Distribution of Cerebral Blood Flow during Gum-Chewing

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The physiological mechanism for the prevention of obesity by increasing the chewing frequency has recently been clarified, and its hygienic characteristics have been reported. Research into masticatory movement has not been initiated only due to its involvement in health promotion, but is also being increasingly investigated as a factor influencing the development and maintenance of brain function. Chewing training is not only useful for middle-aged and elderly obese individuals, but also employed as educational instruction at health centers and schools. In this study, in order to elucidate the influence of masticatory movement on the brain, we examined young males during gum-chewing. Electromyography of their masticatory muscles and near-infrared spectroscopy were simultaneously conducted to investigate the relationship between chewing and local cerebral blood flow. The influence of masticatory movement on the brain was confirmed by examining images of the brain obtained on magnetic resonance imaging. Through these findings, gum chewing was suggested to reduce stress.
Key words: Mastication, Cerebral Blood Flow, Electromyograms (EMGs), Near-Infrared Spectroscopy (NIRS), Magnetic Resonance Imaging (MRI)

1. Effect of Mastication on Human Brain Activity

In the stadium, we can often find that athletes chew gum during a game. Reportedly, effects of the mastication on arousal and high performance are expected in the athletes. In addition, the mastication does not only enhance digestion/insorption and health of human but also the cerebral blood flow (Kurokawa *et al*., 2008).

Masticatory movement is not only investigated with regard to its involvement in health promotion, but it is also attracting attention as a factor influencing the development and maintenance of brain function (Paulson *et al*., 1990; Fisher *et al*., 2008). The relationship between chewing and brain function is attracting increasing attention. Reportedly, chewing is not a mere voluntary movement to move the teeth and jaws, but it is established involving advanced integrative function in the brain.

Histamine is released as the chewing frequency increases and acts on the satiety center in the brain (Fujise *et al*., 1998). Histamine also inhibits fat synthesis from glucose (Masaki *et al*., 2001) and promotes visceral lipolysis (Masaki *et al*., 2003). A physiological obesity-preventive mechanism has recently being clarified, and its hygienic practice has been reported (Ookuma *et al*., 2000; Veyrune *et al*., 2008). Moreover, the histamine neuron activity inhibits food intake. It is also expected that accumulated body fat is reduced as the chewing frequency increases due to the decrease of food consumption.

With the recent development of noninvasive brain activity measurement techniques, such as functional magnetic resonance imaging (fMRI) and near-infrared spectroscopy (NIRS), and down-sizing of the devices, brain science has rapidly developed and various brain dynamics have being elucidated.

In this paper, to clarify the influence of masticatory movement on the brain, young males chewed gum, and electromyography of the masticatory muscles and NIRS were simultaneously performed to investigate the relationship between chewing and distribution of cerebral blood flow.

2. Electromyograms (EMG) of the Masticatory Muscles and Near-Infrared Spectrum (NIRSpec)

Surface electromyogram (sEMG) of the masticatory muscles is capable of noninvasively recording muscle activity when chewing food in humans (Plesh *et al*., 1986; Van der bilt *et al*., 1995, 2006). It is also attracting attention as a method of measuring the load and intensity of chewing because the frequency, duration, and intensity of chewing by the masticatory muscles can be numerically compared (Plesh *et al*., 1986; Lassauzay *et al*., 2000; Foster *et al*., 2006).

The action potential of the mouth-closing muscles on sEMG appears in each clenching motion, but no potential appears at rest or while opening the jaws. Thus, the chewing frequency and time can be calculated by analyzing the amplitude of the EMGs and duration of muscle activity on

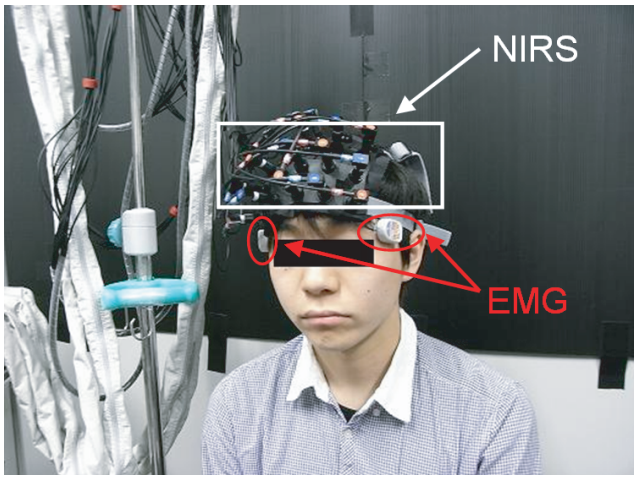

Fig. 1. The setup of the experiment.

