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The effect of mastication on human cognitive processing: A study using event-related potentials

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ABSTRACT

Objective: The purpose of the present study was to clarify the effect of mastication on cognitive processing using reaction time (RT) and event-related potentials (ERPs).
Methods: The two experiments consisted of two conditions, Mastication (chewing gum) and Control (relaxing without chewing gum) in Experiment 1, and Jaw Movement (opening and closing the jaw) and Finger Tapping (tapping the right index finger) in Experiment 2. The subjects performed four sessions of an auditory oddball paradigm. RT and ERPs were recorded in these four sessions, Pre (before chewing), and Post 1, Post 2 and Post 3 (after chewing).
Results: In Mastication for RT and the peak latencies of P300 and N100, the values were significantly longer in Pre than in Post 2 or Post 3. By contrast, in Control, Jaw Movement, and Finger Tapping, they were almost identical among sessions or significantly shorter in Pre than in Post 2 or Post 3.
Conclusions: Mastication influences cognitive processing time as reflected by RT and the latency of ERP waveforms.
Significance: This is the first study investigating the effect of mastication on the central nervous system using event-related potentials.

1. Introduction

Mastication consists of the activities of the lower jaw and masticatory muscles concerned with rhythmic and voluntary movement. The motor command for this sequential rhythmic movement is generated by a neural population in the central pattern generator (CPG) of the brainstem (Nakamura and Katakura, 1995; Nakamura et al., 2004). Recent neuroimaging studies using functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) in humans have reported that several regions of the brain are activated during mastication, including the primary somatosensory cortex (SI), primary motor cortex (MI), supplementary motor area (SMA), premotor area (PM), prefrontal cortex (PFC), insula, posterior parietal cortex (PPC), thalamus, striatum, and cerebellum (Momose et al., 1997; Onozuka et al., 2002, 2003; Tamura et al., 2003; Takada and Miyamoto, 2004; Takahashi et al., 2007). Thus, these studies suggest that mastication is a complicated movement generated from a neural population in the brainstem and a neural network including several brain regions.

Some studies have reported an effect of mastication on psychological tests relating to arousal (Endo et al., 1982; Nageishi et al., 1993; Otomaru et al., 2003), energy expenditure and heart rate (Suzuki et al., 1992, 1994), choice reaction time (Chu, 1994), and working memory (Wilkinson et al., 2002; Baker et al., 2004; Stephens and Tunney, 2004; Hirano et al., 2008). Several neurophysiological studies have also tried to clarify the effect by recording background electroencephalography (EEG) activity (Endo et al., 1982; Masumoto et al., 1999; Morinushi et al., 2000); however, there is contradictory evidence showing no significant change in memory (Tucha et al., 2004; Johnson and Miles, 2007), and background EEG (Suzuki et al., 1989; Masumoto et al., 1998) after gum-chewing. Therefore, the effect of mastication has been a matter of debate, and it is not well known why mastication modulates cognitive performances and background EEG, even though a significant effect has been found. Consequently, objective methods and indexes are needed to investigate the effect in detail, instead of psychological and working memory tests.

Based on the research background, the present study used event-related potentials (ERPs) obtained by time-locked averaging EEG to evaluate the effect of mastication on the central nervous

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system (CNS). In human ERP studies, P300 or P3b is one of the most widely studied components with a parietal distribution on the scalp, and has been linked to the cognitive processes of context updating, context closure, and event-categorization (Donchin and Coles, 1988;Kok, 2001; Bledowski et al., 2004). P300 occurs 300–600 ms after a target stimulus in oddball paradigms, wherein two stimuli are presented in a random series with one of the two, that to which the subject is instructed to respond, occurring relatively infrequently (Jeon and Polich, 2001). The amplitude of P300 is proportional to the amount of attentional resources devoted to a given task (Wickens et al., 1983; Kramer and Strayer, 1988; Schubert et al., 1998), whereas the latency is considered a measure of stimulus classification speed or stimulus evaluation time (Kutas et al., 1977) and is generally unrelated to response selection processes (McCarthy and Donchin, 1981; Pfefferbaum et al., 1983). To our knowledge, no study has examined the effects of mastication on P300. Therefore, we aimed to evaluate whether the peak latency and/or amplitude of this component are influenced by mastication.

In addition to P300, we focused on an earlier negative component, N100 or N1, which has been recorded just prior to P300 during auditory oddball paradigms. N100 has a frontocentral distribution on the scalp, and is detected approximately 100 ms after auditory stimulus onset, indicating neural activities relating to auditory processing. Thus, we also focused on the peak latency and amplitude of N100 as an index of auditory processing.

Here we show a significant effect of mastication on ERPs waveforms.

