

Effects of blood flow restriction on cerebral blood flow during a single arm-curl resistance exercise

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Low-intensity resistance exercise with blood flow restriction (BFR), also known as “Kaatsu,” causes a dramatic increase in the secretion of growth hormone. Several reports have shown that Kaatsu is effective for training in patients with stroke. However, the influence of Kaatsu training on brain function remains unclear. This study aimed to investigate the acute effects of Kaatsu training on blood flow in the brain. Six healthy male subjects performed a single-arm curl with and without BFR using 20% of the weight of 1 repetition maximum (RM); 1 set of 30 repetitions (reps) was followed by 3 sets of 15 reps, with a 30-s interval in between. During the procedure, cerebral blood flow was measured using near-infrared spectroscopy (NIRS). During arm curls with BFR, the oxygenated hemoglobin (oxy-Hb) concentration of the contralateral motor cortex increased significantly compared to that during curls without BFR. The results of this study suggest that Kaatsu training has a positive effect on the brain by increasing cerebral blood flow and that it is useful for treating diseases such as stroke and cognitive disorders caused by brain dysfunction.

Key words: Kaatsu training, near-infrared spectroscopy, cerebral blood flow, blood flow restriction

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INTRODUCTION

New techniques for functional brain imaging such as functional magnetic resonance imaging (fMRI) and near-infrared spectroscopy (NIRS) have been developed since the late 1990s. These modalities can elucidate brain activity during exercise (Vladislav et al., 2001), and have produced data showing that exercise has a positive effect on the brain (Charles et al., 2008).

Kaatsu training involves low-intensity resistance exercise or walking with blood flow restriction (Takarada et al., 2000a, b; Abe et al., 2006). Although it is a low-intensity exercise, Kaatsu training induces muscle hypertrophy comparable to that induced by high-intensity exercise (Takarada et al., 2000b) and stimulates the secretion of growth hormone (Takarada Y et al., 2000a). Japan's Kaatsu training society has reported a number of cases showing that Kaatsu training has a positive effect on the recovery of stroke patients, although there are insufficient data to support this assertion. Although Kaatsu training is expected to have a beneficial influence on the brain, its effects have not been investigated systematically.

The purpose of this study was to investigate the impact of Kaatsu training on cerebral blood flow. We found that a single episode of Kaatsu training may have a positive effect on the brain by increasing cerebral blood flow.

MATERIALS AND METHODS

Subjects

Six healthy adult men, aged 20-40 years (30 ± 5 years), participated in this study. All were non-trained volunteers, and informed consent was obtained prior to the study. Mean height was 169 ± 5 cm, and mean weight was 66 ± 4 kg. None of the subjects had any diseases or took medication. The study protocol was approved by the ethics committee of the University of Tokyo.

NIRS instruments

We used a multichannel NIRS optical topography system (ETG-4000; Hitachi Medical Corporation, Kashiwa, Japan), using 2 wavelengths of near-infrared light (785 and 830 nm). We analyzed the optical data based on the modified Beer-Lambert Law (Cope et al., 1988) as previously described (Maki et al., 1995). This method allowed us to calculate signals reflecting concentration changes in oxygenated hemoglobin (oxy-Hb), deoxygenated hemoglobin (deoxy-Hb), and total hemoglobin (total-Hb), calculated in arbitrary units (millimolar-millimeter; $\text{mM} \cdot \text{mm}$) (Maki et al., 1995). The sampling rate was set at 100 ms.

NIRS probe placement

We set the NIRS probes to cover activation foci in the lateral prefrontal cortex (LPFC), as found in previous fMRI and positron emission tomography (PET) studies (Derrfuss et al., 2005; Laird et al., 2005). Specifically, we used 2 sets of 2×2 multichannel

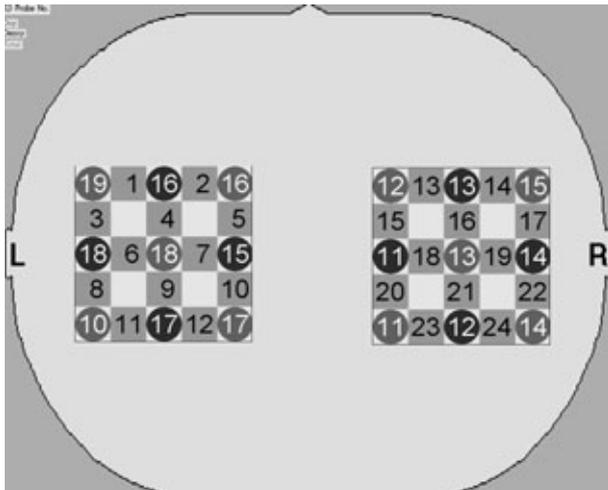


Figure 1. Exercise protocol (see methods)

probe holders, consisting of 5 illuminating and 4 detecting probes arranged alternately at an inter-probe distance of 3 cm, resulting in 12 channels (CH) per set (Fig. 1).