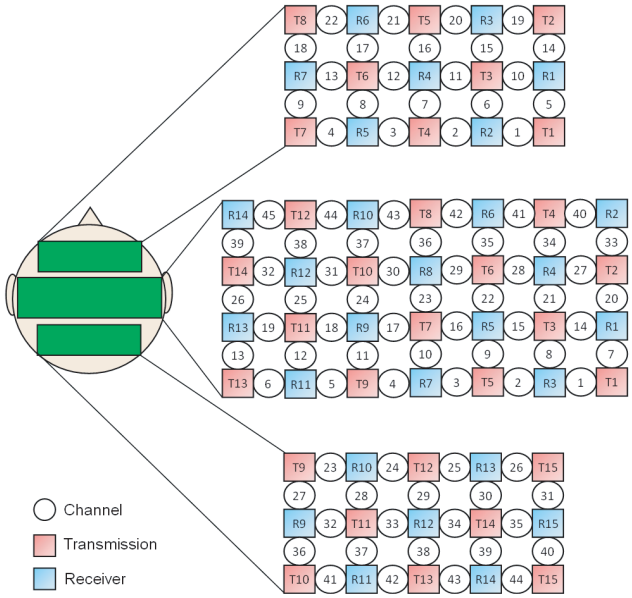

Fig. 2. Arrangements of channels between transmission and receiver probes.

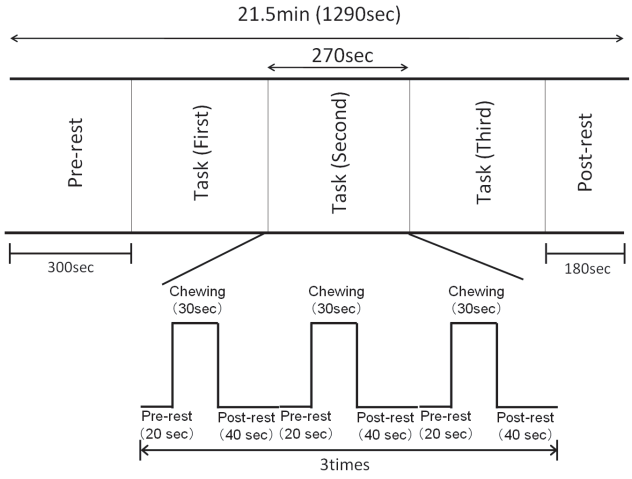

Fig. 3. Experimental protocol.

each chewing action.

NIRS is less restrictive for examinees compared to other brain function imaging methods, such as positron emission tomography (PET) and fMRI, and fixation of the head and recumbence on a special device during measurement are unnecessary (Villringer and Dirnagl, 1995; Villringer and Chance, 1997; Okamoto *et al.*, 2000). However, measured values of NIRS represent relative changes in the concentration, and are not absolute values, because the optical path length from irradiation through detection cannot be measured.

When a brain region is active, blood flow increases in the region. Thus, the activity of cerebral regions can be estimated by measuring changes in cerebral blood flow. In NIRSpec, blood flow is determined by measuring hemoglobin carrying oxygen consumed by cell activity.

In NIRS, the cerebral cortex activity is measured employing multichannel reflected light measurement on the scalp. In this method, light transmission and receiver probes are attached to the scalp. Markedly biological tissue-penetrable near infrared light at about 700–1,000 nm is irradiated from the light transmission probe, and scattered and reflected light on the cerebral cortex surface are detected through the light receiver probe.

There are 2 types of blood hemoglobin: oxygen-bound oxidized hemoglobin (Oxy-Hb) and oxygen-unbound deoxidized hemoglobin (Deoxy-Hb), and the absorbance wavelength characteristics are different. Utilizing these properties, blood flow is calculated from the attenuation level of detected light.

