Chapter 33
Effects of Occlusal Disharmony on Working Memory Performance and Prefrontal Cortex Activity Induced by Working Memory Tasks Measured by NIRS

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Abstract The effects of artificial occlusal disharmony (AOD) on working memory function and prefrontal cortex (PFC) activity in the elderly were examined. We evaluated working memory function using the modified Sternberg test (ST). We measured activity in the bilateral PFC during ST using near-infrared spectroscopy (NIRS) before and after AOD: the mandibular position was displaced by a splint for 10 min. AOD caused a gradual increase of oxyhemoglobin (oxy-Hb) in the bilateral PFC. The response time of ST (six digits) after AOD was longer than that before AOD. The oxy-Hb increase during ST after AOD was smaller than that before AOD. These results indicate that short-term physical stress caused by AOD decreased working memory function in elderly subjects, associated with a decrease of the evoked PFC activity during working memory function.

Keywords Dementia • NIRS • Occlusal disharmony • Prefrontal cortex • Working memory

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1 Introduction

Recent studies have shown that chewing can enhance cognitive performance. For example, gum chewing appeared to be of benefit to verbal working memory, immediate episodic long-term memory, language-based attention, and processing speed [1]. These findings suggested that acute occlusal disharmony might attenuate cognitive function, including working memory function. Indeed, reduced mastication caused by occlusal disharmony could be a risk factor for development of dementia in humans [2].

In the present study, we examined the effects of artificial occlusal disharmony (AOD) on working memory, which is a system for actively maintaining and manipulating information, and forms an integral part of the human memory system. We used NIRS to evaluate the effects of AOD on working memory performance and prefrontal cortex (PFC) activity during a working memory task in the elderly.

2 Methods

2.1 Procedures

We studied 18 normal elderly subjects (7 males, 11 females; mean age of 66.1 ± 4.8 years). All subjects were healthy, with no psychiatric or neurological disorders. Written informed consent was obtained from each subject on forms approved by the ethical committee of the Nihon University School of Medicine.

We employed the modified Sternberg test as a working memory task. In the Sternberg test, subjects were asked to remember one digit and six digits by turns. 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 CRT. Then a blank display was inserted 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 LPFC. In order to assess psychological stress levels, subjects were asked to fill in the State-Trait Anxiety Inventory (STAI) before and after AOD.

2.2 NIRS Measurements and Data Analysis

We measured cerebral blood oxygenation (CBO) in the bilateral PFC using a two-channel NIRS system (PNIRS-10, Hamamatsu Photonics K.K., Japan), which sends data wirelessly to a PC. The NIRS system uses LEDs of three different wavelengths (735, 810, and 850 nm) as light sources and one photo-diode as a detector; it has two

channels. Two AAA batteries allow up to 8 h of continuous measurement for the two-probe operation. The sampling rate was 61.3 Hz (i.e., the sampling time was about 16.3 ms). 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 electroencephalographic 10–20 system.

Three experimental conditions were established: a resting condition, AOD (a position in which experimental horizontal mandibular deviation was maintained by a splint), and control condition (a mandibular rest position maintained by a splint). We monitored the CBO changes continuously by NIRS during (1) resting conditions for 5 min, (2) the working memory task for 5 min, (3) the recovery phase for 1 min, (4) AOD or control condition for 10 min, (5) resting conditions for 5 min, (6) the working memory task for 5 min, and (7) the recovery phase for 5 min.

To analyze PFC activity, we calculated changes in oxy-Hb concentration. The mean control values (measured during the first 10 s) were subtracted from the mean activation values (measured throughout task performance). We compared oxy-Hb changes and STAI score in control condition (splint without displacement of the lower jaw) and AOD (splint with displacement of the lower jaw).

3 Results

STAI in the AOD condition (38.6 ± 1.9) tended to show a higher score than that in the control condition (37.9 ± 1.9, $p = 0.07$). NIRS showed a gradual increase of oxy-Hb in the bilateral PFC during AOD. Figure 33.1a shows a typical example of oxy-Hb changes in the bilateral PFC during AOD. AOD increased oxy-Hb in both the right and left PFC. However, the increase of oxy-Hb in the right PFC was statistically significant ($p < 0.05$), while the increase in the left PFC was not significant ($p = 0.18$) (Fig. 33.2b).