Induction of muscle blood flow restriction by Kaatsu

The method for inducing blood flow restriction (BFR) in muscle has been previously described (Takarada et al., 2000a, b; Takano et al., 2005; Abe et al., 2006). Local application of external pressure over both arms (a banding pressure 1.3-times higher than resting systolic blood pressure, 130-170 mm Hg) was used to reduce muscle blood flow. Briefly, both arms had pressure applied at the proximal ends of the upper limbs by means of specially designed belts (20 mm in width, 500 mm in length) just before the start of the exercise, and the pressure was released immediately after the exercise.

Exercise protocols

As illustrated in Figure 2, subjects first performed 30 repetitions (reps) of 1 arm curl using 20% of their pre-determined 1-RM using the right arm without BFR. Following a 30-s rest period, the subjects performed 3 sets of 15 reps, with each set of exercises separated by a 30-s rest period. Following a 15-min rest, the subjects performed the same protocol (1 set of 30 reps and 3 sets of 15 reps) with BFR. They then performed a left-arm curl (1 set of 30 reps and 3 sets of 15 reps using 20% of the 1-RM weight, with a 30-s rest between sets) with BFR. Following a 15-min rest, they performed the same protocol without BFR. Cerebral blood flow was monitored by NIRS during each exercise.

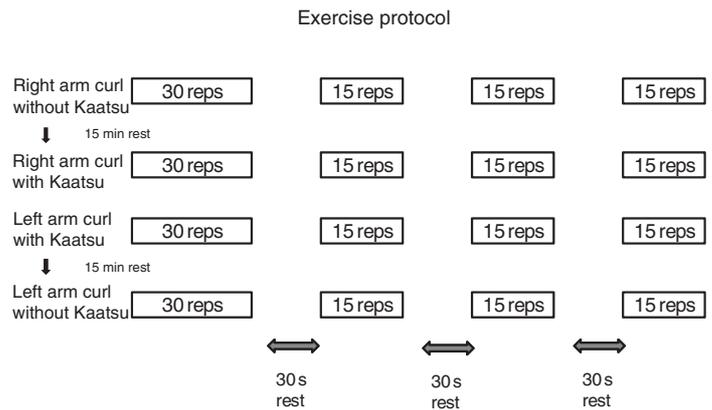


Figure 2. Near-infrared spectroscopy probe arrangement.

Analysis of NIRS data

Individual timeline data for the oxy-Hb signal of each channel were preprocessed with a band-pass filter using cut-off frequencies of 0.04 Hz to remove baseline drift and 0.7 Hz to filter out heartbeat pulsations. From the preprocessed time series data, we obtained channel-wise and subject-wise comparisons by calculating the inter-trial mean of the differences between the oxy-Hb signals of the peak (4-11 s after trial onset) and baseline (0-2 s before trial onset) periods. The results are expressed as means \pm standard deviations (SD). Student's paired t-test was used to compare changes in oxy-Hb during Kaatsu and those without Kaatsu. Statistical significance was set at $P < 0.05$.

RESULTS

Relative changes in oxy-Hb were measured during the procedure. During right-arm curls without BFR, oxy-Hb increased by 0.107 ± 0.028 mM \cdot mm in the left motor cortex area and by 0.035 ± 0.013 in the right. The oxy-Hb concentration of the left side significantly increased compared to that of the right side ($P < 0.05$) (Fig. 3). During right-arm curls, the oxy-Hb of the left motor cortex area was higher with BFR than without BFR (0.171 ± 0.074 mM \cdot mm), but the differences were not significant. Similarly, in the right motor cortex, the oxy-Hb concentration increased more with BFR than without BFR (0.154 ± 0.101 mM \cdot mm), but the differences were not significant (Fig. 4).

