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Original Article

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Effects of Low Intensity Blood Flow Restriction Training on Brain Motor Area Activation

Min-Hyung Rhee, P.T., Ph.D. · Jong-Soon Kim, P.T., Ph.D.[1†]

Department of Rehabilitation Medicine, Pusan National University Hospital
[1]Department of Physical Therapy, College of Health Sciences, Catholic University of Pusan

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| Abstract |

Purpose: The purpose of this study was to identify the effects of low intensity blood flow restriction training (LBFR) on the central nervous system of healthy adults.

Methods: Ten healthy right-handed adults (eight males and two females, mean age of 28.6 ± 2.87 years) were selected as study subjects. Functional magnetic resonance imaging (fMRI) was conducted to measure brain activation (BA) following LBFR and non-LBFR. The primary motor area, premotor area, and supplementary motor area, which are closely related to exercise, were set as the regions of interest.

Results: The BA recorded during the LBFR condition was 931.7 ± 302.44 voxel, and the BA recorded during the non-LBFR condition was 1,510.9 ± 353.47 voxel.

Conclusion: BA was lower during LBFR than during non-LBFR.

Key Words: Low intensity blood flow restriction training, Functional magnetic resonance imaging, Brain activation

†Corresponding Author : Jong-Soon Kim (ptjskim@cup.ac.kr)

Ⅰ. Introduction

In general, low frequency and high intensity resistance exercises increase muscle strength and muscle bulk, while high frequency and low intensity resistance exercises increase endurance (DeLorme, 1945; Suga et al., 2009). These resistance exercises affect protein synthesis, bring about myocyte hypertrophy with hormonal actions (Staron et al., 2000; Suga et al., 2010), and increase muscle protein metabolism, leading to the repetition of muscle protein synthesis and decomposition (Bodine et al., 2001). The American College of Sports Medicine (Medicine, 2013) recommends exercises of 60～80% intensity of 1RM as muscle strengthening exercises and proposes exercises of the maximum intensity and the minimum number of repetitions. There are a number of ways to enhance the effectiveness of exercise.

Among them, LBFR is a method that can enhance the effect of exercise even if it is not a strong intensity exercise. Various studies indicating that low intensity blood flow restriction training (LBFR) increases muscle strength have recently been reported (Kim, 2020; Manini et al., 2011; Park et al., 2022; Yasuda et al., 2010).

Blood flow restriction training (BFR) restricts venous return, leading to blood pooling in muscles. If exercises are continued under this condition, oxygen concentrations in muscles are reduced. This leads to local accumulation of anaerobic metabolites generated in muscles, such as lactic acid, hydroxide ions, and adenosine. In this case, even low intensity exercises are highly likely to become anaerobic exercises instead of aerobic exercises. Therefore when blood flow is restricted, the metabolic circulation of the relevant muscle is restricted, leading to low oxygen conditions in the muscle and the occurrence of anaerobic exercise(Abe et al., 2006; Rowell et al., 1981).When blood flow is restored after exercises, the muscle is filled with high concentrations of oxygen, the number of muscle fibers increases to heal the damaged microstructures, and the muscle cross sectional area (MCSA) increases (Takarada et al., 2002). According to a study conducted by Takarada et al(2000), LBFR increased growth hormone (GH), lactate (LA), norepinephrine (NE), interleukin-6 (IL-6), and muscle activity. Sato(2005) advised that LBFR increased GH and LA. Manini et al(2011) reported that LBFR reduced FOXO3A, Atrogin-1, and MuRF-1, while increasing muscle activity. According to a study conducted by Abe et al(2005), LBFR increased muscle strength, MCSA, and Insulin-like growth factor 1 (IGF-1), and Yasuda et al(2010) indicated that LBFR increased muscle strength and MCSA. Although the physiological and histological effects of exercise was identified through previous studies, changes in the central nervous system could not be identified. Changes in the central nervous system modulate the activity of lower motor neurons and affect local circuits in the brain stem and spinal cord that constitute motion. Upper motor neurons in the cortex indirectly affect motion by changing the motor control central pathway of the brain stem(Purves et al., 2019). Therefore, the purpose of this study is to identify the effects of LBFR on the central nervous systems of healthy adults.

Ⅱ. Method

1. Subjects

Ten healthy adults (eight males and two females, mean age 28.6±2.87), proven as right-handers by the Edinburg Handedness Inventory (Oldfield, 1971), were selected as study subjects. The selection criteria for the subjects were individuals with no neurologic or psychological problem who were sufficiently well acquainted with the purpose and experimental procedure of the present study and could carry out the given tasks. All experiments were conducted

in accordance with the Declaration of Helsinki (Institutional Review Board of Pusan National University Hospital: H-1507-009-031).