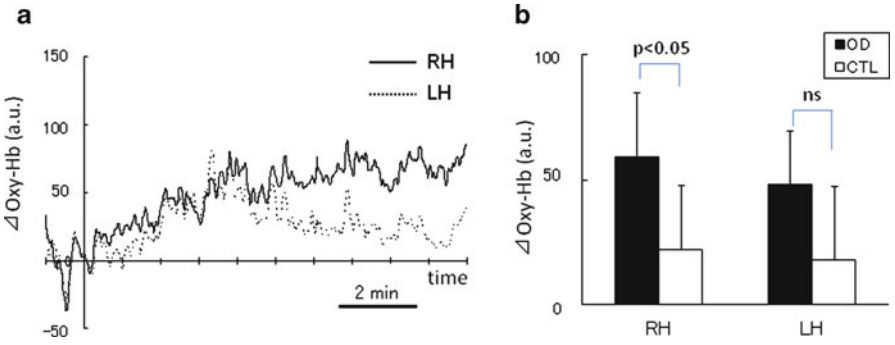

Fig. 33.1 Changes of oxy-Hb during AOD. (**a**) A typical example of oxy-Hb changes during AOD. (**b**) Differences in AOD-induced oxy-Hb changes between the right and left PFC. AOD increased oxy-Hb in both the right and left PFC. However, the increase of oxy-Hb in the right PFC was statistically significant ($p < 0.05$), while the increase in the left PFC was not significant ($p = 0.18$)

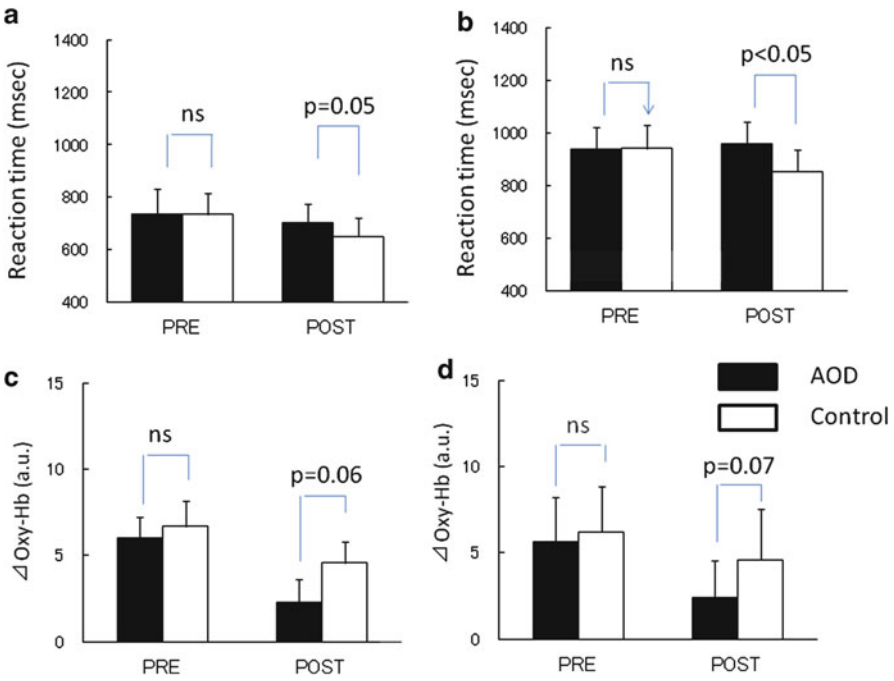

Fig. 33.2 Effects of AOD on working memory. (**a**) Effect of AOD on reaction time during the Sternberg test (one-digit). The reaction time after AOD tended to be slower than that before AOD ($p=0.07$). (**b**) Effect of AOD on reaction time during the Sternberg test (six-digit). The reaction time after AOD was significantly slower than that before AOD ($p<0.05$). (**c** and **d**) Effect of AOD on PFC activity during working memory performance in the left (**c**) and right (**d**) PFC. AOD tended to suppress the oxy-Hb increase during the Sternberg test in the left ($p=0.06$) and right ($p=0.07$) PFC

The response time of the Sternberg test (six digits) after AOD (960.9 ± 83.7 ms) was longer than that before AOD (941.0 ± 84.2 ms, $p<0.05$) (Fig. 33.2a). In contrast, there was no difference in response time of the Sternberg test (one digit) or the accuracy (one digit, six digits) before and after AOD (Fig. 33.2b).

