# Chapter 27
# Effects of Physical Exercise on Working Memory and Prefrontal Cortex Function in Post-Stroke Patients

**M. Moriya, C. Aoki, and K. Sakatani**

**Abstract** Physical exercise enhances prefrontal cortex activity and improves working memory performance in healthy older adults, but it is not clear whether this remains the case in post-stroke patients. Therefore, the aim of this study was to examine the acute effect of physical exercise on prefrontal cortex activity in post-stroke patients using near-infrared spectroscopy (NIRS). We studied 11 post-stroke patients. The patients performed Sternberg-type working memory tasks before and after moderate intensity aerobic exercise (40 % of maximal oxygen uptake) with a cycling ergometer for 15 min. We measured the NIRS response at the prefrontal cortex during the working memory task. We evaluated behavioral performance (response time and accuracy) of the working memory task. It was found that physical exercise improved behavioral performance of the working memory task compared with the control condition ($p < 0.01$). In addition, NIRS analysis indicated that physical exercise enhanced prefrontal cortex activation, particularly in the right prefrontal cortex ($p < 0.05$), during the working memory task compared with the control condition. These findings suggest that the moderate-intensity aerobic exercise enhances prefrontal cortex activity and improves working memory performance in post-stroke patients.

**Keywords** Cognitive function • Exercise • Rehabilitation • NIRS • Prefrontal cortex

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# 1 Introduction

It has been reported that physical exercise ameliorates age-related cognitive decline [1, 2]. Acute effects of physical exercise on the performance of higher-order cognitive tasks have been demonstrated in aged people [2]. Recently, a study using near-infrared spectroscopy (NIRS) indicated that acute moderate exercise elicits increased activation of the prefrontal cortex (PFC) and improves cognitive performance in the Stroop test in normal young adults [3]. In addition, moderate exercise enhances PFC activity concomitantly with improved working memory performance in older subjects [2, 4]. However, the effect of physical exercise on PFC activity and working memory performance in patients with brain disorders, such as stroke, is not known.

In order to clarify this issue, we evaluated the acute effect of physical exercise on PFC activity in post-stroke patients using NIRS.

# 2 Methods

## *2.1 Subjects*

We studied 11 post-stroke patients (seven males, four females, aged 69.6 ± 12.0 years). Six patients had suffered cerebral hemorrhage while five had suffered cerebral infarction. Three patients exhibited right hemiparesis and eight patients exhibited left hemiparesis. None of the patients had apparent cognitive dysfunction or heart diseases such as arrhythmia and ischemic heart diseases. The ethical committee of Teikyo Heisei University approved this study (No. 25-053). All subjects provided written informed consent as required by the ethical committee.

## *2.2 Working Memory Task and Physical Exercise*

We employed the modified Sternberg test as a working memory task [4–6]. In the Sternberg test, subjects were asked to remember one digit and six digits successively. There were eight 1-digit trials and eight 6-digit trials. Each trial began with the presentation of one digit or a set of six digits to be encoded for 1 s on a display. Then a blank display was shown for 2 s, followed by the test digit until a response was obtained within 2 s. Subjects held a small box with two buttons side by side. They were required to press the right button if they thought the test digit was contained within the encoded stimulus and to press the left one if not, as quickly and accurately as possible. Similar tasks have been used previously in NIRS experiments and have been demonstrated to activate the PFC [4–6].

The patients performed Sternberg-type working memory tasks before and after moderate intensity aerobic exercise (40 % of maximal oxygen uptake) with an ergometer for 15 min. The subjects performed the Sternberg test 15 min after the end of exercise.

### *2.3 NIRS Measurements of PFC Activity*

We measured concentration changes of oxyhemoglobin (oxy-Hb), deoxyhemoglobin (deoxy-Hb) and total Hb (t-Hb) in the bilateral PFC during the working memory task using a two-channel NIRS (PNIRS-10, Hamamatsu Photonics K.K., Hamamatsu, Japan). The NIRS probes were set symmetrically on the forehead; the positioning is similar to the midpoint between electrode positions Fp1/Fp3 (left) and Fp2/Fp4 (right) of the international 10–20 system [7]. The sensor part (weighing approximately 100 g, which imposes only a minimal burden on the subject) communicated with a PC via Bluetooth™ (class 2).

### *2.4 Data Analysis*

We analyzed the changes in NIRS parameters (oxy-Hb and deoxy-Hb) by subtracting the mean control values from the mean activation values (during the whole task period). We evaluated behavioral performance (response time and accuracy) of the working memory task. The oxy-Hb concentration changes and behavioral performance before and after the exercise were compared using Student's *t*-test.

