Brain and Cognition 81 (2013) 376–381

Contents lists available at SciVerse ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Effects of chewing on cognitive processing speed

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A R T I C L E   I N F O

Article history:
Available online 29 January 2013

Keywords:
Chewing
Attention
Attentional networks
Alerting
Executive function
Functional MRI

A B S T R A C T

In recent years, chewing has been discussed as producing effects of maintaining and sustaining cognitive performance. We have reported that chewing may improve or recover the process of working memory; however, the mechanisms underlying these phenomena are still to be elucidated. We investigated the effect of chewing on aspects of attention and cognitive processing speed, testing the hypothesis that this effect induces higher cognitive performance. Seventeen healthy adults (20–34 years old) were studied during attention task with blood oxygenation level-dependent functional (fMRI) at 3.0 T MRI. The attentional network test (ANT) within a single task fMRI containing two cue conditions (no cue and center cue) and two target conditions (congruent and incongruent) was conducted to examine the efficiency of alerting and executive control. Participants were instructed to press a button with the right or left thumb according to the direction of a centrally presented arrow. Each participant underwent two back-to-back ANT sessions with or without chewing gum, odorless and tasteless to remove any effect other than chewing. Behavioral results showed that mean reaction time was significantly decreased during chewing condition, regardless of speed-accuracy trade-off, although there were no significant changes in behavioral effects (both alerting and conflict effects). On the other hand, fMRI analysis revealed higher activations in the anterior cingulate cortex and left frontal gyrus for the executive network and motor-related regions for both attentional networks during chewing condition. These results suggested that chewing induced an increase in the arousal level and alertness in addition to an effect on motor control and, as a consequence, these effects could lead to improvements in cognitive performance.

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1. Introduction

Recently, behavioral studies were performed to examine the relationship between chewing and cognitive performance including memory, attention and executive function. With regard to memory, it has been reported that gum chewing improves episodic and working memory during chewing, suggesting at least in part that chewing promotes regional cerebral blood flow and glucose delivery (Stephens & Tunney, 2004; Wilkinson, Scholey, & Wesnes, 2002; Zoladz & Raudenbush, 2005). However, the existence of enhanced performance of episodic memory task by context-dependent effects induced by chewing has remained controversial (Baker, Bezance, Zellaby, & Aggleton, 2004; Johnson & Miles, 2007, 2008; Stephens & Tunney, 2004). As for attention, it was reported that sustained attention (Smith, 2009a, 2010; Tucha, Mecklinger, Maier, Hammerl, & Lange, 2004) and language-based attention (Stephens & Tunney, 2004) were improved by chewing. On the other hand, Tucha et al. (2004) claimed not only that memory functions were not improved but also that tonic and phasic alertness were adversely affected by chewing. With respect to executive function, a study claimed that chewing gum does not appear to be of benefit to word association executive function (Stephens & Tunney, 2004), but another study reported a beneficial effect (Onyper, Carr, Farrar, & Floyd, 2011).

To elucidate these inconsistent results and their mechanisms, several functional neuroimaging studies have been conducted. These studies suggested that chewing facilitated the process of working memory and also that it was related to attention

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0278-2626/$ - see front matter Published by Elsevier Inc.
http://dx.doi.org/10.1016/j.bandc.2012.12.002

(Hirano et al., 2008; Wang, Gitelman, & Parrish, 2009). As well, several studies mentioned that chewing affects arousal (Onyper et al., 2011; Sakamoto, Nakata, & Kakigi, 2009; Smith, 2010; Stephens & Tunney, 2004). Sakamoto et al. (2009) studied the effect of chewing on the central nervous system by measuring reaction time (RT) and event-related potentials (ERPs). They suggested that chewing influences the state of arousal via the ascending reticular activating system, and that it accelerates cognitive processing.

Based on these studies, we assumed that chewing also affects aspects of attention and accelerates cognitive processing. Indeed, recent studies, pointing out that reaction times were shortened by chewing in the categoric search task (Allen & Smith, 2012a; Smith, 2010), vigilance task (Allen & Smith, 2012a), language-based attention task (Stephens & Tunney, 2004), and the encoding of new information in the focused attention task (Smith, 2010). Smith (2010) speculated that positive cognitive performance may come from the fact that subjects feel more alert as described, being energetic, quick-witted and attentive, all based on mood improvement. However, some studies reported not only that the performance of sustained attention was not accelerated (Kohler, Pavy, & Van den Heuvel, 2006; Smith, 2010; Tucha et al., 2010) but also that vigilance task was decelerated (Tucha et al., 2010). Tucha et al. (2010) indicated that the psychodynamics of gum chewing might be an important factor, and these conflicts of cognitive performance may originate from the duration of the study (Tucha et al., 2010) and time of the task (Allen & Smith, 2012a, 2012b; Tucha & Simpson, 2011). Indeed, Tänzer, Von Fintel, and Eikermann (2009) reported that chewing benefit in concentration performance showed up after 14 min from the initiation of the test. To elucidate the mechanism of this issue, we considered that a functional magnetic resonance imaging (fMRI) assessment might be helpful. The attentional network test (ANT) provided a way of testing for the efficiency of the alerting, orienting and executive (conflict resolution) functions of attention (Fan, McCandliss, Sommer, Raz, & Posner, 2002), and it was adapted within a single session of event-related fMRI (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005). In the current study, we examined the effects of chewing on alerting and executive attention and their processing speed by comparing the behavioral and fMRI results of ANT.