NIRS revealed increases of oxy-Hb during the Sternberg test before and after AOD; however, the oxy-Hb increase during the Sternberg test after AOD (R-PFC 2.3 ± 1.4; L-PFC 2.4 ± 1.2) was smaller than that before AOD (R-PFC 6.0 ± 1.3; L-PFC 5.7 ± 1.1) (Fig. 33.2c, d).

4 Discussion

The subjects felt discomfort or pain during AOD, which could cause stress responses in the brain. Indeed, AOD increased oxy-Hb in the bilateral PFC, indicating that AOD induced neuronal activation of the PFC. The AOD-induced PFC activation

could cause activation of the hypothalamic–pituitary–adrenal (HPA) axis, since neuronal networks exist between the PFC and the neuroendocrine centers in the medial hypothalamus [3]. Interestingly, recent studies have demonstrated that the HPA axis is regulated by the PFC, particularly the right PFC. Electroencephalographic studies have shown that a greater right frontal activation is associated with increased heart rate during unpleasant emotional stimuli [4]. Animal experiments demonstrated that lesions to the right or bilateral PFC decrease prestress glucocorticoids (GC) levels and the stress-induced GC response in rats [5]. A recent fMRI study revealed that right dominance of PFC activity during mental stress tasks correlated with changes in salivary-GC levels and heart rate [6]. In addition, employing NIRS, we have demonstrated that right dominant PFC activity during mental tasks caused larger heart rate changes and activation of the HPA axis [7–10].

The present study revealed that AOD decreased working memory performance, associated with a decrease of the evoked PFC activity during working memory performance in elderly subjects. The decreases of working memory performance and evoked PFC activity might be caused by activation of the HPA axis, which increases levels of GC secretion. It has been reported that stress exposure or GC administration impairs working memory, which relies on the integrity of the PFC. Systemic injections of GC impair working memory performance in rats [11] and human subjects [12].

In summary, the present results indicate that short-term physical stress caused by AOD decreased working memory function in elderly subjects, associated with a decrease of the evoked PFC activity during working memory function. We suggest that reduced mastication could be a risk factor for cognitive dysfunction in the elderly, and emphasize the importance of oral care in elderly persons.

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References

1. Wilkinson L, Scholey A, Wesnes K (2002) Chewing gum selectively improves aspects of memory in healthy volunteers. Appetite 38:235–236
2. Stein PS, Desrosiers M, Donegan SJ et al (2007) Tooth loss, dementia and neuropathology in the Nun study. J Am Dent Assoc 138:1314–1322
3. Buijs RM, van Eden CG (2000) The integration of stress by the hypothalamus, amygdale and prefrontal cortex: balance between the autonomic nervous system and the neuroendocrine system. Prog Brain Res 126:117–132
4. Waldstein SR, Kop WJ, Schmidt LA et al (2000) Frontal electrocortical and cardiovascular reactivity during happiness and anger. Biol Psychol 55:3–23
5. Sullivan RM, Gratton A (1999) Lateralized effects of medial prefrontal cortex lesions on neuroendcrine and autonomic stress responses in rats. J Neurosci 19:2834–2840
6. Wang J, Rao H, Wetmore GS et al (2005) Perfusion functional MRI reveals cerebral blood flow pattern under psychological stress. Proc Natl Acad Sci U S A 102:17804–17809

7. Tanida M, Sakatani K, Takano R et al (2004) Relation between asymmetry of prefrontal cortex activities and the autonomic nervous system during a mental arithmetic task: Near infrared spectroscopy study. Neurosci Lett 369:69–74
8. Tanida M, Katsuyama M, Sakatani K (2007) Relation between mental stress-induced prefrontal cortex activity and skin conditions: a near infrared spectroscopy study. Brain Res 1184:210–216
9. Tanida M, Katsuyama M, Sakatani K (2008) Effects of fragrance administration on stress-induced prefrontal cortex activity and sebum secretion in the facial skin. Neurosci Lett 432:157–161
10. Sakatani K, Tanida M, Katsuyama M (2010) Effects of aging on activity of the prefrontal cortex and autonomic nervous system during mental stress task. Adv Exp Med Biol 662:473–478
11. Roozendaal B, McReynolds JR, McGaugh JL (2004) The basolateral amygdala interacts with the medial prefrontal cortex in regulating glucocorticoid effects on working memory impairment. J Neurosci 24:1385–1392
12. Wolf OT, Convit A, McHugh PF et al (2001) Cortisol differentially affects memory in young and elderly men. Behav Neurosci 115:1002–1011