

## A New Application of MEG and DTI on Word Recognition

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### ABSTRACT

This paper presented a novel application of Magnetoencephalography (MEG) and diffusion tensor image (DTI) on word recognition, in which the spatiotemporal signature and the neural network of brain activation associated with word recognition were investigated. The word stimuli consisted of matched and mismatched words, which were visually and acoustically presented simultaneously. Twenty participants were recruited to distinguish and gave different reactions to these two types of stimuli. The neural activations caused by their reactions were recorded by MEG system and 3T magnetic DTI scanner. Virtual sensor technique and wavelet beamformer source analysis, which were state-of-the-art methods, were used to study the MEG and DTI data. Three responses were evoked in the MEG waveform and M160 was identified in the left temporal-occipital junction. All the results coincided with the previous studies' conclusions, which indicated that the integration of virtual sensor and wavelet beamformer were effective techniques in analyzing the MEG and DTI data.

**Index Terms**— Word recognition, Virtual sensor, Magnetoencephalography, Diffusion tensor imaging

### 1. INTRODUCTION

Magnetoencephalography (MEG) is a relatively new technology for the measurement of neuromagnetic signals associated with brain activation [1-4]. Diffusion tensor imaging (DTI) can provide information about white matter fiber tracts in the brain [5].

There are extensive studies done in word recognition with MEG, using both sensor space analyses and different kinds of source localization methods [6,7]. But to our knowledge, the time course and neural network involved in word recognition with both MEG and DTI have not been reported. In the present study, we used the new source localization analysis of MEG data, and MEG source-guided DTI tractography. The objective of the present study was to investigate the neural network associated with word recognition with a specific focus on the interaction of the visual, auditory and language systems. The spatial location of word recognition in the brain was investigated using wavelet-based beamformer. The time course and

connectivity of word recognition in the brain was investigated with virtual sensor technique and DTI tractography. To address the aim, we presented the spoken and written words simultaneously. We hypothesized that the visual and auditory inputs were integrated in a brain area in a time window between the activation in primary auditory/visual cortices and the language functional areas. To test the hypothesis, we reconstructed the DTI tractography to track the connection of the cortical regions implicated in word recognition. The results may provide information about the spatiotemporal activations of auditory and visual inputs in the brain.

### 2. MATERIALS AND METHODS

#### 2.1. Subjects and stimuli

Twenty healthy, native English-speaking adults were recruited for the present study. In the twenty participants, all of them (age: 19-49, mean age: 30 years; 10 female and 10 male) qualified for the present study. A written informed consent approved by the Institutional Review Board (IRB) at Cincinnati Children's Hospital Medical Center (CCHMC), was obtained from each participant prior to testing.

The stimuli consisted of 120 words. All words were selected from the MRC Psycholinguistic Database, which is an online database interface that can output words according to the users' requests. All selected words were common-used verbs and nouns, which were categorized into frequent cluster in the Lexical Frequency Profile. And the words' phonetic lengths were less than four syllables. All the auditory and visual words were presented simultaneously. The visual words were presented on a backlit screen positioned at a comfortable position in front of the participants. The auditory words were recorded by an American native male English speaker and presented through earphones, and the spoken words' loudness was 40dB. The onset of the visual and auditory presentation was aligned. Word presentation and video/audio recording were accomplished and synchronized using BrainX software [3]. One hundred stimuli consisted of matched words, which meant that the visually presented word and auditorily presented word were identical; twenty stimuli consisted of mismatched words, which meant that the visually presented word was different from the auditorily presented word. The inter-stimulus interval was randomized between 2400 and

2600 ms to avoid the prediction to the stimulus onset by the subjects. The participants were asked to compare the visually presented words and the auditorily presented words. If the words did not match, the subjects were asked to press a button; no response was required when the visual and auditory stimuli matched.

## 2.2. Data acquisition

The MEG recordings were acquired in a 275-channel whole cortex CTF OMEGA MEG system (VSM Ltd., Port Coquitlam, Canada). The MEG measurements were performed in a magnetic shielded room (MSR) with a system white noise level below 10 fT/ $\sqrt{\text{Hz}}$ . The relative location of the subject's head to the sensor array was measured using three small coils affixed to the nasion and the left and right pre-auricular points.