2. Experimental procedures

2.1. Subjects

Nineteen healthy volunteers (aged 20–34) were enrolled for assessment by random-effect analysis (Seghier, Lazeyras, Pegna, Annoni, & Khateb, 2008) in this study. Two participants were excluded from the analysis due to motion (>0.56 mm, corresponding to 15% of voxel size in-plane) during the fMRI scan. Therefore, data from 17 healthy volunteers (mean age ± SD, 25.2 ± 4.79 years; range, 20–34 years; 8 females) were evaluated in this study. Written informed consent was obtained from all subjects. The subjects briefly practiced ANT outside, and then inside the MRI scanner just before the fMRI scan. Experiments were performed according to the ethical guidelines approved by the Ethics Committee of the National Institute of Radiological Sciences.

2.2. Task paradigm

ANT was adjusted by adding the gum chewing session while keeping the total scan time comparable to the original ANT for the fMRI study of the previous report (Fan et al., 2005) to avoid a reduction in the level of attention. For that reason, we used two cue conditions (no cue and center cue) instead of the three cue conditions (no cue, center cue and special cue) used in their study. As in their study, however, we also used the two target conditions (congruent and incongruent). The cue durations and stimulus intervals were also reduced from 300–11800 ms (mean, 2800 ms) to 300–6800 ms (mean, 1800 ms) and from 3000–15000 ms (mean, 6000 ms) to 3000–8000 ms (mean, 5000 ms), respectively. Fig. 1 shows the gum chewing and the following ANT, which was used for our fMRI study, consisting of a 10-min session during each chewing and control condition. Cues consisted of a crosshair in either bold or the same thickness as the fixation crosshair colored in black against a gray background. Targets consisted of a row of five arrows with arrowheads pointing leftward or rightward either above or below the fixation crosshair. Conflict resolution was introduced by incongruent or congruent stimuli, which showed that the central arrow was either flanked or not. Subjects chewed gum for 10 s at their normal speed (~1 Hz) according to instructions on the screen every six cue-target trials during chewing condition. The existence of cue before showing target activates the alerting system, and flankers adjacent to a target activate executive control of attention (Fan et al., 2002). Then, during control condition, subjects were instructed not to chew gum. We used moderately hard-type gum (5.6×10^3 Pa·s; Lotte Co., Ltd., Tokyo, Japan) without odor or taste components to remove any effects other than mastication. ANTs were conducted and synchronized with the MRI scanner by using E-Prime software (Psychology Software Tools, Inc., Sharpsburg, PA, USA). Each subject underwent the adapted ANT continuously, with or without chewing gum, in two back-to-back sessions, which were interspersed by a 10-min rest period, during which T1 anatomical images were acquired. The order of conditions was randomized among individuals (eight subjects started with chewing) and a 10-min waiting period, during which T1 anatomical images were acquired, was inserted between the two conditions. Subjects were instructed to press a button with the right or left thumb according to the direction of the centrally presented arrow. Each of the button presses and RTs were also recorded. The following operational definitions of the efficiencies of the attentional networks were used to compare the performance between conditions.

$$\text{Alerting effect} = \text{RT (no cue)} - \text{RT (center cue)}$$

$$\text{Conflict effect} = \text{RT (incongruent)} - \text{RT (congruent)}$$

RT and accuracy for each condition were subjected to three-way repeated analysis of variance (ANOVA) followed by Tukey's post hoc test. Behavioral effects (alerting and conflict effect) and mean RT for each chewing condition were subjected to two-way ANOVA. Estimates of effect size were reported for all ANOVAs (partial eta-squared, h2). Correlation coefficients were calculated between the behavioral effects and RT. All statistical analyses were calculated using SPSS (IBM, Chicago, IL, USA).

2.3. Image acquisition and data analysis

fMRI experiments were performed using gradient-echo echo-planar imaging (TE = 30 ms, TR = 2 s, field of view = 24 cm, slice thickness = 3.8 mm, gap = 0.2 mm, image matrix = 64 × 64, number of slices = 30, flip angle = 90°). After two fMRI scans, T1-weighted anatomical MR images (sequence = 3D fast SPGR, TE = 1.4 ms, TI = 450 ms, TR = 6.5 ms, field of view 25.6 cm × 25.6 cm, slice thickness = 1 mm, image matrix = 256 × 256, number of slices = 196, flip angle = 12°, number of acquisitions = 1) were acquired to help spatial image normalization. Data were acquired by GE Signa Excite 3.0 T MRI equipped with 8-ch phased array coil (GE, Waukesha, WI, USA). fMRI data were analyzed by SPM5 (Wellcome Trust Centre for Neuroimaging, University College London, London, UK). Data from the first five volumes were discarded to avoid transient magnetization. Correction for head