Blood oxygenation level-dependent functional magnetic resonance imaging analysis of functional representation of taste information processing in the rat brain

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Introduction - In animals, food discrimination is critical for proper responses to the environment, for example, for mediating nutrient ingestion, maintaining energy balance, and rejecting poisons. In the gustatory system, the insular cortex (IC) has been identified as the primary gustatory cortex, which receives taste information from the taste periphery via the gustatory thalamic nucleus. However, the neuronal mechanisms underlying taste discrimination and perception in the cortical and subcortical regions remain unclear because of the spatial limitations of previous studies, which used methods such as electrophysiological and optical methods [1,2]. Recently, we reported that asymmetrical gustatory responses are seen in both ICs on sucrose stimulation [3]. In the present study, we have extended the previous study [3] to clarify the neuronal network in the cortical and subcortical regions with respect to taste discrimination. We performed blood oxygenation level-dependent (BOLD) functional magnetic resonance imaging (fMRI) at 7 T for basic tastes in anesthetized animals.

Materials and Methods - *Animal preparation:* Male Sprague-Dawley rats (200–280 g) were initially anesthetized with 2% isoflurane. The anesthetic agent was switched to urethane (i.p., 0.8 g/kg) before placing the rat into a magnet. The head was fixed in a holder designed to minimize movement, and the body temperature was maintained using a water-heated blanket. *Taste Stimulation:* Sucrose and NaCl solutions (0.5 M, diluted in distilled water) were used as the tastants. The tastant was delivered through a polyethylene tube using a syringe pump. The polyethylene tubes used for stimulation and tastant rinsing were inserted 10 mm into the oral cavity, which was held agape, without touching the rat's tongue. Stimulation paradigms for 1-block design were employed. After each fMRI experiment, the papillae were rinsed using sufficient distilled water to wash out the tastant on the tongue. *MRI measurements:* MRI experiments were performed on a horizontal 7 T magnet interfaced to a Varian^{INOVA} console with a circular radio-frequency transmit-receive surface coil. T1-weighted gradient echo images (image dimension, 128 × 128 pixels; in-plane resolution, 0.2 × 0.2 mm; slice thickness, 1.0 mm; repetition delay, 5.0 s; and TE, 15 ms) were obtained with variable inversion recovery weighting per slice. fMRI data were acquired using a gradient-echo sequence with the following scan parameters for 5 slices: TR/TE, 470/12 ms; slice thickness, 1 mm; FOV, 25.6 × 25.6 mm^2; and matrix size = 64 × 64. *Data analysis:* Functional images were created as Student's t-test statistical images on a pixel-by-pixel basis. The activated regions were defined as multipixels that showed a statistically significant response ($p < 0.05$). Anatomical MRI images were carefully compared with anatomical figures from the rat brain atlas [4] on the basis of the coordinates of the anterior part of the anterior commissure and the lateral ventricle.

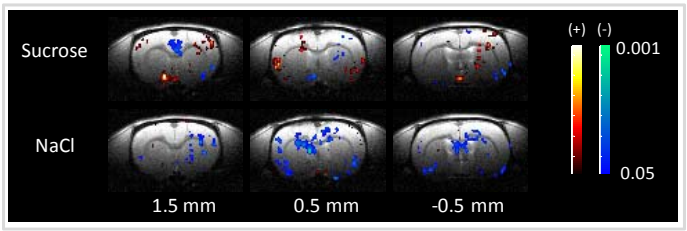

Fig. 1 BOLD fMRI activation during taste stimulation. During the sucrose stimulation, the BOLD signal increased unilaterally or bilaterally in the insular cortex. During the NaCl stimulation, the BOLD signal decreased in the insular cortex. The colored bars provide a statistical significant for the increase (warm colors) and the decrease (cold colors).

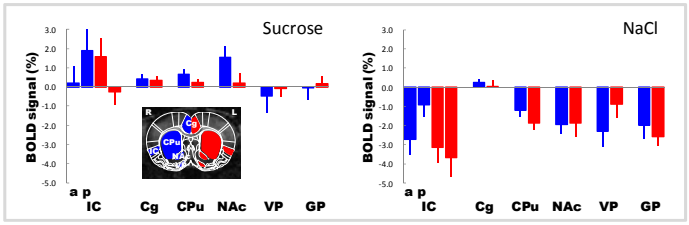

Fig. 2 Averaged BOLD signals in brain regions in response to taste stimulation. BOLD signals for all the rats were averaged within ROIs of right (blue) and left (red) hemispheres. For the insular cortex (IC), BOLD signals were averaged at 2.3–0.9 mm (a) and 0.9–0.0 mm (p) anterior to the bregma; these regions were located anterior and posterior to the intersection of the middle cerebral artery and rhinal fissure, respectively. Data have been provided in terms of mean ± SEM values. IC, insular cortex; Cg, cingulate cortex; Cpu, caudate-putamen; NAc, nucleus accumbens core; VP, ventral pallidum; GP, globus pallidus.

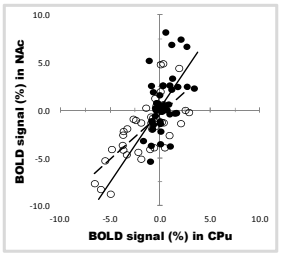

Fig. 3 Relationship between the BOLD signals in the caudate-putamen and nucleus accumbens core. The closed and open circles show the signals during sucrose and NaCl stimulation, respectively. Cpu, caudate-putamen; NAc, nucleus accumbens core.

Results and Discussion - The sucrose solution increased the BOLD signals in the IC and nucleus accumbens core (NAc) and decreased it in the cingulate cortex (Cg), whereas the NaCl solution decreased the BOLD signals in the cortical and subcortical regions (Fig. 1). The positive BOLD signals for the sucrose solution were asymmetrical in both hemispheres, which is in agreement with the results of a previous study [3]. Asymmetrical negative BOLD signals during NaCl stimulation were not completely observed in both hemispheres (Fig. 2). Therefore, the activated area during sucrose stimulation was relatively localized in the IC, whereas a broad area within the IC was stimulated during NaCl stimulation, resulting in partial overlapping of the encoding of the tastants NaCl and sucrose [2]. However, taste information processing differed between both tastants because positive and negative BOLD signals were observed [4-6]. Correlation analysis was performed between the neuronal networks in the cortical and subcortical regions (e.g., Fig. 3). A statistically significant correlation was observed (1) between the Cg and caudate-putamen (CPu) and between the Cg and VP for sucrose stimulation and (2) between the Cg and CPu and between the Cg and NAc for NaCl stimulation. These regions are involved in hedonic feelings and aversion because they play a key role in positive and negative emotional and affective processes, including food preferences [7,8].

Conclusion - The BOLD fMRI results revealed the functional representation of taste information processing, which may include rewards and aversion, during sucrose and NaCl stimulation in the rat brain.

References - [1] Yamamoto et al., J Neurophysiol 51:616-35, 1984, [2] Accolla et al., J Neurosci 27:1396-1404, 2007, [3] Kida et al., NeuroImage 56:1520-5, 2011, [4] Harel et al., JCBFM 2002, [5] Shmuel et al., Nat Neurosci 2006, [6] Schridde et al., Cereb Cortex 2008, [7] De Araujo et al. J Neurophysiol 90:1865-76, 2003, [8] Inui et al., Neurosci 177:66-73, 2011.