All of the DTI images were acquired on a 3T Siemens Trio MR imaging scanner (Siemens, Erlangen, Germany). A 46-section, diffusion-weighted, spin-echo echo-planar imaging scan was acquired in the axial plane with the following parameters: TR/TE=6000/87 ms; FOV=25.6×25.6 cm; matrix=128×128; section thickness=2mm; b-value=1000 s/mm<sup>2</sup>; and 4 repetitions. Reference T2-weighted images (b=0) were also acquired. The duration of the DTI sequence was 5 minutes 48 seconds.

## 2.2. Data analysis

MEG data were averaged and then filtered with a band-pass filter of 20-200 Hz. Neuromagnetic responses (or deflections) were then identified with the averaged data using DataEditor (VSM MedTech Ltd., Port Coquitlam, BC, Canada). Subsequently, the latencies and the amplitudes of each recognizable response were measured using DataEditor.

Magnetic sources were localized using wavelet-based beamformer. The intensity of each voxel in the beamformer image was the strength of the brain activation at the designated location. Beamformer images were fused into MRI using Magnetic Source Locator (MSL) software based on the three matched fiducial points [3]. The maximal activation location, defined as the X, Y and Z coordinates of the largest magnitude voxel in a focal activation area, was used for quantitative comparison.

Virtual sensors were also computed with wavelet-based beamformer. The virtual sensor analysis revealed morphological characteristics, location, latencies of neuromagnetic activation and much more robust neuromagnetic activation than the physical sensor [4]. In this study, the virtual sensors were placed within the functional areas that were localized by wavelet-based beamformer at the voxel locations that showed peaks in functional activation.

DTI tractography was analyzed and computed using Riemannian framework [8]. MEG results were then co-registered with DTI scans to provide Regions of Interest (ROI) for evaluating tractography between those regions.

## 3. RESULTS

### 3.1. Waveforms

The waveforms corresponding to the matched words showed at least three clear reproducible responses (see Figure 1). The three responses were named as PM1, PM2, PM3, respectively. These three responses' latencies of averaged MEG physical waveform components were 104.1±5.2 ms, 198.8±6.0 ms, and 302.1±10.1 ms, respectively. Statistical comparisons were tested for the three responses' latencies from twenty participants using a paired t-test, with the result of significant differences ( $p < 0.05$ ).

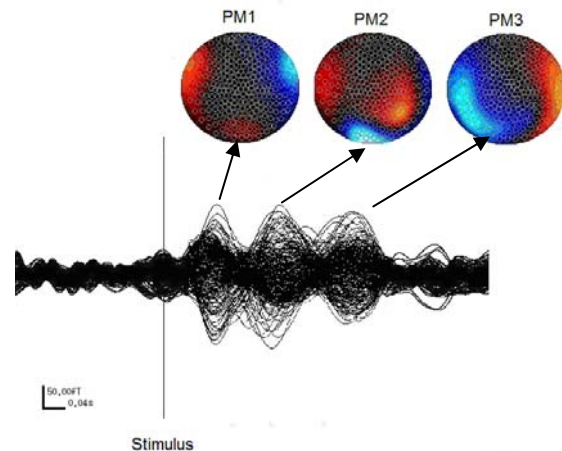


Fig.1 MEG waveform and topographical map of neuromagnetic activation elicited by visual and auditory words. Three neuromagnetic responses are clearly identified. They are named as PM1, PM2 and PM3, respectively. In topographical maps, red colour represents the incoming magnetic fields; blue colour represents outgoing magnetic fields. The magnetic source is located between the two magnetic fields. Each small circle represents one physical sensor.

### 3.2. Magnetic source localization

The neuromagnetic responses were localized using wavelet-based beamformers. The PM1 was localized in the occipital and temporal cortices for all participants (see Figure 2). The PM2 and PM3 were respectively localized in the left superior-posterior temporal cortex, namely Wernicke's area (18/20, 90%) and the inferior frontal cortex, namely Broca's area (18/20, 90%) (see Figure 2).

