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SOURCE LOCALIZATION OF EVENT-RELATED BRAIN ACTIVITY ELICITED BY FOOD AND NONFOOD ODORS

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Abstract—Tastes and odors influence the perception of a meal. Especially food aromas can act as potent signals to modulate our eating behavior with strong dependency on the reward produced by food. In this investigation we aimed to study the electrophysiological response to food- and non-food-related odors in healthy volunteers. Analyses revealed specific scalp potential maps for the two conditions; in particular the source of the map in the ''food'' condition seemed to be associated with the processing of rewards; the specific map in the ''non-food'' condition reflects odor characteristics excluding the reward.

Key words: EEG, odor, food, source localization, event-related potential.

INTRODUCTION

The food-related axis is one of the many categories that define odor perception. This category is shaped by our eating experience. When we decide to ingest a food, first we smell it through the nostril (orthonasal route), then we put it into the mouth and we appreciate its flavor via the nasopharynx (retronasal route) together with its taste and texture mediated by the gustatory and the somatosensory systems. Here it seems as if olfaction is most important in terms of the distinction between various flavors. For example, an orange and a grapefruit may have a distinct flavor but their tastes can be similar.

This ability of the brain to coherently produce meaningful categories is a research topic of high interest studied in various sensory modalities, like the visual (Rosch, 2003), auditory (Miller et al., 2003; Tsunada and Cohen, 2014) or olfactory systems (Howard et al., 2009). Food-related odors are of interest not only for food- and cosmetics-related industries, but also in terms of the study of odor-related behavior, social interaction, or individual well-being. For example, it has been shown that food-related smells can affect how much we eat with smaller bite sizes taken for foods containing strong aromas. This suggests that aroma may be used as a means to control portion size (de Wijk et al., 2012). The reward produced by food explains parts of this relationship. Generally, food aromas can act as potent signals to modulate our eating behavior.

Aim of the study was to investigate whether food- and non-food-related odors would produce different activations in the brain. We hypothesized that the main differences between the two kinds of odor will be in a brain network associated with reward in favor of food odors. To analyze this we used both psychophysical and electrophysiological techniques with a high temporal resolution to obtain insights into the very early processing of this information.

EXPERIMENTAL PROCEDURES

Participants

Eighteen healthy volunteers (mean age 25 years, range 18–35 years) participated in this study. Normal olfactory function was ascertained in all subjects using the ''Sniffin' Sticks'' (Kobal et al., 1996; Hummel et al., 2007). None of the subjects had a clinical history of major diseases and, accordingly, none of them took any drugs known to affect olfactory function. In order to participate in the experiment free of any physical need the volunteers were instructed not to eat or drink one hour before the start of the experiment. Moreover, they were all non-smokers and right-handed as determined with a translated version of the Edinburgh Handedness Inventory (Oldfield, 1971). The experimental procedure was explained to all subjects, and all subjects provided written informed consent. The study design was approved by the Ethics Committee of the Medical Faculty at the TU Dresden (application number EK55022014).

Stimuli

Two stimulants were chosen: strawberry aroma and the odor of lily of the valley (odors from Takasago, Paris, France). For each stimulant two concentrations were initially chosen [low (15% v/v) and high (20% v/v)] and

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Abbreviations: EEG, electroencephalogram; ERP, event-related potential; GMD, global map dissimilarities; MNI, Montreal Neurological Institute; OERP, olfactory event-related potentials; OFC, orbitofrontal cortex; TF, timeframes.

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delivered via a computer-controlled olfactometer based on the principles of air-dilution (OM6b; Burghart, Wedel, Germany). The stimuli were embedded in a constantly flowing air stream of 7.0 L/min, with controlled humidity (80% relative humidity) and temperature (37 °C) (Kobal, 1981). Based on the results from psychophysical testing (see below) the lower concentrations were used for odorous stimulation during the electroencephalogram (EEG) recordings.

