Chapter 41
Acute Effects of Physical Exercise on Prefrontal Cortex Activity in Older Adults: A Functional Near-Infrared Spectroscopy Study

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Abstract We examined the acute effect of physical exercise on prefrontal cortex activity in older adults using functional near-infrared spectroscopy (NIRS). Fourteen older adults visited our laboratory twice: once for exercise and once for the control condition. On each visit, subjects performed working memory tasks before and after moderate intensity exercise with a cycling ergo-meter. We measured the NIRS response at the prefrontal cortex during the working memory task. We found that physical exercise improved behavioral performance of the working memory task compared with the control condition. Moreover, NIRS analysis showed that physical exercise enhanced the prefrontal cortex activity, especially in the left hemisphere, during the working memory task. These findings suggest that the moderate intensity exercise enhanced the prefrontal cortex activity associated with working memory performance in older adults.

Keywords NIRS (near-infrared spectroscopy) • Physical exercise • Older adults • Working memory • Prefrontal cortex

1 Introduction

It is often claimed that physical exercise may ameliorate or protect against age-related cognitive decline [1, 2]. For example, a neuroimaging study on chronic exercise effect indicated that aerobic exercise training for 6 months increased the volume of grey and white matter in the prefrontal cortex [3]. Similarly, acute effects of exercise on the performance of a higher-order cognitive task (flanker task) have also

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been demonstrated in older subjects [2]. It is, however, still unclear whether the acute exercise could enhance the prefrontal cortex activity during higher-order cognitive tasks in older adults.

The aim of this study was to examine the acute effect of physical exercise on prefrontal cortex activity in older adults using functional near-infrared spectroscopy (NIRS), an emergent imaging technique for investigating cortical hemodynamic response. Since oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb) have different absorption spectra in the infrared range, changes in oxy-Hb and deoxy-Hb can be calculated by detecting infrared light at different wavelengths on the skull. In general, enhanced oxy-Hb and reduced deoxy-Hb are associated with regional cortical activation. NIRS is noninvasive, is robust against body movement, and has been validated as a suitable technique for investigating neural mechanisms in psychological experiments.

Recently, an NIRS study found that moderate exercise enhanced prefrontal cortex activity associated with improved performance of higher-order cognitive tasks in young adults [4]. However, it is still unknown about the exercise effect on the prefrontal cortex activity in older adults. In the present study, 14 older adults visited our laboratory twice: once for the exercise condition and once for the control condition. On each visit, subjects performed working memory tasks before and after moderate intensity aerobic exercise with a cycling ergo-meter. We measured the NIRS response at the prefrontal cortex during the working memory task, whose procedure is known to activate the prefrontal cortex [5–7]. We compared NIRS responses between the exercise and control conditions.

2 Methods

2.1 Procedures

Fourteen subjects participated in this study (mean age = 65.9 ± 1.0 years, 9 female and 7 male) without history of cerebrovascular disease. The study was conducted in accordance with the principles of the Declaration of Helsinki, and all protocols were approved by the Ethics Committee of Nihon University School of Medicine. Written informed consent was obtained from all subjects prior to enrolment in the study.

The experiment was run individually, consisting of cardiopulmonary exercise (CPX) session and NIRS-recording session. The CPX session was conducted to determine the individual's exercise intensity for the subsequent NIRS recording session. Exercise was performed with a cycling ergo-meter (Strength Ergo 240, Mitsubishi electric engineering, Tokyo, Japan). Because our subjects were elderly persons, we indirectly estimated the maximum oxygen uptake (VO2max) from a reference value of Japanese subjects [8].

In the NIRS recording session, subjects visited our laboratory twice: once for the exercise and once for the control condition. In the exercise condition, subjects performed moderate intensity exercise (about 40% of VO2max) with the cycling ergo-meter for 10 min. Immediately before (pretest) or 10 min after (posttest) the exercise session, we measured NIRS response at the prefrontal cortex while subjects performed the working memory task for about 5 min. In the control condition, subjects took a rest during the exercise session.

In the working memory task, two test blocks were sandwiched between three baseline blocks. Subjects were required to remember four digits on the test blocks and one on the baseline blocks. Each block was presented for about 50 s, involving 5 trials. Each trial began with a central fixation cross for 500 ms, followed by the presentation of a set of one or four digits to be learned for 3 s. The delay period was inserted for 5 s, which was followed by the probe digit until response. Subjects were required to indicate whether they thought the probe digit was contained within the learned stimulus set by pressing one of two mouse buttons as quickly and as accurately as possible.

2.2 NIRS Recordings

During the working memory task, relative changes in oxy- and deoxy-Hb concentration values were measured in the prefrontal region using a two-channel portable-type NIRS system (PNIRS-10, Hamamatsu Photonics K.K., Hamamatsu, Japan). This device uses near-infrared light at three wavelengths, ranging around 735 ± 15, 810 ± 18, and 850 ± 20 nm. The oxy-Hb and deoxy-Hb values were estimated from the detected changes of the near-infrared light using the modified Beer-Lambert Law [9]. Because the individual optical path length is unknown, the hemoglobin concentration value is not an absolute but a relative value; this value is expressed as a change from baseline concentration (a.u., arbitrary units). The sampling frequency was 10.2 Hz (97.8 ms/data).

