BRAIN SURFACE CURRENT DENSITY MAPPING IN PIANISTS AND NON-PIANISTS

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Abstract-**Brain surface current density reconstructions are widely used to analyze magnetoencephalographic data arising from electrical activity in the human brain. Commonly, this mapping is performed in single subjects. We present a methodology to apply brain surface current density mapping to group studies. The technique includes stepwise transformation of the magnetic sensors into a standard sensor system and linear scaling of individual heads in Talairach space. We demonstrate the usefulness of the technique with a comparison of the motor activation in pianist and non-pianist while listening to piano pieces.**
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I. INTRODUCTION

In magnetoencephalography (MEG), one of the common types of data analysis is the reconstruction of the sources which produced the magnetic field measured. This analysis involves the estimation of the sites of cortical activity, as well as the estimation of the strength and orientation of this activation. Brain surface current density mapping is one of the most widely used techniques for the solution of this non-unique inverse problem. However, the standard implementations of brain surface current density mapping are not suited for group studies, where one would like to compare groups of patients or volunteers. Thus, we developed a methodology to perform brain surface current density mapping in group studies. The following paragraph gives an introduction to the study which serves as an example for our new methodology.

Musicians learn and perform quite complex trains of movements. They frequently report that listening to a well trained piece of music can trigger the associated movements (e.g. finger movements in pianists). This leads to the question whether the mere perception of music can involuntarily evoke the motor cortex activity needed to produce the same music. Using MEG we investigated the motor activation related to musical stimuli in pianists and non-pianists. In order to focus on the involuntary aspect of the activation of the motor cortex we chose a task that was completely unrelated to movements. If there was indeed an involuntary motor activation we would have expected increased activity in the motor areas in pianists, but not in non-pianists. Additionally, for activity originating from the primary motor cortex a spatial dissociation between the activity related to notes played with different fingers had to be expected.

II. METHODOLOGY

A. Data Acquisition

The study was carried out on 20 volunteers; 10 had a history of piano playing of at least 7 years (6 female; age 21.4 ± 3.1; all right handed). The other 10 subjects (all female; age 21.9 ± 2.8; one left-handed) had a comparable experience in producing music (11.9 ± 4.0 years vs. 13.2 ± 2.3 years in pianists). All of the non-pianists were singers in a university chorus. Some of them had played an instrument other than piano in the past (3 x strings, 5 x flute) for 4.8 ± 4.2 years. All subjects gave written informed consent to participate in the study. The study was approved by the ethics committee.

The stimulus material consisted of 24 sequences of well-known piano pieces, generated on a MIDI based synthesizer. All pieces were typical piano pieces without singing text or singing tradition and were played on a piano in order to avoid undesired silent singing. For each of the pieces, a second version existed, with one note out of key (roughly in the middle of the piece). These pieces were used as filler items. All pieces were played in a single voice (melody only, no bass) and contained between 18 and 64 notes of the principal theme. They where presented in a randomized sequence of 192 items with 3 seconds inter-stimulus interval. Each of the 48 pieces (24 correct and 24 incorrect) occurred exactly 4 times. The resulting 192 stimuli were divided into 4 block with several minutes break in between. Their sequence was balanced by presenting them in inverse order to half of the subjects in each group. The notes of the presented pieces were shown to the subjects before the experiment. The volume was adjusted to 45 dB above the individual hearing threshold at 1 kHz (separately for left and right ear).

Because this study focused on the involuntary activation of motor areas, the task for the subjects had to be unrelated. They were instructed to detect a certain piece of music and press a button (with the thumb of their dominant hand) when this piece contained a wrong note. The response button was held by the dominant hand during the entire experiment, the thumb resting on the button and the hand resting on the tight. They were further asked to relax, keep their heads and eyes still, and refrain from blinking as much as possible. The task was accomplished correctly by all subjects.

The measurements were performed with the subjects sitting with their eyes open in a magnetically shielded room. A total of 148 channels of MEG (BTi, MAGNES II, magnetometers), 2 channels of EOG (horizontal and vertical, bipolar), and 2 channels of EMG (bipolar) were recorded. The EMG was measured to make sure that no real movements

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were carried out (bipolar over both extensor and flexor digitorum communis muscles). EOG was used to detect eye movements. The sampling frequency was 506.7 Hz (band-pass 0.1 to 100 Hz). The position of the head with respect to the dewar was determined before and after each block.

In order to minimize superposition of the fields evoked by different notes, the trigger points were selected at the onsets of notes with at least 500 ms distance to both the previous and the following note. These notes were approximately equally distributed over the entire lengths of the pieces. Furthermore, all trials containing eye blink or movement artifacts and all trials associated to stimuli containing wrong notes were not used. This yielded about 225 sweeps per block average. Two additional sets of averages were computed by taking only those notes into account that are preferably played by the little finger or the thumb, respectively. The rating was done by a professional musician. This yielded about 30 sweeps per block and finger condition.