2. Methods

2.1. Subjects

Eleven normal right-handed subjects (eight males and three females; mean age 30.9 years, range 24–42) participated in Experiment 1, and nine normal right-handed subjects (eight males and one female; mean age 30.6 years, range 25–43) participated in Experiment 2. None of the subjects had a history of neurological or psychiatric disorder. Seven subjects joined both experiments. Informed consent was obtained from all subjects, but they were not told the aim of these experiments to avoid the effect of information and the intended bias on all data. The study was approved by the Ethics Committee of the National Institute for Physiological Sciences, Okazaki, Japan.

2.2. Experiment 1

The experiment consisted of two conditions, Mastication and Control, each performed on a different day. Half of the subjects began with the Mastication condition and half with the Control condition. The Mastication condition comprised four sessions of recordings at different times: Pre, Post 1, Post 2, and Post 3. In each session, the subjects performed an auditory oddball paradigm for approximately five minutes. After one session, the subjects were asked to chew gum for five minutes at a relaxed self-pace. In total, there were three gum-chewing intervals. The Control condition included the same four sessions (Pre, Post 1, Post 2, and Post 3), but the subjects were instructed to relax without chewing gum in each interval (see Fig. 1). The present study used Post 2 and Post 3 as well as Post 1 for two reasons. First, indeed, previous studies investigating background EEG compared a control Pre recording with only a Post recording after 3-min gum-chewing (Masumoto et al., 1998, 1999; Morinushi et al., 2000), but we wondered whether the effect of mastication was found in Post 1 after only 5-min mastication. Second, if there was a real effect, we wanted to investigate how the effect changed with repetitive sessions. For Mastication, a special gum

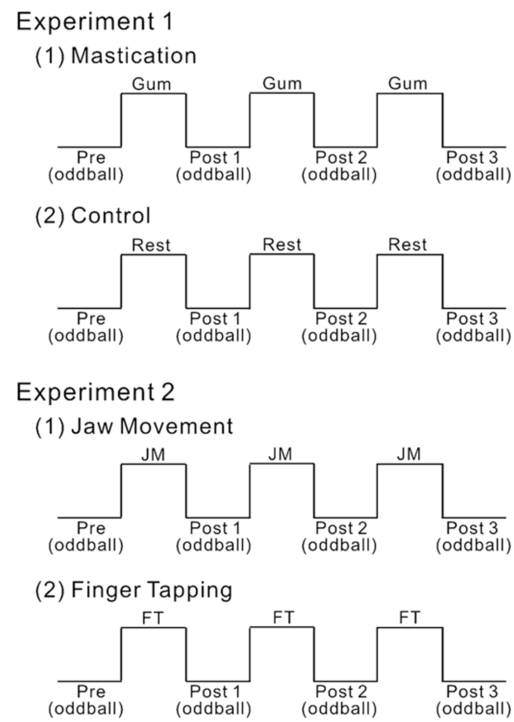

Fig. 1. Protocol for the Mastication and Control conditions in Experiment 1, and the Jaw Movement and Finger Tapping conditions in Experiment 2. In each condition, the subjects performed four oddball sessions. In Mastication, the subjects were asked to chew a gum base that was odorless and tasteless during the intervals between sessions for five minutes. In Control, the subjects were instructed to relax without gum-chewing during the intervals. In Jaw Movement, the subjects were asked to open and close their jaw during the intervals between sessions for five minutes. In Finger Tapping, the subjects were instructed to tap their right index finger during the intervals.

base that was odorless and tasteless was prepared (CAT21 Chewing Pellet, NAMITEC Co., Ltd., Osaka, Japan). This gum was made of polyvinyl acetate, wax, and polyisobutylene, based on the Japan food hygiene law. The auditory stimulation was an auditory pure tone (55 dB sound pressure level, 500 ms duration, 10 ms rise time, 10 ms fall time), presented binaurally through headphones. The probability of the stimulus for target tones (2000 Hz) and standard tones (1000 Hz) was 20% and 80%, respectively, in a random series. The interstimulus interval was 2 s. The subjects had to respond by pushing a button with their right thumb as quickly as possible only after the presentation of a target stimulus. During the recordings, the subjects were instructed to keep their eyes open and look at a small fixation point positioned in front of them at a distance of approximately 1 m. One session comprised 150 epochs of stimulation, which included 30 epochs for the target stimuli and 120 epochs for the standard stimuli. The practice session consisted of 10 stimuli before the recordings.

2.3. Experiment 2

The experiment consisted of two conditions, Jaw Movement and Finger Tapping, each performed on a different day from Experiment 1. Half of the subjects began with Jaw Movement and half with Finger Tapping condition. The procedure of this experiment was the same as Experiment 1. In Jaw Movement, the subjects were asked to open and close their jaw at their own pace during each interval (Fig. 1), and were asked not to bite to avoid the effect of tactile afferent information. In Finger Tapping, the subjects were instructed to tap their right index finger at their own relaxed pace during each interval (Fig. 1). Tasks involving repetitive muscle activity or move-