In NIRSpec, Oxy-Hb, Deoxy-Hb, and the total hemoglobin level (Total-Hb) combining these in the cerebral cortex are estimated from detected light (Villringer and Dirnagl, 1995; Villringer and Chance, 1997). Since changes in each Hb measured by NIRS are relative to the baseline at measurement initiation, and the optical path length of the near infrared laser light varies depending on the physical characteristics of the subjects, it is difficult to simply compare the measured value among the subjects and calculate the mean.

3. Simultaneous Measurement of Masticatory Muscle sEMG and NIRSpec

We performed the following experiment to provide an example of the influence of masticatory movement on the brain. Using sEMG and NIRSpec, chewing muscle activity and local cerebral blood flow were simultaneously measured, respectively. The influence of chewing on brain activity was evaluated.

The subject was a young healthy male aged 24 years with no stomatognathic function abnormality, such as a defective tooth, pain of the temporomandibular joint or muscles, or disturbance of mouth opening. A temporal muscle EMG and the cerebral blood flow while chewing were simultaneously recorded. After simultaneous measurement of the sEMG of masticatory muscles and the NIRSpec, images of sections in the subject's brain were taken by using magnetic resonance imaging (MRI), (Achieva 1.5T A-series; Royal Philips Electronics) so that we can confirm

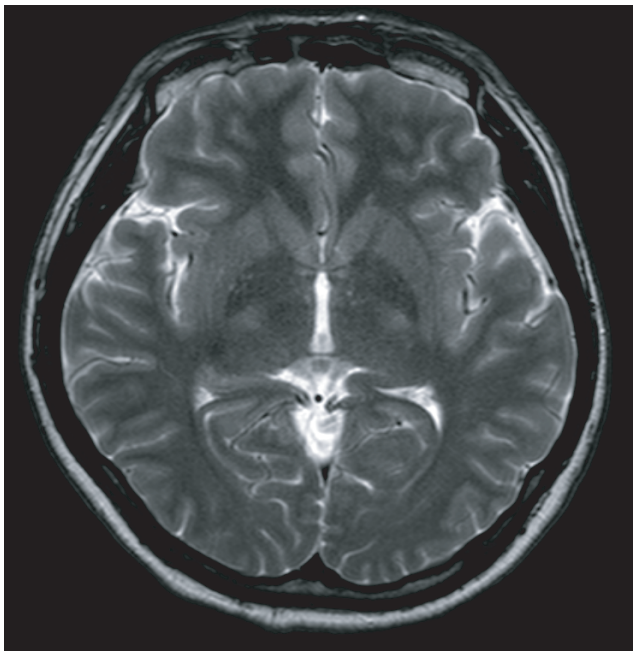

Fig. 4. A cross-section view of the brain by using MRI.

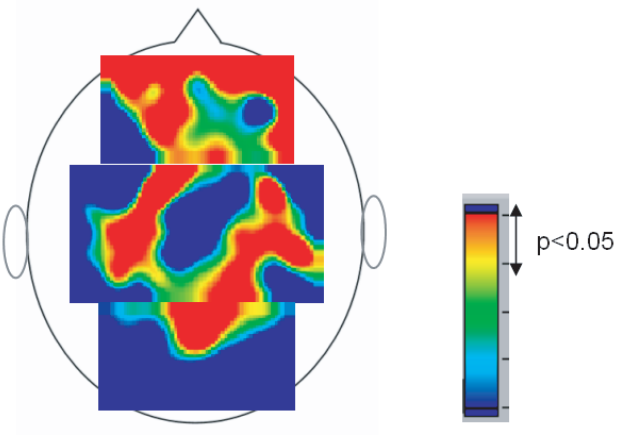

Fig. 5. The cerebral blood flow changes as shown in the brain mapping of the significant difference obtained by the post-hoc test.

the central sulcus (Appendix) and the field on which the cerebral blood flow increases. The experiment was fully explained to the subjects beforehand, and written consent was obtained. The experiment was approved by the Ethics Committee of Nagoya University Graduate School of Information Science.

The temporal muscle EMG was recorded using a multichannel telemeter system, WEB-7000 (Nihon Kohden), at a sampling frequency of 1 KHz. The measurement sites of the temporal muscle were set by assigning 1 ch each to the bilateral temples (2-ch measurement) (Fig. 1).

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Changes in the blood oxygenized hemoglobin level in the brain were measured using a near infrared light brain function imaging system, FOIRE-3000 (Shimadzu Corporation), at a sampling frequency of 7.7 Hz. A head holder was attached to the subject's head, and light transmission/receiver probes were attached as shown in Fig. 2. Cerebral blood flow on the frontal lobe, occipital lobe, and parietal lobe can be measured at 22-ch, 22-ch, and 45-ch, respectively (Fig. 2).

