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# Odor and Taste Interaction on Brain Responses in Humans

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## Introduction

Central neural integration of sensory input from different modalities is a prerequisite for flavor perception. Chemosensory information as part of flavor perception is mediated by (i) specific and (ii) general sensory systems. The mouth and the nose are areas housing specific sensory systems, i.e. the gustatory and the olfactory systems. In the gustatory and olfactory systems, as well as in the vomeronasal organ, information is mediated by chemoreceptors. In the somatosensory system, which is classified here as the general sensory system, chemoreceptors are mainly nociceptors. But there are other modalities present as well, such as mechano- and thermoreceptors.

It is commonly accepted that there are plenty of opportunities for the above-mentioned systems to interact. This can happen at several levels of the information processing before reaching the cortical level and even peripheral interactions seem possible.

In the psychophysical literature there are numerous demonstrations of taste/smell interactions. However, our understanding of the CNS mechanisms and detailed characteristics thereof are rather limited. In humans, some experiments have recently been published addressing this phenomenon by using imaging technologies (Small *et al.*, 1997, 2004; Cerf-Ducastel *et al.*, 2001; de Araujo *et al.*, 2003; Cerf-Ducastel and Murphy, 2004).

We wanted to know if the method of event-related potential (ERP) recording could be a useful tool for the investigation of taste and smell interactions. The reason for this approach is that ERPs have the highest possible time resolution compared to most imaging techniques except magnetic source imaging (MSI). Although we do not report any results here, it has now become possible to obtain information about areas of activation by applying electrical source localization methods based on ERPs. In addition, we have demonstrated that ERP components, namely the N1/P2 portion of the ERP, are generated in the insular cortex (Kettenmann *et al.*, 1997) and also postulated that this area might play a crucial role in integrating taste and smell information. This assumption has been recently supported by Fu *et al.* (2004).

## Materials and methods

Seventeen volunteers participated in six measurement days of recording olfactory event-related potentials (OERPs). In addition to the OERPs, hedonic and intensity ratings to the three different odorants [*n*-butylacetate (mild fruity smell); linalool (sweet floral smell, used as background for peach and apricot flavor); octanal (waxy citrus/orange/grapefruit smell)] were registered.

Odorants were applied by a vapor-dilution olfactometer (Burghart OM4b). Stimuli were applied at a constant flow rate of 140 ml/s, a humidity of 80% and a temperature of 37°C. Stimulus duration was 200 ms and the interstimulus interval was 40–50 s. Each volunteer participated in an additional training session prior to the actual measurement to become acquainted with the experimental procedures.

For taste stimulation, five different tastants and blank (sweet, sour, salty, bitter, and umami) were applied using taste strips. Taste strips were made of paper soaked in taste solutions and dried on a slowly rotating wheel. The length of a taste strip was 8 cm and an area of 2 cm$^2$ was impregnated with a taste stimulant (Mueller *et al.*, 2003) (Figure 1).

In each session, one out of the three odorants was applied and OERPs were recorded while keeping the taste strips with one out of the five different tastants or blank at the center (not the tip) of the tongue. During one measurement day, one of the three odorants was combined with three out of the six different tastants in a randomized order. Odorants had to be rated for intensity and pleasantness after each of 16 olfactory stimuli necessary for obtaining an OERP. Endpoints for this study were intensity and hedonic ratings of odors and amplitudes and latencies of OERPs.

The quantities of tastants (dissolved in 100g double-distilled water) used to load the taste strips are given in Table 1. For olfactory stimuli, the three odorants were used at concentrations of 10% saturated vapor at 36°C.

The EEG was recorded from 13 positions according to the 10/20 system referenced to both earlobes. Possible eye movement artifacts were recorded from an additional site. EEG segments of 2048 ms were recorded starting 500 ms prior to stimulus onset. The mean of this 500 ms pre-stimulus period served as a baseline for amplitude measurements.

Data analyses were performed using the BOMPE 03 program (Burghart Instruments, Germany). The 16 EEG segments linked to

**Figure 1** Taste strips.

**Table 1** Quantities of tastants used on the taste strips

| Sweet | Sour | Salty | Bitter | Umami | Blank |
|---|---|---|---|---|---|
| Sucrose, 20 g | Citric acid, 16.5 g | Sodium chloride, 10 g | Quinine sulfate, 0.24 g | Sodium glutamate, 10 g | Unloaded paper spoon |

All tastants were solved in 100 g double-destilled water.

the olfactory stimulus of each recording were filtered and averaged. The resulting OERPs were further evaluated in measuring amplitudes and latencies of the P1, N1 and P2 components, separately for each recording site.

To stabilize vigilance during the intensity and hedonic ratings and during the OERP measurements, volunteers performed a tracking task on a video monitor (Kobal *et al.*, 1990).

SPSS 10.0 was employed for statistical evaluation.

## Results and discussion

Although data are not fully evaluated and electric source localization has not been performed, there are some preliminary statistically significant results ($P < 0.05$) that are very promising. For the hedonic ratings, there were a couple of changes in the odor perception due to differences of the background taste stimulation. *n*-Butylacetate was perceived as most pleasant during sweet stimulation compared to umami and sour taste. Octanal was most pleasant with sour taste compared to salty, and linalool was most pleasant with the blank taste compared to salty and umami. In the intensity ratings we only found that octanal was most intensely perceived during umami stimulation compared to sour and sweet.

The five tastants modified OERP patterns differently and this interaction also seemed to be odor specific, e.g. the 'early' component N1 elicited by *n*-butylacetate was significantly reduced during sour stimulation, the later component P2 elicited by linalool was significantly enhanced during bitter stimulation and the same component elicited by octanal was significantly prolonged during salty stimulation.

Since we have not yet performed electric source localization, changes in amplitudes and latencies cannot be interpreted with the degree of certainty we would like to have. However, next to the possibility that changes in amplitudes and latencies can always be related to changes in the composition of neuronal populations, the fact that the N1 component elicited by *n*-butylacetate was significantly smaller during sour stimulation could either indicate a difference in intensity perception, which we could not find in the intensity estimates, or a change in the attention level towards the stimulus, as has been shown in other sensory modalities for this component. Changes in the P2 component of the linalool OERP during bitter stimulation and in the octanal OERP during salty stimulation could indicate changes in cognitive evaluation. Interestingly, the response to octanal as the major component of the grapefruit smell was influenced significantly by the salty taste in its more cognitive late positive component. In some regions, grapefruit juice is combined with salt to enhance the taste of the beverage.

The observed interactions between taste and the OERP components were mostly related to potential components that are generated in the insular cortex. In MSI studies, we found strong indications of an important representation of the insular cortex in the processing of olfactory information. The vicinity of taste representation as a possible location for interactions was recently stressed by findings of Fu *et al.* (2004). They interpret their results that the olfactory and gustatory pathways appeared to be reciprocally connected through the insular cortex as the evidence that this area could modulate mechanisms involved in food selection and emotional reactions.

In summary, we found that tastants can modify the pattern of OERPs, that different tastants modify OERP patterns differently and that tastants' modifications of OERP seem to be odor-specific.

Hence, observed changes were clearly not uniform but followed specific and characteristic patterns. N1/P2 components seem to be useful in studying taste/smell interactions, because they are generated in the insular cortex.

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