The Effects of Sweet, Bitter, Salty and Sour Stimuli on Alpha Rhythm. A Meg Study

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**ABSTRACT**

**Objective:** the possible differences in processing gustatory stimuli in healthy subjects was investigated by magnetoencephalography (meg).

**Material and Method:** meg recordings were evaluated for 10 healthy volunteers (3 men within the age range 20-46 years, 7 women within the age range 10-28 years), with four different gustatory stimuli: sweet, bitter, sour and salty. Fast fourier transform was performed on meg epochs recorded for the above conditions and the effect of each kind of stimuli on alpha rhythm was examined.

**Outcomes:** A significant higher percent of alpha power was found irrespective of hemispheric side in all gustatory states located mainly at the occipital, left and right parietal lobes. One female volunteer experienced no statistically significance when comparing normal with salty and sour taste respectively. Two female volunteers exhibited no statistically significance when comparing their normal with their salty taste. One male volunteer experienced no statistically significance when comparing the normal-bitter and normal-salty states correspondingly. All the other subjects showed statistically significant changes in alpha power for the 4 gustatory stimuli.

**Conclusion:** The pattern of activation caused by the four stimuli indicated elevated gustatory processing mechanisms. This cortical activation might have applicability in modulation of brain status.

**Keywords:** Alpha rhythm, sweet, bitter, sour, salty

**INTRODUCTION**

Frequency analysis of the electroencephalogram (EEG) exposed an asymmetrical response pattern in infants to sweet stimuli, localized to the left, frontal and parietal area (1). Increased alpha power was found after gum-chewing (2) finding that was accompanied by increased power of the beta band as a result of adding flavor to the gum (3). Yagyu et al (4) studied global complexity of spontaneous brain electric activity on EEG before and after chewing gum without flavor and with 2 differ-
ent flavors. They concluded that the effects on R-Complexity differed significantly between these conditions, and the differences were maximal between gum base and theanine gum. In a positron emission tomography (PET) study by Zald et al. (5), it was shown that both pleasant and unpleasant gustatory stimuli activated the right posterior and left inferior and anterior parts of the orbitofrontal cortex. Henkin and Levy (6) supported that pleasant taste specifically activated the left hemisphere, while unpleasant taste stimulated the right hemisphere.

Toth et al. (7) found that compared to controls, a significantly higher percent of theta and lower percent of alpha1 band power (8-11 Hz) was recorded in anorexic patients, irrespective of the kind of taste and hemispheric side. Funakoshi et al. (8) reported that there was no significant change in EEG activity after the chewing of marketed gum, while Chu (9) reported that change of arousal by betel-chewing indicated by EEG was caused by arecoline contained in betel nuts. Masamoto et al. (10) showed that alpha power in the post-chewing recording was significantly higher than that in the control recording at almost all the EEG recording sites. Onoda et al., (10) in a magnetoencephalography (MEG) study in humans, suggested that unilateral gustatory stimulation activates the transitional cortex between the insula and the parietal operculum, bilaterally. Yamamoto et al., (11) using MEG, suggested that electrogustatory stimulation with intensities of induced electric taste evoked responses bilaterally, mainly in the opercular-insular cortex while subthreshold electrogustatory stimulation induced modest responses in the cortex. Stronger stimulation induced a tingling sensation and elicited large transient responses in both the opercular – insular and somatic sensory cortices.

Neuroimaging studies have revealed variations in food-related reward processing. The understanding of the precise mechanisms by which food modulates reward circuits will be important in the etiology of obesity and eating disorders. The human gustatory system has been studied using functional magnetic resonance imaging (fMRI), PET, EEG, and MEG. MEG is a non-invasive method with high temporal and spatial resolution and is not affected by the cerebrospinal fluid, skull, and skin. Therefore is thought to be a powerful method to identify the human primary gustatory cortex (12-15).

The purpose of this study was to investigate the effects of sweet, bitter, sour and salty stimuli on alpha rhythm (8-13 Hz) in healthy volunteers by means of MEG. Compared to other sensory modalities, very few electrophysiological data are available concerning the effect of gustatory stimuli on MEG.