The flexible NIRS probe (P-Probe-1M, Hamamatsu Photonics K.K., Hamamatsu, Japan) consisted of a LED emitter and a detector, separated by a distance of 30 mm. The emitters were always placed more medially relative to the detectors on the subject's forehead. The emitters were placed at the Fp1 position for left hemisphere (LH) measurements and at the Fp2 position for the right hemisphere measurements (international 10–20 system).

3 Results

3.1 Behavioral Performance

The reaction time (RT) during the working memory task is summarized in Fig. 41.1. The significant acute exercise effect was found in the test block, which is a more demanding task than the base block. After the exercise, subjects responded significantly faster compared with control condition ($p < 0.05$) in posttest. On the

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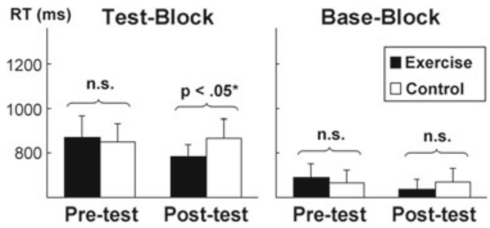

Fig. 41.1 Mean reaction times (RTs) for the test block and base block in the working memory task. The pretest was performed immediately before the exercise (or control) session while the posttest was performed 10 min after the exercise session

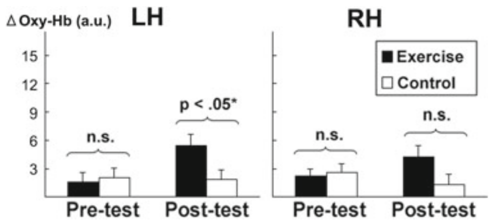

Fig. 41.2 Mean Δoxy-Hb concentration during the working memory task at the left-hemisphere (LH) and right-hemisphere (RH) prefrontal cortex. The pretest was performed immediately before the exercise (or control) session while the posttest was performed 10 min after the exercise session

other hand, there was no significant difference between the exercise and control condition in pretest ($p=0.35$). In the base block, the exercise effect was not significant both in pretest ($p=0.16$) and posttest ($p=0.16$).

The STAI score was also statistically tested. We found that subjects felt more relaxed after exercise (posttest; STAI = 31.07) compared with before exercise (pretest; STAI = 36.57) in the exercise condition ($p<0.05$). On the other hand, there was no significant difference between pretest (STAI = 35.21) and posttest (STAI = 33.14) in the control condition ($p=0.25$). These findings suggest that acute exercise made the older subjects more relaxed and improved their performance in the working memory task.

3.2 NIRS Response

For the evaluation of the prefrontal cortex activation, we analyzed the Δoxy-Hb during the time window from 0 s (trigger-point: start time of the test block) to 50 s. Baseline epochs were set for a pre-trigger of 10 s in the baseline block. A summary of mean Δoxy-Hb values for each condition is shown in Fig. 41.2. The posttest analysis showed that exercise significantly more activated the left prefrontal cortex compared with the control condition ($p<0.05$), whereas there was no significant difference between the exercise and control condition for the right prefrontal cortex activation ($p=0.11$). The pretest analysis showed that there was no significant difference between the exercise and control condition both for the right hemisphere ($p=0.40$) and the left hemisphere prefrontal activation ($p=0.41$).

4 Discussion

The present study examined the acute effect of physical exercise on prefrontal cortex activity in older adults using NIRS. Older subjects visited our laboratory twice: once for the exercise condition and once for the control condition. On each visit, subjects performed working memory tasks before and after exercise (or control) sessions. We measured the Δoxy-Hb change at the prefrontal cortex during the working memory task. Behavioral analysis found that physical exercise improved behavioral performance of the working memory task compared with the control condition. Older subjects can respond more quickly after the exercise. This is consistent with several behavioral studies which reported that physical exercise may ameliorate or protect against age-related cognitive decline [1, 2]. STAI analysis also showed that subjects felt more relaxed after aerobic exercise.

NIRS analysis showed that physical exercise enhanced the prefrontal cortex activation during the working memory task compared with the control condition. These findings suggest that the moderate intensity exercise enhanced the prefrontal cortex activity associated with working memory performance. This is in line with a previous NIRS study which demonstrated the acute exercise effect on the prefrontal cortex activity in young adults [4]. The present findings indicated the hemispheric asymmetry of the exercise effect in the prefrontal cortex activity. Acute physical exercise enhanced activity of the left hemisphere more than the right hemisphere. One possible reason may be that the present working memory task used verbal materials. Numerous studies suggested that the verbal working memory performance was more associated with the left prefrontal cortex activity [10]. In conclusion, the present study could successfully demonstrate, for the first time, the acute exercise effect on the prefrontal cortex activity in older subjects using NIRS.

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