Methods

The experiment consisted of two sessions. In the first session, subjects came to the Smell & Taste Clinic for screening and preparation for the recording session. Here participants were familiarized with the stimuli and the procedures performed. Subjects were placed in a comfortable chair in a dedicated room with controlled temperature and humidity. Odorous stimuli were presented to the right nostril with a length of 250 ms with an inter-stimulus interval of 28 ± 2s. Subjects were trained to perform the velopharyngeal closure breathing technique to minimize nasal air flow during the experiment (Kobal, 1981). During measurements, subjects performed a simple visual tracking task to reduce uncontrolled eye movements, which are a common cause of artifacts in EEG acquisition. The task also helped to stabilize subjects' vigilance. During the training session subjects also became acquainted with psychophysical rating scales for the assessment of intensity (scale from 0 to 10), pleasantness (scale from −5 to +5), edibility (scale from 0 to 10), sweetness (scale from 0 to 10), and irritation (scale from 0 to 10), of the stimulus condition. Each stimulus was presented 10 times and its qualities were rated on two occasions each. To dampen ambient sounds (e.g., switching of the valves of the olfactometer) subjects received white noise of approximately 50 dB speaking level (SPL) via headphones during the experimental session.

During the second session iso-intense olfactory stimuli were presented 50 times/condition at an inter-stimulus interval of approximately 20–30 s mixed in a pseudo-random way between strawberry and lily of the valley, with same stimulus duration as during the training. Stimuli were presented in three different sequences that were randomly used for individual participants. This session lasted approximately 60 min.

EEG acquisition

To record olfactory event-related potentials (OERP), 128 electrodes (Ag–AgCl active-electrodes, BioSemi, Amsterdam, NL, Netherlands) were mounted on a standard 10/20 system headcap (BioSemi – CAP) available in various sizes to comfort individual head sizes. Four pairs of flat-type, active electrodes were used to record the vertical and horizontal electro-oculogram (EOcG). Linked earlobes were used for reference. Electrodes were connected to the EEG amplifier (BioSemi Active Two AD-box). The output of all analog–digital converters were multiplexed and sent via a single optical fiber to a USB2 Receiver connected to a PC, where the data were registered and stored (Biosemi ActiveView 605). The sampling frequency was set at 512 Hz. To maximize conductivity and reduce impedance, electrode gel (Signa gel – Parker laboratories, Fairfield, NJ, USA) was applied to each electrode tip. The signal indicating stimulus onset was co-registered with the EEG signal.

Data analysis

The psychophysical data were analyzed by means of IBM SPSS v21 (IBM, Ehningen, Germany). The academic software Cartool 3.51 by Denis Burnet (web site: http://brainmapping.unige.ch/cartool) was used to perform the ERP analysis.

EEG pre-processing

Data from two subjects were discarded because of a large number of artifacts. Recordings were additionally filtered off-line (low pass 15 Hz), epoched (200-ms pre-stimulus segment used as baseline plus 1000–ms post-stimulus onset), and artifacts cleaned following visual inspection. Single-subject analysis gave OERP for each condition. Then a Grand Mean was computed for each condition and electrode among the final group of 16 subjects.

OERP component analysis

The classical OERP peaks P1, N1 and P_{late} (Kobal, 1981) were defined in amplitude and latency for each condition based on the group Grand Mean. A paired *t*-test (16 subjects, $p < 0.05$) was applied to highlight the amplitude differences between the two conditions among all the electrodes.

Topographic pattern analysis

The basic assumption in topographic analyses (Michel et al., 2009) is the definition of stable microstates (Koukkou and Lehmann, 1987; Lehmann et al., 1987; Lehmann, 1992). In our experiment the topographic analysis was based on (a) nonparametric randomization test of the global map dissimilarities (GMD) (Murray et al., 2008) which is done with permutation of the data, recalculation of the group-average ERPs, recalculation of the resulting GMD value for the resulting group-average ERPs, and following comparisons between the original GMD and the one resulting from the randomization test. (b) The microstate segmentation allows to identify the dominant scalp potential map for each condition applying a spatial k-means cluster analysis followed by a cross validation criterion to the grand-mean ERP of both conditions (Michel et al., 2009). Cluster maps that correlated more than 90% were merged and segments less or equal to 12 data points (24 ms) were rejected. The segments, or microstates, are successively marked under the global field power (GFP) curves, which is the standard deviation of the potentials at all electrodes of an averaged reference map and it has dimensionless units with values from 0 to 1. (c) Then a fitting procedure based on the spatial correlation of the cluster maps and the map at each single time point, was applied to determine the time period during