### METHOD

Ten healthy volunteers, 3 men within the age range 20-46 years old and 7 women within the age range 10-28 years old, were referred to our Lab and their MEGs were evaluated for the following 5 states: no stimuli; sweet taste; bitter taste; sour taste and salty taste. The study was approved by the Scientific Committee and the Committee for Graduate Studies of our Medical School. Informed consents for the methodology and the aim of the study were obtained from the participants prior to the procedure.

Biomagnetic measurements were performed using a whole-head Neuromag 122-channel MEG system in a magnetically shielded room (12-15). Each subject was comfortably seated on a non-magnetic chair in a magnetically shielded room covered by the helmet-shaped Dewar. During the recordings the healthy volunteers were relaxed and closed their eyes to avoid artifacts from eye flickering. The spontaneous MEG recordings were obtained with a sampling frequency of 256Hz and filtered with cut-off frequencies between 0.3 to 40Hz. The time taken for each recording was 3 min. The duration of the above records is justified because the chosen time interval is enough to cancel out, on the average, all random events and to allow only the persistent ones to remain (12-15). All MEG data tracings were visually inspected carefully off-line for movement artifacts and periods contaminated with movement artifacts were cut off.

Each subject consumed 50 ml of each solution and stayed for 5 min resting. The MEG recordings were starting after the 5 min resting. The time taken from one state to the next was 30 min. Each subject stayed in our lab about 2 hours, so all the procedure (5 states) to be completed. The normal state was an unstimulated baseline (no solution) and it was immediately recorded before the stimulation conditions.
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A software program has been developed in our lab in order to detect the 1st dominant frequency of the power spectra of each channel after the application of Fast Fourier Transform on the MEG raw data, and to build a map of their spatial distribution over the scalp. The numbers in each of the squares in the map represent the 122 MEG channels for each brain region (Table 1). Statistical analysis was performed using the z-score which is applied for normal distributions, since the MEG distributions for normal subjects is Gaussian according to Kotini and Anninos (15).

RESULTS

Table 1 shows the brain regions and the corresponding channels. We used the z-score to compare the frequencies 8-13 Hz (alpha rhythm) for each gustatory stimuli (sweet, bitter, sour, salty) with the normal state for each volunteer. The statistical analysis revealed the following results according to Table 2. We compared the number of channels that had different frequencies of the alpha band (8, 9, 10, 12, 13 Hz) for each stimuli (sweet, bitter, sour, salty) with the number of channels that had different frequencies of the alpha band (8, 9, 10, 12, 13 Hz) in the normal state for each volunteer. The comparison of normal with salty and sour taste for the volunteer no 2 was not statistically significant. The comparison of normal and salty taste for the volunteers no 3 and 6 showed no statistical significance. The comparisons of normal-bitter and normal-salty states for the volunteer no 8 was not statistically significant. All the other conditions were statistically significant for the above volunteers and for the rest of them comparing the normal with each one of the four tastes (Table 2).

Figure 1 shows the maps of the spatial distribution of the frequencies over the scalp for the 5 states for the female volunteer no 2 who had two conditions salty and sour that were not statistically significant. Figure 2 illustrates the overlapping of the frequencies for the above 5 states. There was not any clear discrimination between the states. Figure 3 demonstrates the maps of the spatial distribution of the frequencies over the scalp for the 5 states for the female volunteer no 4 who had all the conditions statistically significant. We observed an increase of the alpha rhythm after all gustatory

<table>
<thead>
<tr>
<th>Brain Regions</th>
<th>Channels</th>
</tr>
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<tbody>
<tr>
<td>Frontal</td>
<td>17-42</td>
</tr>
<tr>
<td>Right Temporal</td>
<td>1-14, 111-120</td>
</tr>
<tr>
<td>Right Parietal</td>
<td>5-6, 11-16, 97-100, 109, 110, 115-122</td>
</tr>
<tr>
<td>Left Temporal</td>
<td>43-50, 55-62, 67-74</td>
</tr>
<tr>
<td>Left Parietal</td>
<td>47-52, 59-64, 71-74, 79, 80, 87-90</td>
</tr>
<tr>
<td>Occipital</td>
<td>75-86, 91-96, 101-110</td>
</tr>
<tr>
<td>Vertex</td>
<td>13-16, 49-54, 61-66, 73,74, 89, 90, 99, 100, 117-122</td>
</tr>
</tbody>
</table>