2. Experimental procedure

Functional magnetic resonance imaging (fMRI) was conducted to measure brain activation (BA) following LBFR. For the composition of fMRI, a block design was used to repeat rest periods five times and stimulus periods five times. Each block of the rest periods and stimulus periods was set to 30 seconds. Each subject wore a blood flow restriction cuff on the right upper arm in a comfortable supine position in the fMRI equipment and performed the exercises under two conditions. For LBFR, the subject performed fist clenching exercises at the most comfortable speed for the subject while upper limb blood flow was being restricted. For non-LBFR, the subject performed the same exercises while there was no restriction of blood flow. Considering the continuous compression for five minutes, the upper limb blood flow restriction pressure was set to 60mmHg.

3. Magnetic resonance data acquisition

For fMRI, Blood Oxygen Level Dependent (BOLD) images were obtained in the single shot Echo Planar Imaging (EPI) technique using a 3T MRI system (MAGNETOM Trio A Tim System, Siemens, Germany) and the results were derived. The time of repeat (TR: 2000ms), time of echo (TE: 21ms), flip angle (FA: 90°), field of view (FOV: 230mm), matrix size (64×64), and thickness (5mm) were set as variables for the fMRI and 20 brain section images on the transverse plane parallel to the line (AC-PC line) that connected the anterior commissure to the posterior commissure were obtained. TR (1800ms), TE (2.19ms), FA (9°), FOV (230mm), matrix size (307×320), and thickness (0.7mm) were set as variables for fMRI for measurement of structure images (T1 mprage sequence).

4. Data analysis

The images taken were analyzed using the SPM8 software (Statistical Parametric Mapping 8 version, Wellcome Department of Cognitive Neurology, UK) and xjView software (Human Neuroimaging Lab, Stanford University, USA) implemented in MATLAB (MATLAB, Mathworks, Inc., USA) environments. The procedure for analysis using SPM8 was as follows: Head movements were corrected through “realign” and mean-images and EPI images were aligned to the T1 MRI images of individual subjects through “coregister”. In addition, morphological differences among the brains of individuals were corrected through “normalization” and Gaussian kernel filters with 6mm full width half maximum (FWHM) applied for “smoothing”.

To analyze the results, statistical thresholds were determined at the level of volume elements using the fixed effect model. Height thresholds were determined at levels with corrected p values lower than 0.001 and extent thresholds were determined based on 5 voxel. The statistical thresholds were calculated through interactions between height thresholds and extent thresholds using SPM8 software.

The coordinates obtained through the analysis were indicated as Brodmann’s areas using the xjView program. The regions of interest (ROI) in the data were set as the primary motor area (PMA), premotor area (PA), and supplementary motor area (SMA), which are closely related to exercises, and the voxel values of the activation were analyzed.

Statistical analysis was performed using IBM SPSS Statistics 22 program. The cerebral activity of LBFR and

Non-LBFR was analyzed using Wilcoxon signed rank test, and the significance level was set to 0.05.

Ⅲ. Results

The results of the fMRI that measured changes in brain activity during LBFR and non-LBFR are shown in Table 1. Brain activity was activated by 931.7±302.44 voxel during LBFR and by 1510.9±353.47 voxel during non-LBFR in Table 2.

Table 1. Brain activity of LBFR and Non-LBFR

Case	LBFR Voxel	Non-LBFR Voxel
1	705	1434
2	1308	1705
3	710	941
4	1191	1330
5	895	1571
6	1402	1816
7	533	1275
8	587	1559
9	1048	1257
10	938	2221

LBFR: low intensity blood flow restriction training

Table 2. Comparison of brain activity between LBFR and Non-LBFR

Case	Mean SD	Z	*p*
LBFR Voxel	931.70 302.45	-2.80	.001
Non-LBFR Voxel	1510.90 353.47		

LBFR: low intensity blood flow restriction training

Ⅳ. Discussion

Blood flow restriction training (BFR) restricts venous return, leading to blood pooling in muscles. This could be identified by measuring the levels of oxygen concentrations in muscles through near-infrared spectroscopy (NIRS). Oxygen concentrations in muscles decreased during BFR and increased during decompression after exercises (Tanimoto et al., 2005). That is, blood flow increased and the recovery of microstructures was promoted during decompression to recover the damage to microstructures caused by BFR. According to muscle biopsies after BFR, Type-I fiber (5.9%) and Type-II fiber (27.6%) hypertrophy was identified and Type-II fiber hypertrophy was mainly identified in particular (Yasuda et al., 2005). In general, during muscle strengthening exercises, Type-I fibers contract first and Type-II fibers are mobilized in sequence as the load increases. However, during BFR, many muscle fibers are mobilized simultaneously regardless of exercise loads (Yoo, 2015). During BFR, oxygen supply to muscles is reduced and due to the resultant accumulation of anaerobic metabolites, many motor units, including Type-II fibers, are mobilized simultaneously to maintain muscle strength. That is, BFR can simulate the effects of anaerobic exercises regardless of intensity. Although many studies have been conducted on physiological changes due to exercises, studies that identified changes in the central nervous system are insufficient. Therefore, the present study aimed to identify changes in the central nervous system following BFR by measuring BA through fMRI images.