During left-arm curls without BFR, oxy-Hb increased by 0.107 ± 0.028 mM \cdot mm in the left side and 0.035 ± 0.013 mM \cdot mm in the right side. The oxy-Hb concentration of the left side was significantly increased compared with that of the right side ($P < 0.05$) (Fig. 5). During left-arm curls with BFR, oxy-Hb increased significantly ($P < 0.05$) in both sides (by 0.098 ± 0.062 mM \cdot mm in the left and 0.213 ± 0.071 mM \cdot mm in the right). The concentration of

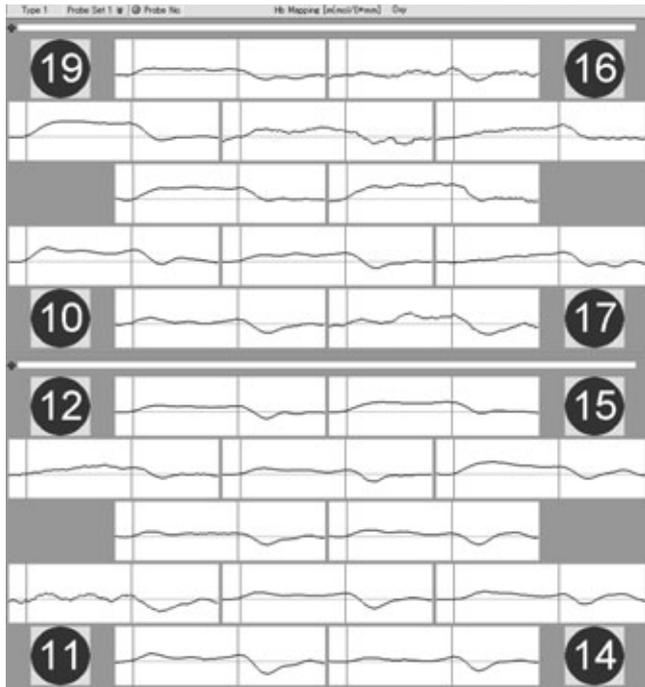


Figure 3. Relative change of oxygenated hemoglobin concentration during right arm curl without blood flow restriction.

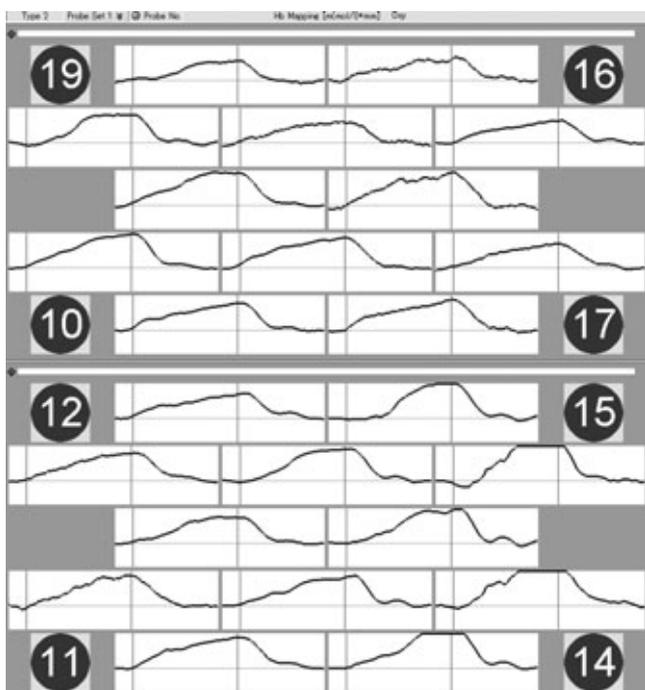


Figure 4. Relative change of oxygenated hemoglobin concentration during right arm curl with blood flow restriction.

oxy-Hb in the right side increased significantly compared with the left side ($P < 0.05$) (Fig. 5)