**TABLE 1.** The brain regions and the corresponding channels

<table>
<thead>
<tr>
<th>Number of Volunteers</th>
<th>Male/Female</th>
<th>Age (Years)</th>
<th>z-score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal Sweet</td>
<td>Normal Bitter</td>
<td>Normal Salty</td>
</tr>
<tr>
<td>1</td>
<td>F</td>
<td>19</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>24</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>27</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>28</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>14</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>10</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>21</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>20</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>22</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>46</td>
<td>P&lt;0.01</td>
</tr>
</tbody>
</table>

**TABLE 2.** Statistical analysis. We applied the z-score for each volunteer between the normal and each gustatory state (sweet, bitter, salty, sour). The results were statistically significant at the level of P<0.05. (NS: no significance)
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Figure 1 shows the overlapping of the frequencies for the five conditions at all brain regions (Table 1) for the female volunteer no 2.

Figure 2 presents the power spectra analysis: Overlapping the power spectra from all channels for the female volunteer no 2.

Figure 3 displays the frequency distribution from all channels for the five conditions at all brain regions (Table 1) for the female volunteer no 4.

Figure 4 illustrates the power spectra analysis: Overlapping the power spectra from all channels for the female volunteer no 4. We observe a dominant frequency at 10 Hz.

Stimuli. Figure 4 shows the overlapping of the frequencies for the 5 states. The increase of the alpha rhythm according to the gustatory stimuli was noticeable with a dominant frequency at 10 Hz, located mainly at the occipital, left and right parietal lobes. The color code in Figures 1, 3 represent the frequencies 8-13 Hz (alpha rhythm).
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Discussion

To our knowledge, there are no any reports in the literature investigating with MEG, the effects of taste (sweet, bitter, salty, sour) on alpha rhythm. EEG measures electrical activity generated by extracellular currents whereas MEG measures the corresponding magnetic fields. In addition, MEG is most sensitive to electrical dipoles with tangential orientation whereas EEG is equally sensitive to tangential and radial dipoles (16). EEG and MEG have superior temporal resolution compared to PET, and fMRI, due to the fast fluctuations of the underlying postsynaptic potentials. EEG and MEG can be considered real-time measures of brain electrical activity. This is very significant studies investigated sensation, perception, or cognition (17).

Gemousakakis et al. (13) evaluated MEG recordings for healthy female volunteers in five different gustatory states: normal, sweet, bitter, sour and salty in the frequency range 2-7 Hz. The results showed that there is a differentiation in the distribution of the frequencies with increasing age which may provide novel insights into the age-dependence of taste quality brain centers. Gemousakakis et al. (14) also evaluated MEG recordings in five different states: normal condition, sweet, bitter, sour, and salty taste in the frequency range (2-7 Hz) in male and female volunteers. The results showed that, under normal conditions, as well as in the sweet and the bitter taste, the male volunteers exhibited a higher count of low-frequency than high-frequency channels compared to the female ones; for the sour taste, there was no clear differentiation between the genders; for the salty taste, the female volunteers exhibited a higher count of low-frequency channels whereas there was no clear differentiation in the number of high frequencies between the genders. Anninos et al. (12) investigated the localization of current sources for spontaneous MEG data in delta and theta rhythms. MEGs were evaluated in three different states: physiological condition; sweet taste, and salty taste. Low frequencies can be seen in the maps obtained with the sweet taste, whereas in the physiological and salty taste, the maps showed higher frequencies in the majority of channels.

The results of our research showed a significant percent of alpha power, irrespective of hemispheric side in all gustatory states. This was in accordance with other EEG studies which found an increased alpha power after gum-chewing accompanied with an increased power of the beta band as a result of adding flavour to the gum (2,3). The results of our study revealed the significance of MEG by spectral analysis in determining gustatory responses. The activation of the alpha power might have applicability in the modulation of brain status. Any attention-related, changes in alpha rhythm affects the amplitude of the alpha rhythm and not the frequency of each channel. However, the specific constituents that caused these responses still need further investigation.

Conflict of interests: none declared.

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