To identify changes in the central nervous system following BFR, fMRI images were obtained during LBFR and non-LBFR exercises to compare BA. According to the results, as for changes in the central nervous system following exercises, BA was approximately 63% lower during LBFR compared to during non-LBFR. To investigate the effects of LBFR exercises on BA, Morita et al (2010) had six healthy adults perform non-BFR exercises with the right arm first, followed by the left arm, and applied BFR thereafter while measuring BA

through NIRS. According to the results, no significant difference could be identified during non-BFR that was conducted first according to the experimental procedure, while some increases in BA were identified during BFR that was performed last. This is contrary to the results of the present study. However, the results of the study conducted by Morita et al (2010) are considered attributable to the small number of subjects, the fact that exercises that showed some increases in BA were performed last according to the experimental procedure, and motor learning due to repeated exercises as left BA was high during left arm exercises. However, although this study is smail subjects, it was attempted to secure more objectivity through fMRI study. And, in order to avoid the effect of motor learning, it was designed with block design, without training and comparing both arms. To assess the degree of nervous excitation during LBFR, Kim (2009) checked compound muscle action potential (CMAP) following one-off BFR in healthy adults. According to the results, CMAP increased after BFR compared to before exercises. However, since the degree of nervous excitement was measured when BFR had been removed, changes in the nervous system during BFR could not be identified as in the present study. Moreover, increases in the excitation of the peripheral nervous system were noted without identifying changes in the central nervous system. In the present study, whereas changes in the central nervous system following BFR were identified, the degree of excitation of the peripheral nervous system could not be demonstrated. However, according to previous studies, nerves are tissues with densely distributed blood vessels and BFR by external compression can lead to nervous conduction disorders and may induce sensory and/or motor disorders (Lundborg, 1988; Nee & Butler, 2006). Through experiments, Bickler et al (1990) reported that upper limb compression of 250mmHg applied for 45－50 minutes induced reversible conduction disorders to nervous segments to which pressure was directly applied and slowed the nervous conduction of the distal region below the tourniquet. Sensory inputs in distal regions may increase BA and can enhance the activity of the brain motor area when motor nerves have been paralyzed. Researchers have reported that, when sensory stimuli were actually given to the palm, activation signals were observed in regions similar to those when the fingers moved (Yetkin et al.,

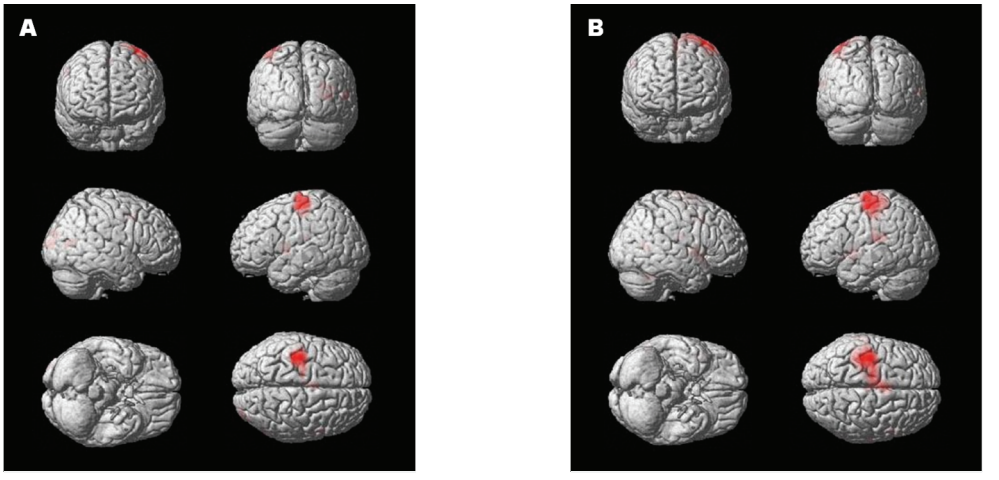

Fig. 1. Cortex activation areas identified from the functional magnetic resonance imaging analysis displayed on low intensity blood flow restriction training (A) and non-low intensity blood flow restriction training (B).

1995). Therefore, the upper limb compression applied during exercises with BFR in the present study should have restricted nervous conduction in regions below the compressed region leading to restricted sensory inputs going to the brain, thereby reducing BA.

In the present study, the degree of excitement of peripheral nerves in regions below the compressed region could not be identified. That is, although the excitement of the central nervous system was identified, its correlation with the peripheral nervous system could not be demonstrated. In addition, despite the excited state of the central nervous system under the condition of BFR, changes in the central nervous system after removing the blood flow restriction could not be identified. Therefore, future studies are necessary to supplement the foregoing research.

Ⅴ. Conclusion

As a result of this study, the brain motor activation was lower during LBFR than during non-LBFR. LBFR is effective methods for morphological changes of muscles. But there are not effective for the central nervous system activation like brain motor area activation. Therefore, we need to choose the appropriate exercise according to the main purpose of the exercise.

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