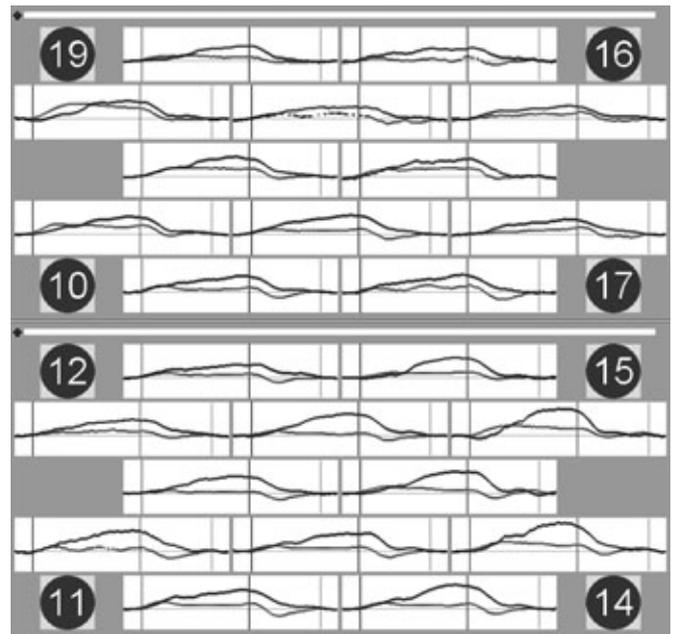


Figure 5. Comparison of relative change of oxygenated hemoglobin (oxy-Hb) concentration between left arm curl with and without blood flow restriction (BFR). Red line shows the relative change of oxy-Hb concentration during left arm curl with BFR and blue line shows the relative change without BFR.

DISCUSSION

The Japan Kaatsu training society has reported that Kaatsu improved the motor function of stroke patients. But whether or not Kaatsu is indeed effective for stroke patients remains unclear, because randomized control trials have not been performed. If Kaatsu training truly is effective for stroke patients, it would suggest that Kaatsu contributes to brain plasticity in these patients.

Many reports have noted that exercise improves brain activity by increasing the concentration of growth factors such as brain-derived neurotrophic factor (BDNF), insulin-like growth factor-1 (IGF-1), and vascular endothelial growth factor (VEGF). We reported previously that IGF-1 and VEGF increased after Kaatsu resistance training (Takano et al., 2005). Although there are no data regarding BDNF, it is expected to be increased by Kaatsu. A previous report showed that increases in BDNF depend upon exercise intensity (Ferris et al 2007). Although Kaatsu is a low-intensity resistance exercise, its effects on muscle hypertrophy and the secretion of growth hormone are comparable to the effects of very high-intensity exercise (Takarada et al., 2000a, b). These data lead to the hypothesis that Kaatsu has a strong influence on brain activation.

Many recently developed devices evaluate brain function and brain activity. For example, fMRI measures the hemodynamic response (change in blood flow) related to neural activity in the brain or

spinal cord. Since the early 1990s, fMRI has come to dominate the brain-mapping field because it is relatively non-invasive, does not expose patients to radiation, and is relatively widely available. The procedure has high spatial resolution; the resolution is typically 2-3 mm but can be as high as 1 mm. fMRI can record signals from all regions of the brain, unlike electroencephalography (EEG) and magnetoencephalography (MEG), which are biased towards the cortical surface (Gusnard et al., 2001). However, fMRI has some disadvantages. Blood oxygen level-dependent (BOLD) MRI imaging, first developed in 1990, is used to measure blood deoxy-Hb (Ogawa S. et al 1990). The BOLD signal is only an indirect measure of neural activity, and therefore is susceptible to the influence of non-neural changes in the body. As a result, positive and negative BOLD responses are difficult to interpret. Ferromagnetic objects cannot be taken into the scanning environment and the subjects must not move their head during the measurement. Therefore, cerebral blood flow during dynamic movement cannot be measured.

An optical topography system using NIRS has several unique advantages over current measurement methods. It is non-invasive and can be used under various conditions with minimal restriction on the examinee. Measurements can be obtained under more natural conditions, giving more freedom in task design. This system also enables simultaneous measurements with other testing modalities such as EEG, fMRI, and MEG. The system's design facilitates longitudinal studies and monitoring over extended time periods. Therefore, we used NIRS to evaluate brain function in this study. Although NIRS has superior time resolution and inferior spatial resolution compared to those of fMRI, the oxy-Hb concentration measurements during this study showed significant laterality, supporting the conclusions that changes in oxy-Hb concentration are a reflection of changes in cerebral blood flow and that the contralateral motor cortex is activated during exercise, especially with BFR. High-intensity exercise may activate the prefrontal cortex (Rupp T 2008). Similarly, Kaatsu may activate the prefrontal cortex and improve cognitive function. Further studies are required to prove the effectiveness of Kaatsu training.

In summary, Kaatsu training may have a positive effect on the brain by increasing cerebral blood flow and may be useful in the treatment of diseases such

as stroke and cognitive disorders caused by brain dysfunction.

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