## 3 Results

Performance of the Sternberg test increased NIRS-evaluated concentrations of oxy-Hb and total-Hb, concomitantly with a decrease of deoxy-Hb, in the bilateral PFC (Fig. 27.1). These NIRS parameter changes indicate activation of the bilateral PFC in the post-stroke patients. Similar NIRS parameter changes were observed after physical exercise.

The effects of physical exercise on behavioral performance of the Sternberg test are summarized in Table 27.1. Interestingly, both accuracy and reaction time in the Sternberg test were improved after physical exercise ($p < 0.01$). In addition, NIRS analysis revealed that physical exercise enhanced PFC activation, particularly the right PFC ($p < 0.05$), during the working memory task compared with before the physical exercise.

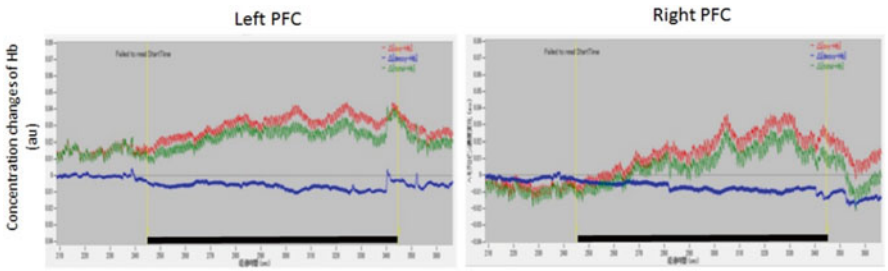


**Fig. 27.1** Typical example of Hb changes in the right/left PFC in a post-stroke patient. The red, green and blue lines indicate oxy-Hb, total-Hb and deoxy-Hb respectively. The vertical axis indicates Hb concentration expressed in an arbitrary unit (au). Thick bars indicate the period of performance of the Sternberg test

**Table 27.1** Effects of physical exercise on behavioral performance of Sternberg test and changes of oxy-Hb during the test

| | | Before | After |
|---|---|---|---|
| Sternberg test | Accuracy (number) | 3.18 ± 2.0 | 4.54 ± 1.6** |
| | Reaction time (ms) | 2051 ± 356 | 1833 ± 293** |
| Changes of oxy-Hb | R-PFC (au) | 0.018 ± 0.02 | 0.026 ± 0.02* |
| | L-PFC (au) | 0.017 ± 0.02 | 0.022 ± 0.02 |

**$p < 0.01$, *$p < 0.05$

## 4 Discussion

This is the first study to evaluate the effect of physical exercise on cognitive function in post-stroke patients. Our results show that moderate-intensity aerobic exercise improved performance of the working memory task compared with the control condition. The post-stroke patients could respond more quickly after exercise, and also answered correctly more often after exercise.

In addition, NIRS showed that physical exercise increased the concentration changes of oxy-Hb in the PFC during the working memory task compared with the control condition, indicating that the improved performance of the working memory task was not caused by habituation. We believe that moderate-intensity exercise enhanced the PFC activity concomitantly with the improvement of working memory performance. These findings indicate that physical exercise has beneficial effects on cognitive function in not only normal adults [2–4], but also in post-stroke patients.

It should be noted that oxy-Hb concentrations increased in the bilateral PFC, but statistical significance was achieved only in the right PFC. This asymmetry of PFC activity could not be explained by the laterality of the lesion in the post-stroke patients, since three out of eleven patients had right-side lesion. A possible explanation is that hemispheric asymmetry of PFC activity is associated with working

memory function [8–10]. For example, young subjects showed activation of the right-lateralized PFC in a logical reasoning task, though no hemispheric asymmetry was observed in older subjects during the same task [10]. Interestingly, administration of *Ginkgo biloba* (EGb), which is well known to improve cognitive functions in healthy subjects and patients with dementia, to older subjects improves working memory function by counteracting the aging-related hemispheric asymmetry reduction [5]. These observations are consistent with the present findings that right-dominant PFC activity is associated with enhanced working memory performance after physical exercise.

Physical therapy has been shown to improve motor function of post-stroke patients. Neuroimaging studies, including NIRS, demonstrated that physical therapy could enhance neuronal activation during motor tasks associated with improvement of motor function in post-stroke patients [11].

In conclusion, our results indicate that introduction of moderate-intensity aerobic exercise into physical therapy improves not only motor ability, but also cognitive performance in post-stroke patients by enhancing PFC activity during cognitive function.

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