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On-line psychophysical data acquisition and event-related fMRI protocol optimized for the investigation of brain activation in response to gustatory stimuli

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Abstract

An experimental method for event-related functional magnetic resonance imaging that allows for the presentation of several chemosensory stimuli in the oral cavity during the same run, the collection of psychophysical measures (intensity or pleasantness) during the presentation of the stimuli, and the analysis of the data in an event-related fashion are described. The automatic pumps used to present taste stimuli allowed for multiple tastes to be delivered in small amounts under computer control. Psychophysical ratings of pleasantness or intensity were collected after each presentation of a taste stimulus and water, with the general labeled magnitude scale, using a joystick that controlled the movement of an arrow on the visual display. Performing these cognitive tasks required that the participant remained focused, and aided in the interpretation of the data collected. The perceived pleasantness differed across stimuli for all conditions; however, pleasantness ratings for the same stimulus displayed consistency, over the duration of the run and before each scan on separate days. Activation in response to sucrose and caffeine while the participant rated pleasantness was found in the insula, frontal operculum, rolandic operculum and orbitofrontal cortex which is consistent with previous taste fMRI studies.

Keywords: Taste; Intensity; Pleasantness; Event-related functional magnetic resonance imaging; fMRI; On-line psychophysical data collection

1. Introduction

The present article describes an experimental protocol for event-related functional magnetic resonance imaging (fMRI), which was designed to optimize the acquisition and data processing of responses to taste stimulation. Positron emission tomography (PET) studies have previously used methods of taste stimulation that directly place stimuli in the mouth prior to scanning, for example, pieces of chocolate on an extended tongue (Zald et al., 1998), or filter papers containing stimuli (Small et al., 1997). While these techniques are suitable for PET, they cannot be reliably used in fMRI experiments because of the physical restrictions of fMRI, such as, reaching the mouth of the subject to deliver stimuli, difficulty in administering water for rinsing between stimuli, and the technical demands of fMRI for precise timing of stimulation. However, accurate timing and precise stimulus control are critical for fMRI experiments, particularly those using event-related paradigms.

In taste fMRI experiments using the block design, more advanced stimulus delivery systems have since been developed, that involve the use of tubing systems, which deliver stimuli intra-orally (Cerf-Ducastel and Murphy, 2001; Cerf et al., 1998; De Araujo et al., 2003a; Faurion et al., 1999; Francis et al., 1999; Murphy et al., 2005; O'Doherty et al., 2001). In a series of experiments by Cerf-Ducastel and Murphy (2001, 2003, 2004), the tubing system was designed so that delivery of both olfactory (retronasal) and gustatory stimuli would be possible in order to investigate cortical activation to odor, taste, and mixtures of the two in the mouth (Murphy et al., 1977). In those experiments and in Cerf et al. (1998), Cerf-Ducastel et al. (2001), and Faurion et

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al. (1999); stimuli were delivered manually in discrete boluses (50 μl) every 3 s with an 18 or 30 s stimulation period and a subsequent interval of 75 or 90 s, respectively, for rinsing. This stimulus delivery system was successful in delivering stimuli that facilitated normal ingestion and swallowing while limiting adaptation and head movement. However, the block design is limited relative to the event-related design because it does not allow for discrimination between two different stimuli within a block. Tubing delivery systems are now widely used in gustatory, retronasal olfactory, and flavor fMRI studies (De Araujo et al., 2003b; Kringelbach et al., 2004; O'Doherty et al., 2002; Small et al., 2003).

