activation effects for the motor areas relevant to shoulder exercises, especially in the arm somatotopy of SM1. However, SVE has an additional cortical activation effect for the leg and trunk somatotopy of SM1.

A number of studies have reported on the physiological effects of vibration exercise in the enhancement of muscle activity or power, cardiovascular function, and increasing corticospinal pathway excitability (Lister et al., 2007; Moreside et al., 2007; Anders et al., 2008; Mileva et al., 2009; Pollock et al., 2010; Cochrane, 2011; Lau et al., 2011; Marconi et al., 2011; Parry et al., 2012). Among these studies, a few studies have demonstrated the effect of vibration exercise using the flexible pole, like the current study (Lister et al., 2007; Moreside et al., 2007; Anders et al., 2008; Parry et al., 2012). Moreside et al. (2007) reported that vibration exercise increased the activation of trunk muscles and spinal stability. Therefore, they demonstrated that the use of vibration pole was effective for the recruitment of spinal stabilizers. During the same year, Lister et al. (2007) reported that vibration exercise using the Bodyblade led to a greater scapular stability than exercises using an elastic band or cuff weight. In a recent study, Parry et al. (2012) reported similar results indicating that shoulder vibration exercise using the Bodyblade induced greater recruitment of shoulder and back muscles than shoulder exercise using dumbbells. Therefore, it appears that the results of the aforementioned previous studies using

Table 1 Values for oxygenated hemoglobin (M) in the regions of interest during the performance of shoulder simple or vibration exercises

	SM1					
	Total	Somatotopic area			SMA	PFC
		Arm	Leg and trunk	PMC		
SSE	0.0083±0.0026	0.0107±0.0056	0.0055±0.0049	0.0065±0.0050	0.0046±0.0056	0.0052±0.0028
SVE	0.0117±0.0048	0.0133±0.0051	0.0107±0.0051	0.0080±0.0082	0.0084±0.0048	0.0053±0.0068
<i>P</i>	0.234	0.161	0.038*	0.505	0.130	0.959

Data were expressed as the mean ± SD. SM1: Primary sensorimotor cortex; SMA: supplementary motor area; PFC: prefrontal cortex; SSE: shoulder simple exercise; SVE: shoulder vibration exercise. **P* < 0.05 for significant difference between SSE and SVE using the Mann-Whitney *U* test.

the Bodyblade were in agreement with our results showing that SVE using the flexible pole induced activation of the leg and trunk sommatotopy of the SM1 as well as the arm sommatotopy of SM1.

In conclusion, we investigated cortical activation patterns during the performance of SVE versus SSE. According to our findings, SVE induced additional activation in the leg and trunk somatotopy of SM1 as well as the cortical areas relevant to the shoulder exercise. To the best of our knowledge, this is the first study to demonstrate the cortical activation pattern induced by vibration exercise using the flexible pole. We believe that these findings have an important clinical implication with respect to the brain activation pattern induced by physical exercise. However, the current study has some limitations to consider. The number of the subjects was small and we did not use individual MRI data for the spatial registration of the acquired channels on the MNI brain. In addition, we could not include the whole PFC area due to the limited number of channels in the NIRS system. In order to further investigate the clinical application of vibration exercise for motor recovery in patients with brain injury, further studies are necessary. Moreover, further studies are also necessary to better understand the cortical activation pattern induced by other physical modalities.

Author contributions: MYL designed this study and SSY collected experimental data. SHJ and SHL provided technical assistance and supervised the study. SHJ and MYL wrote the manuscript, provided critical revision of the manuscript for intellectual content. SHJ approved the final version of the paper. All authors approved the final version of this paper.

Conflicts of interest: None declared.

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Declaration of participant consent: The authors certify that they have obtained all appropriate participant consent forms. In the form, the participants have given their consent for their images and other clinical information to be reported in the journal. The participants understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Data sharing statement: The datasets analyzed during the current study are available from the corresponding author on reasonable request.

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