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Research Report

Oral texture influences the neural processing of ortho- and retronasal odors in humans

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ABSTRACT

Eating implies mutual interactions between different senses. In the present work we aimed at studying relations between food texture and food odor, using both psychophysical and imaging techniques.

Eighteen right-handed healthy human subjects participated to both behavioral and fMRI sessions. Fresh, sweetened milk and a more thickened version were delivered orally; in addition, a buttery-cream aroma was presented ortho- or retronasally. Stimuli were applied using a gustometer and or an air-dilution olfactometer, both computer-controlled. In each session subjects rated separately odor-, taste- and thickness intensities of the stimuli.

The behavioral data show that odors, presented through either retro- or orthonasal path, induce a significant flavor enhancement with respect to the no-odor condition. Brain functional data indicated a significant enhancement of the activation of olfactory eloquent areas in favor of ortho-nasal odor presentation while activations of mechanosensory areas were favored by the retro-nasal odor route. As effect of oral stimuli we found a significant correlation between the texture intensity rating vs. the BOLD signal in the supplementary motor area, known to drive subconsciously primed movement, putatively associated in this case with the tongue movement required with the handling of the stimulus. Moreover, we found inhibition of the signal in different sensory specific areas as an effect of the mutual interaction between stimulus qualities.

In conclusion, ortho- and retronasal odors differentially affect the neural processing of the texture of oral stimuli.

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Abbreviations: OFC, orbitofrontal cortex; ACC, anterior cingulate cortex; fMRI, functional magnetic resonance imaging

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1. Introduction

When we eat, we see, smell, taste, feel and hear the food before we decide to swallow it. Each of these senses, in its own right, has received considerable scientific attention. Particularly the interactions among olfaction, taste and texture have been investigated in several aspects. Odors that are associated with a specific taste quality have been shown to enhance taste intensity at many occasions (Frank et al., 1989, 1993; Stevenson et al., 1999; Sakai et al., 2001; Djordjevic et al., 2004; Delwiche, 2005; Labbe et al., 2007; Knoop et al., 2008). Other modalities like audition (Seo and Hummel, 2011) and touch contribute to the properties of the food like perceived texture, taste or smell (Zampini and Spence, 2004; Zampini and Spence, 2005).

Interaction between food, texture and odor has been localized at both primary-sensory and cognitive levels of stimulus processing (Roudnitzky et al., 2011). Neural correlates of multi-modal integration processes have been described for odor-taste interactions in primary and secondary cortical areas of taste and smell like the insula (Small et al., 2005), amygdala (Zald et al., 1998; Small et al., 2005), the orbito-frontal cortex (OFC) (Zald et al., 1998; Small et al., 2005) and the anterior cingulate cortex (ACC) (Zald et al., 1998; Zald and Pardo, 2000; Gottfried et al., 2002; Small et al., 2003; de Araujo and Rolls, 2004; Small et al., 2005; Welge-Lüssen et al., 2005; Seo et al., 2013). Anterior insula, OFC and ACC are also directly involved in multimodal integration processes, especially for flavors (Verhagen and Engelen, 2006a).

Cross-modal integration of taste and smell appears to depend on the pathway of odor presentation. Behavioral studies show interactions between olfaction and gustation when the odor is presented in the epipharynx of the soft palate (retronasal presentation) as a natural result of swallowing during eating (Frank et al., 1989; Rankin, 2000; Busch et al., 2007) but less pronounced interactions when odors are presented via the nostrils (orthonasal presentation). Odor-taste interactions involving retronasal presentation suggests involvement of brain structures like amygdala (Zald et al., 1998; Cerf-Ducastel and Murphy, 2001), the frontal operculum, the anterior insula (Cerf-Ducastel and Murphy, 2001), the caudal OFC (Cerf-Ducastel and Murphy, 2001) medial OFC (Small et al., 2005) the ACC (Small et al., 2005) and the cerebellum (Cerf-Ducastel and Murphy, 2001).