Due to the large drifts in the MEG signals it was necessary to perform a baseline correction per sweep. Because motor activity is to be expected from several hundred milliseconds before to several hundred milliseconds after the onset of the notes, there is no signal-free stretch of data. This makes it inevitable that the motor activity is diminished by the baseline correction. In order to gain the maximum statistical power, the baseline was chosen to cover the strongest non-motor activity, i.e. the primary auditory components (20..250 ms). Note that primary auditory components mainly consist of higher frequencies which are not projected into the analysis interval by a baseline of 230 ms length. We have to be aware, however, that part of the (slow) motor activity found in the analysis interval might originate from the baseline interval.

B. Transformation to average sensor positions

The averages of the 4 blocks belonging to one subject were transformed to an average sensor position using a source space projection scheme [1] and averaged. This source space projection scheme included an inverse computation where the sources were distributed on a sphere within the head. A minimum norm algorithm was employed to performed this inverse computation. Afterwards, a forward computation from the estimated source distribution allowed the prediction of the MEG data at the averaged sensor positions. The resulting subject averages were transformed again to the average sensor position of all subjects within each group (pianists or non-pianists). This two stage procedure proved more stable than the immediate transformation of the blocks to the global standard position. Now, for each subject, an average was available as if measured at the same sensor position, rendering the computation of grand averages and statistics possible.

C. Brain surface current density mapping

A localization of the sources of the MEG was performed. Because the targeted activity in the primary motor cortex is expected to suffer a great deal of both spatial and temporal overlap by other activity, we chose a localization scheme that does not require any a priori knowledge on the nature of the generators. This method, referred to as brain surface current density mapping [2], reconstructs tangential currents on the surface on the standard brain model.

This standard brain has been obtained by averaging a number of Talairach-scaled MRI scans. Then, the brain surface was extracted and triangulated (about 1100 triangles). The resulting model was used to construct a boundary element model, as well as to define the brain surface where the tangential currents were reconstructed. The surface for the source reconstruction was eroded by 1 cm in order to avoid numerical problems with the boundary element model. For every individual, the sensor array was linearly scaled in order to preserve the principal distances between the head surface and the sensors and therefore to account for different head sizes and shapes. Nasion, left and right ear and Cz anatomical landmarks of the individual head (originating from the Polhemus digitizer) were projected onto the surface of the standard head model and the sensor array was scaled by the distances between projected and original landmarks.

The data analysis was performed using ASA (A.N.T. Software B.V., Enschede, Netherlands).

III. RESULTS

We applied the brain surface current density method to the separate averages of the notes preferably played by the thumb and the little finger. The difference between pianists and non-pianists are depicted in Fig. 1. There is a clear dissociation between the localization of thumb and little finger, being separated about 8 mm in inferior-superior direction ($p=0.05$, multivariate test: thumb and little finger; inferior and superior region; source strength). This is in agreement with the motor homunculus and confirms the involvement of the primary motor cortex. Moreover, the Talairach coordinates (thumb: F c 3; little finger: E3 c 2), are in agreement with literature values for the hand area of the primary motor area (e.g. E-F b-c 3 in a PET study by Carey et al. [3]). We found additional activity in the left temporal region for both conditions. In the little finger condition the right occipital lobe was active, too.

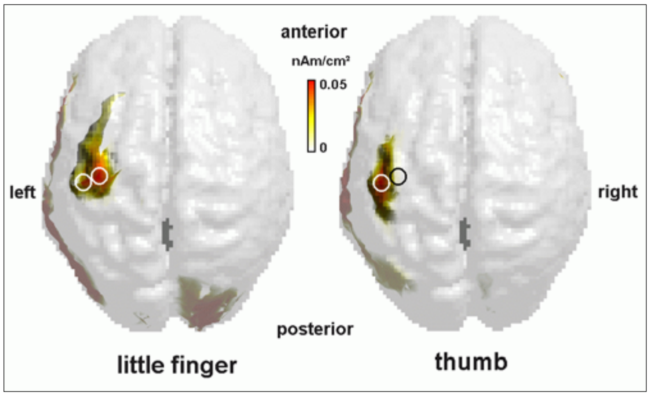

Fig. 1. Brain surface current density mapping results. The plots show the differences of the current source density between pianists and non-pianists group averages plotted on the surface of a standard MRI (light gray). The left brain displays the BSCD result for the little finger and the right brain for the thumb. Both centers of activation are indicated by a circle. The center of activation associated with the thumb is more left inferior than the center of activation for the little finger.

IV. Discussion

The aim of this study was twofold. First, we succeeded to show that brain surface current density mapping can be applied to group studies. Second, we could demonstrate that the mere perception of well-trained piano music can involuntarily evoke motor cortex activity in pianists. Moreover, we provide strong evidence that primary motor activity is involved in this process. However, there is no execution of movements.

Recently, there has been a different attempt to provide statistical processing of current density reconstruction results in group studies [4]. Both this previous approach and the one introduced in this paper have the advantage of being straight forward in the interpretation of the results. In addition, the approach presented here is readily available for most investigators in MEG research.

V. Conclusion

Using the methodology proposed in this paper, brain surface current density mapping is a powerful tool in the analysis of MEG in group studies.

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