The experiment was performed in a sitting position. After resting for 5 minutes, regarding a 20-second pre-rest, 30-second chewing, and 40-second post-rest as one set, the subject held 2 pieces of xylitol gum in their mouth in the pre-rest of the first set and repeated 3 sets, and removed the gum in the post-rest of the 3rd set. This 3-set test was repeated 3 times, and the subjects finally rested for 3 minutes (Fig. 3). The brain activity was measured using NIRS while confirming the chewing motion in the EMG.

Paying attention to changes in Oxy-Hb, we compared changes in Oxy-Hb between those at rest and during the task at each channel employing two-way analysis of variance (ANOVA). States (rest and task) and channels are set as factors in this statistical analysis. When Oxy-Hb significantly changed during the task ($p < 0.05$), it was regarded as a significant change during the task at the channel. In accordance with the Bonferroni's method, the post-hoc test was held at each channel.

On 2 way ANOVA of the hemoglobin levels at rest and during the task, a main effect was noted in each factor ($p < 0.05$). Therefore, the cerebral blood flow did not uniformly change but locally increased or decreased. Difference between Oxy-Hb averaged during the rest and the task is calculated at each channel and is interpolated by the spline method. Fig. 4 shows a cross-section view of the brain by using MRI to confirm the field on which the cerebral blood flow changes. As shown in the brain mapping (Fig. 5), the significant difference between the rest and the task was obtained by the post-hoc test ($p < 0.05$). As a result, the cerebral blood flow on the frontal lobe increased during the gum chewing. In addition, the cerebral blood flow on the primary motor cortex and parietal association area of the parietal lobe increased during the gum chewing. The symptoms of mental illness often involve weakened regulation of thought, emotion, and behavior by the prefrontal cortex (PFC) (Appendix). Therefore, it was also suggested that chewing is effective for reducing stress and enhancing high performance in the athletes.

To clarify the influence of masticatory movement on the brain, young males chewed gum and electromyography of the masticatory muscles and NIRS were simultaneously performed to investigate the relationship between chewing and local cerebral blood flow.

Cerebral blood flow increased with the gum chewing but decreased after chewing and returned to the level before chewing. The increased cerebral blood flow indicated that the gum chewing activated the whole prefrontal area. It was suggested that chewing activates the brain, which may be effective for improving memory and reducing stress.

Effects of the difference in chewing rhythm on the brain activity will be examined in the next step.

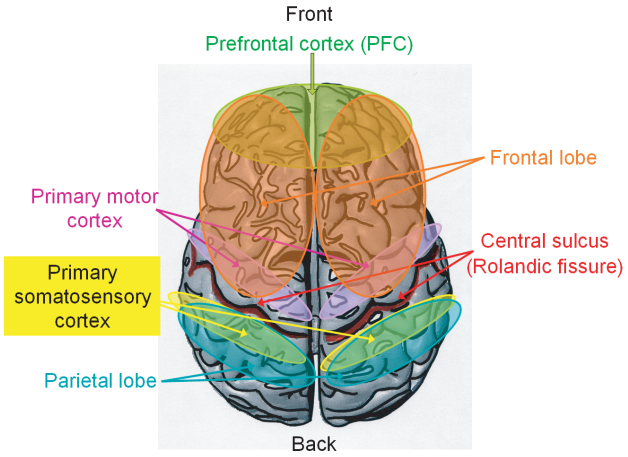

Fig. A.1. Anatomy of brain.

Appendix A.

The central sulcus (Rolandic fissure) is a prominent landmark of the brain, separating the parietal lobe from the frontal lobe and the primary motor cortex from the primary somatosensory cortex (Fig. A.1).

The PFC is the anterior part of the frontal lobes of the brain, lying in front of the motor and premotor areas (Fig. A.1). The PFC has been implicated in planning complex cognitive behaviors, personality expression, decision making and moderating correct social behavior (Yang and Raine, 2009). The basic activity of this brain region is considered to be orchestration of thoughts and actions in accordance with internal goals (Miller *et al.*, 2002). In addition, exposure to stress exacerbates symptoms of mental illness and causes marked PFC dysfunction.

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