In the perception of fat and fat-related properties like creaminess and thickness, contributing modalities are also touch, olfaction (Rolls et al., 2003; Bult et al., 2007) and possibly a taste-like process based on lingual fat receptors, i.e. CD-36 receptors (Gilbertson et al., 2005; Laugerette et al., 2005; Gilbertson, 2006; Sclafani et al., 2007). Viscosity alone cannot fully explain fat-induced neural activations (Verhagen et al., 2004). Moreover creaminess and thickness can be augmented by tactile and olfactory (creamy milk aroma) interventions, while the intensity of the thickness can be enhanced using creamy odor and the flavor intensity can be suppressed increasing viscosity (Bult et al., 2007).

For the present study we considered that congruent olfactory and tactile condition contribute in a coherent way to produce a sensation that emulates the fat-related sensory properties like creaminess. Consequently, the aim of this work is localizing, by means of functional magnetic resonance imaging (fMRI)), neuronal correlates for the described odor-texture integration. To this end, whole-brain fMRI-blood oxygen level dependent (BOLD) signal was collected during the oral evaluation of milk with variable textures with concurrent presentations of a creamy milky odor. Odor routes were either ortho- or retro-nasal.

2. Results

2.1. *Psychophysical results*

Two of the 18 subjects failed to produce complete data sets. Their ratings were left out of the analysis.

A significant effect of "oral stimulus" on thickness ratings was observed [$F(1,15)=14.5$, $p=0.002$]. This effect was due to generally higher thickness ratings for thickened milk than for non-thickened milk (Fig. 2). As expected, effects of "odor" were observed on odor intensity [$F(2,30)=21.0$, $p<0.001$] and

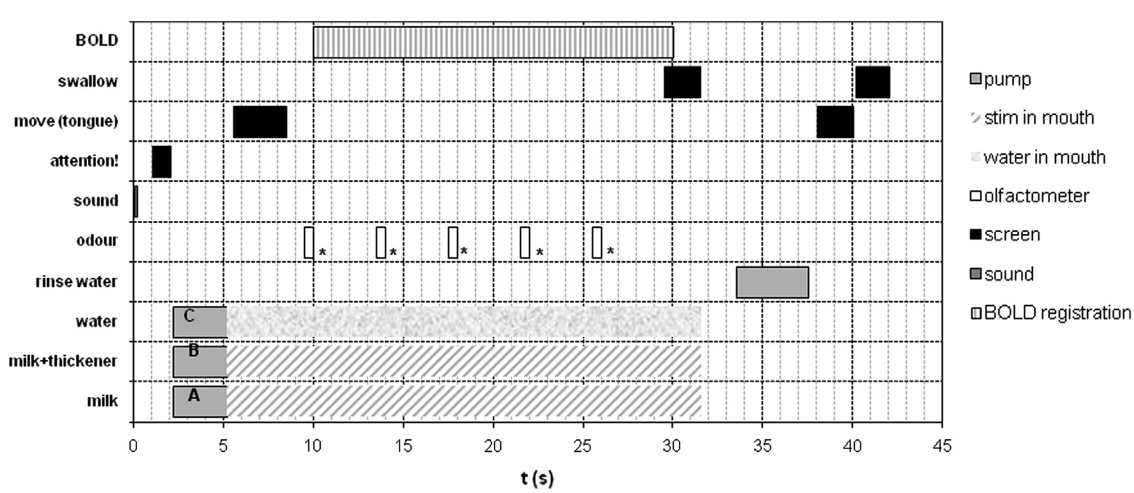

Fig. 1 – Timed event during on- and off periods in the used blocked design. Event times were identical during on-periods and off-periods. During on-periods, oral stimuli were milk (A) or thickened milk (B), during off-periods oral stimuli consisted of water (C). *Odor pulses were only generated during orthonasal and retronasal conditions in the on-periods.

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