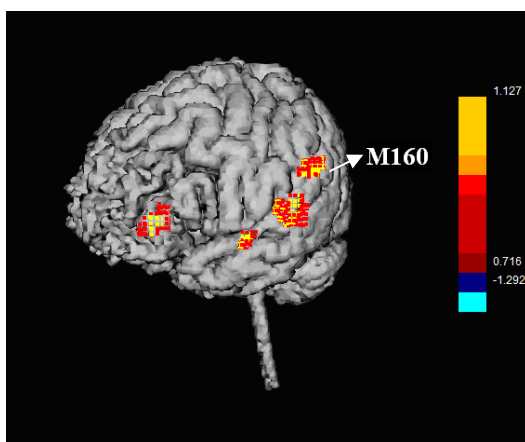


Fig.2 Magnetic source imaging showing the brain activation elicited by simultaneously-presented written and spoken words. The Broca's area, Wernicke's area, and the junction of temporal and occipital area are clearly identifiable. The white color arrow indicated the junction of temporal and occipital area. The colour bar indicates the colour coding of the level of activation.

### 3.3. Virtual sensor

To determine the time course of brain activation at source levels, virtual sensors were placed at the center of magnetic sources. The results showed that the peaks of the virtual sensors' latencies in the occipital, the left temporal and the right temporal cortices were  $95 \pm 3$ ,  $97 \pm 2$  and  $98 \pm 2$  ms, respectively. The amplitude of the virtual sensor response in the occipital region was significantly stronger than the activation in temporal cortices ( $p < 0.01$ ).

Virtual sensor waveforms also revealed activation in the left superior-posterior temporal cortex (Wernicke's area) and the inferior frontal cortex (Broca's area) at latencies of  $320 \pm 11$  ms and  $340 \pm 9$  ms, respectively. Although the amplitude of the virtual sensor response in Broca's area was larger than the response in Wernicke's area in 9 subjects, this difference was not statistically significant ( $p > 0.05$ ).

The junction of the left temporal and occipital region was activated around  $162 \pm 8.9$  ms in 20 participants. With spatial source localization and latency information, we considered that this component correlated with the responses in temporal and occipital cortices, and Wernicke's area.

### 3.4. DTI tractography

DTI tractography was computed based on the ROIs which were localized by magnetic source location and virtual sensor technology. In the left hemisphere, two DTI tractography pathways were found. One pathway connected Wernicke's area to Broca's area (20/20, 100%), which was named "pathway A" (see Figure 3); the other pathway connected the junction of the left temporal and occipital region to Broca's area (18/20, 90%), which was named

"pathway B" (see Figure 3). Noteworthy, there were also bunches of white fiber tract from the junction area to the temporal and occipital cortex. All these DTI tractography formed a white matter fiber network of word recognition.

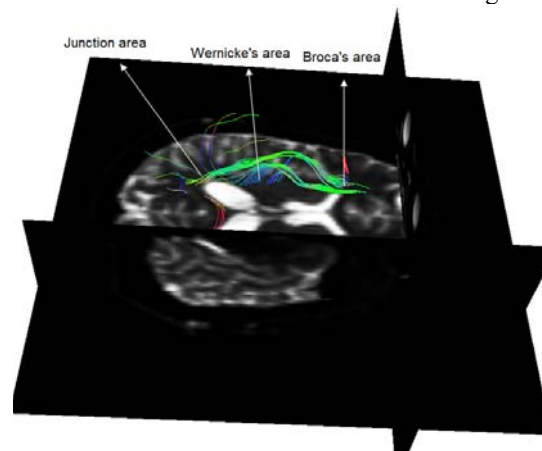


Fig.3 DTI tractography showing the neural network of task of comparing visually and acoustically presented words. The regions of interesting (ROI) are the functional localization guided by MEG. There are clear connections (fibers) between Wernicke's area, Broca's area, and the junction of the left temporal and occipital area. In the left hemisphere, two DTI tractography pathways were found. One pathway connected Wernicke's area to Broca's area (20/20, 100%), which was named "pathway A"; the other pathway connected the junction of the left temporal and occipital region to Broca's area (18/20, 90%), which was named "pathway B". The fibers' color indicated the main directions as follows: red was left-right, green was anteroposterior, and blue was superior-inferior.

