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Somatotopy of the Anterior Cingulate Cortex and Supplementary Motor Area for electric stimulation of the median and tibial nerves: an fMRI study

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Abstract—**In this study, we used functional magnetic resonance imaging (fMRI) to test the hypothesis of a somatotopy in the anterior cingulate cortex (ACC) and in the supplementary motor area (SMA) due to electrical stimulation of the wrist and the medial malleolus. Preliminary results showed a somatotopic organization in both ACC and SMA.**

Keywords— **Functional magnetic resonance imaging (fMRI), electrical stimulation, Somatotopy.**

I. Introduction

In humans, hand and foot have been electrically stimulated to focus on somatotopy in primary and secondary somatosensory cortical areas as revealed by fMRI [1]. In these studies, activation of anterior cingulate cortex (ACC) and supplementary motor area (SMA) has been observed [2]. Somatotopy of the cortical midline including anterior cingulate cortex and supplementary motor area has been investigated by PET during motor finger, hand, and eye tasks [3]. In this study, we tested the hypothesis of a somatotopy in ACC and SMA due to pure somatosensory stimulations of the wrist and the medial malleolus.

II. Methods

Fifteen right handed healthy volunteers ranging in age from 19 to 23 years (7 males, 8 females) were enrolled in this study after giving their written informed consent. The general procedures were approved by the local Institutional Ethics Committee.

The electric stimulus was a rectangular pulse with 2 Hz rate and 400 μs duration and was delivered in different recording blocks to either the right median or the right tibial nerve via non magnetic AgCl electrodes. The level of galvanic stimulation current corresponded to the motor threshold, eliciting a sustained thumb and hallux twitch. Stimulation of the median and tibial nerve was performed in separate runs.

BOLD contrast functional imaging was carried out with a SIEMENS MAGNETOM VISION scanner at 1.5 T by means of T2*-weighted echo planar imaging (EPI) sequences (TR 3 s, TE 60 ms, voxel size 4 mm x 4 mm, flip angle 90°, slice thickness 4 mm). Functional volumes consisted of 22 slices parallel to the AC-PC line. The experimental paradigm was a block design alternating a state of stimulation of 27 s with a control state having the same duration. For each run 84 volumes were acquired starting with a control period. A high resolution structural volume was acquired at the end of the session via a 3D MPRAGE sequence (slice thickness 1 mm, flip angle 12°, TR = 9.7 msec, TE = 4 msec).

Data were analyzed by means of the Brain Voyager 4.9 software (Brain Innovation, The Netherlands). Due to T1 saturation effects, the first 3 scans of each run were discarded from the analysis. Preprocessing of functional scans included motion correction and removal of linear trends from voxel time series. A three-dimensional motion correction was performed by means of a rigid body transformation to match each functional volume to the reference volume (the fourth volume, since the first three were discarded to avoid the T1 saturation effect) estimating three translation and three rotation parameters. Preprocessed functional volumes of a subject were coregistered with the corresponding structural data set. Since the 2D functional and 3D structural measurements were acquired in the same session, the coregistration transformation was determined using the Siemens slice position parameters of the functional images and the position parameters of the structural volume. Both preprocessed functional volumes and structural images were transformed into the Talairach space [4]. Statistical analysis was performed for individual subjects and the group using the general linear model [5], considering a separate predictor for each stimulated nerve. Individual and group statistical maps were thresholded at $p < 0.0004$ at the voxel level and a cluster size of at least four voxels was required. These thresholds yelded an overall significance level (the probability of a false detection for the entire

functional volume) of P<0.05, as estimated using a Monte-Carlo simulation [6]. The Talairach coordinates of activated areas were determined considering the centroid of the related cluster of activation. The mean coordinates across subjects for the activation in the ACC and the SMA were compared by means of ANOVA.

III. Results

The group analysis demonstrated a somatotopic organization in both ACC and SMA, as represented in Fig. 1. The median nerve area, as compared with the tibial nerve area, is more anterior in the ACC and more inferior in the SMA. These results were confirmed also by the ANOVA performed on a preliminary set of individual subjects data. The post-hoc test (Duncan) yielded p<0.003 when comparing the z-coordinates of SMA and p<0.01 when comparing the y-coordinates of ACC.

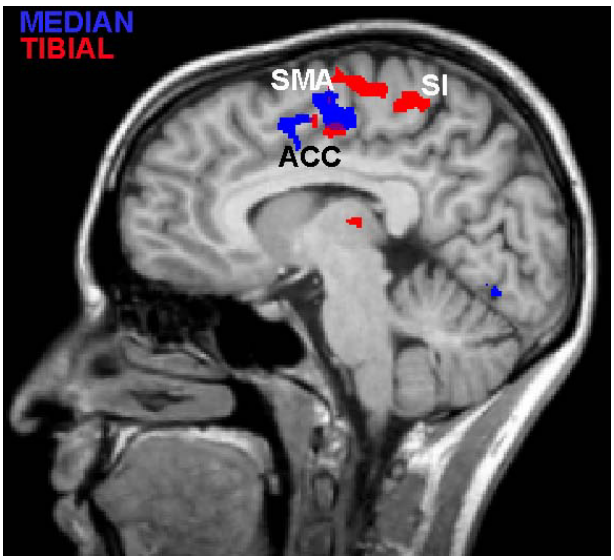

Fig. 1. Group statistical map superimposed on a Talairach transformed anatomical scan of one of the subjects.

IV. Discussion

We used functional magnetic resonance imaging (fMRI) to test the hypothesis of a somatotopic organization in the anterior cingulate cortex (ACC) and in the supplementary motor area (SMA) for electrical stimulation of the wrist and the medial malleolus. Functional maps showed a clear segregation of activation in the two different stimulation conditions.

The results of the present study support the working hypothesis of a spatial segregation of somatosensory inputs in cognitive-sensorimotor areas such as ACC and SMA.

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