Psychophysical measures are an important accompaniment to neuroimaging data. Psychophysical data aid in the interpretation of the response of the brain, however methods and timing of collecting psychophysical data differ dramatically across experiments. For example, Small et al. (2003) adjusted stimulus concentrations based on the individual's psychophysical ratings of pleasantness and intensity; by contrast with the present study, ratings were not collected during the scan itself but were collected between trials (Small et al., 2003). O'Doherty et al. (2001) used the visual analogue scale (VAS) to collect psychophysical ratings before the imaging run. De Araujo et al. (2003c) collected ratings during the scan itself but those ratings served as a post hoc indication of the subject's perception and were not treated as a cognitive task performed by the subject when the stimulus was presented. In previous studies Cerf and colleagues (Cerf et al., 1998; Faurion et al., 1999) collected perception profiles based on intensity measurements when subjects were in the scanner receiving water and tastants. The perception profiles provided a realistic time course of intensity perception, which aided in processing the imaging data (Van de Moortele et al., 1997). Using the retronasal stimulation route, Cerf-Ducastel and Murphy (2004) conducted psychophysical investigation of flavor stimuli off line in a simulated scanning environment with a manually controlled delivery system used to present flavor stimuli in amounts comparable to those typically presented in an fMRI block design and suggested the feasibility of acquiring reliable, quantitative psychophysical measures of flavor perception under these conditions.

The present study aimed at developing an experimental protocol that would allow for the computer-controlled presentation of several gustatory or flavor stimuli in the same run so that resulting fMRI activation could be analyzed in an event-related fashion. The current study had three main methodological goals: (1) produce a taste stimulation technique in an event-related paradigm that would allow for the computer-controlled presentation of multiple tastes, while limiting adaptation; (2) collect psychophysical measures during the presentation of the tastants and the reference period of water to investigate possible variations in perceived pleasantness and intensity over time and repeated exposure; (3) analyze data in an event-related fashion. To our knowledge, the current study is the first event-related fMRI taste study that controls the cognitive task during gustation by requiring the subject to rate intensity or pleasantness during the computer-controlled presentation of the stimulus and during the reference period of water.

2. Materials and methods

2.1. Subjects

Eighteen healthy young adults, nine females and nine males, ranging in age from 19 to 22 years ($M = 20.7$, S.D. = 0.99) participated in the study after giving informed consent. Subjects received monetary compensation for participating in the study. The Institutional Review Boards at both San Diego State University and the University of California, San Diego gave approval of the experiment.

2.2. Psychophysical assessment

The first session consisted of chemosensory assessment for ageusia and anosmia with taste threshold and odor threshold tests (Cain et al., 1983, modified as in Murphy et al., 1990). Exclusionary criteria consisted of upper respiratory infection or allergies within the prior 2 weeks.

2.3. Odor threshold

To screen for anosmia, odor thresholds for the odor *n*-butyl alcohol (butanol) were assessed for each nostril monorhinically using a forced choice, ascending method of limits test (Murphy et al., 1990). The solutions were in a series of 10; each dilution was one-third the concentration of the solution preceding it. On each trial the participant was presented with two bottles: one containing distilled water and the other containing the odor stimulus. The participant was asked to decide which bottle contained an odor. There was a 45 s inter-stimulus interval between each stimulus delivery to avoid adaptation (Ekman et al., 1967). If the participant chose the incorrect bottle, a higher concentration was given on the next trial. Once the participant met the criterion of choosing correctly on five successive trials the odor threshold was determined.

2.4. Taste threshold

To screen for ageusia, taste thresholds for sucrose were assessed using a sip and spit, forced choice staircase procedure (Murphy et al., 1990). Stimuli were presented in 14 concentrations of sucrose, ranging from 0.0032 to 0.36 M in geometrical progression. All stimuli were presented at room temperature in distilled water (Murphy et al., 1990). The experimenter presented the participants with two cups, one containing distilled water and the other containing sucrose solution. The stimulus was sipped, held in the mouth for 10 s, and expectorated. After the participant sampled 10 ml of water and solution he(she) was asked to select the stimulus with the sweet taste. The experimenter increased the concentration until the participant consistently (twice in a row) chose the stronger stimulus. This procedure was then reversed to a descending series until the participant failed to choose the correct stimulus. Participants were required to rinse with distilled water before each stimulus to avoid adaptation and waited a minimum of 30 s between each stimulus. Testing continued for five