## 4. DISCUSSION

To our knowledge, this is the first study focusing on the time course and neural substrates involved in word recognition with both MEG and DTI. Although not all the results of the present paper were surprisingly new, the merit of the paper is mostly finding corroborating evidence to the existing findings on word recognition by using a new source analysis technique. To reveal the time course, localization and neural network of neuromagnetic activation associated with word recognition, the present study used state-of-the-art source localization analysis (virtual sensor technique and wavelet beamformer source analysis), and showcased a methodological innovation, the use of MEG data to guide DTI tractography.

The neuromagnetic responses evoked by visual or auditory stimuli have been well studied. It is known that a auditory stimulus evokes a response around 100ms [9]. Similarly, visual stimuli evoke a neuromagnetic response around 100ms [10]. The MEG waveforms evoked by the present language paradigm showed a similar response around 100 ms (see Figure 1).

The results of the present study have demonstrated that the left posterior temporal and inferior frontal regions were

activated during word recognition. The neuromagnetic activations in the left posterior temporal and inferior frontal regions were considered to be localized to Wernicke's and Broca's areas, respectively. Neuromagnetic activations in the language cortices have been studied in previous reports [11]. The language areas identified in the present study are in agreement with these previous reports.

The novel results of the present study are the time-course and neural network revealed by MEG and DTI. We used both MEG and DTI to reveal the time course and the neural network. The results have demonstrated that there were clear connections between the visual cortex, Wernicke's area and Broca's area. Importantly, the M160 in the present study was just localized to the area which had connections to the visual and language cortices (see Figure 3). Since M160 was identified in latency between visual/auditory activation and language activation, it is reasonable to consider that this component represents the integration of auditory and visual inputs for word recognition. Thus, the results of the present study suggest that the bimodal temporal integration window occur around 160 ms. Similarly, there was a standard evoked response found in intracranial recordings [12], EEG [13] and MEG [6,7], the latencies of these peaks were around 170 ms (N/M 170) for visual stimuli like faces and words, whose sources were consistently found in the occipitotemporal cortex. In terms of latency, location and stimulus responsiveness, there were a lot of similarities between the standard N/M 170 and the activation reported in the present study. From Fig.2, we noticed that the location of the activation found in the present study was more superior than what was reported for the purely visual N/M 170, which was normally found in the inferior parts of occipitotemporal cortex. Therefore, it can very well be the case that this cluster of activation is not an instance of the regular N/M 170, but a new one for the activation of comparing visual words and auditory words.

The results of DTI tractography suggested that a neural network be involved in processing visually and acoustically presented words, and demonstrated that there was a brain area for integration of visual and auditory inputs in word recognition. Our findings can be reasonably explained by the framework of the language model of Price and Hickok [14]. They found that auditory information was first processed in primary auditory cortex, and then decoded phonologically in Wernicke's area. After being decoded, they postulated that the information was conveyed via two possible pathways: 1) from the superior temporal gyrus to Broca's area if the information was to be repeated immediately or 2) relayed to the cortex below the superior sulcus for lexical semantic comprehension. The lexical-semantic area is located on the boundary between the auditory and visual association cortex, receiving inputs from both Wernicke's area and primary auditory cortex, as well as the visual cortex [14]. The lexical-semantic area in their studies perfectly coincides with our virtual sensor results

both in time course ( $162 \pm 8.9$  ms, after auditory-visual activation and prior to activation in Broca's area) and space localization (the junction of temporal and occipital cortices). And the two pathways of conveying decoded information can also be seen vividly in the DTI tractography results, which were "pathway A" and "pathway B".

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