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Source Analysis of Bimodal Event-Related Potentials with Auditory-Visual Stimuli*

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Abstract—**Dipole source analysis is applied to model brain generators of surface-recorded evoked potentials, epileptiform activity, and event-related potentials (ERP). The aim of this study was to explore brain activity of interaction between bimodal sensory cognition. Seven healthy volunteers were recruited in the study and ERP to these stimuli were recorded by 64 electrodes EEG recording system. Subjects were exposed to either the auditory and the visual stimulus alone or the combined auditory-visual (AV) stimuli. The identification of brain areas of the EP was realized using CURRY 6.0 software. A source localization analysis was performed across conditions over initial, early and later temporal stages (i.e. 3 stimuli conditions × 3 temporal stages). The source locations across conditions were contrasted over similar time periods, indicating that source location of the bimodal auditory-visual (AV) stimuli differed from the sum of source locations from the auditory and the visual stimulus alone. These data provide evidence that there exists interplay in the brain in the bimodal auditory-visual stimuli paradigm.**

I. INTRODUCTION

To produce a unified percept of our surrounding environment, the brain must integrate multiple types of sensory information. An increasing number of studies are revealing how the brain achieves such multisensory integration. Evidence is mounting that multisensory interactions occur early in time post-stimulus onset and also within areas typically considered uni-sensory in their function, including even the primary cortices[1]. From such findings, new models of brain organization are being developed that incorporate the occurrence of multisensory interactions and integration both at low(e.g. primary visual cortices) and high levels(e.g. superior temporal sulcus, the intraparietal complex, and the frontal cortex) of processes and also at early and late time following stimulus presentation[2-4].

Although more attention was paid to how the brain integrates multisensory information, it remains unknown how the brain regions vary under multisensory stimuli compared with uni-sensory conditions, and what the difference and relationship are between the multisensory versus unisensory experiences. Joassin et al. have discussed the implication of unimodal and multisensory convergence regions by a source localization analysis from the face recognition perspective [5], and the result was that the dipole modeling always included the superior colliculus, a mid-brain structure considered as a multimodal convergence region, which has been observed in an ERP study investigated the auditory–visual object recognition processes[6, 7]. Raphaël V. Meylan, Micah M. Murraya reported that AV multisensory interactions attenuate subsequent visual responses in humans, and their source estimations indicated that attenuation occurred within low-level visual cortices. Multisensory interactions are ongoing in low-level visual cortices and affect incoming sensory processing[1]. In 2007, Durk Talsma et al. studied interactions between multisensory integration and attention using a combined audiovisual streaming design and concluded that a superadditive audiovisual integration effect was observed on the P50 component when both the visual and auditory senses were attended, this effect was reversed when un-sensory percept or multisensory object attended, and the P50 components of multi- sensory ERPs were smaller than the uni-sensory sum[3]. Mishra et al. showed that short-latency ERP activity located in auditory cortex and polymodal cortex of the temporal lobe, concurrent with gamma bursts in visual cortex, were associated with perception of the double-flash illusion[4]. These results provide evidence that perception of the illusory second flash is based on a very rapid dynamic interplay between auditory and visual cortical areas that is triggered by the second sound[8].

The present research was aimed to explore brain activity of interaction between bimodal sensory cognition, and it focused on dipole source analysis of event related potentials with AV stimuli and response these sources to known areas of activity, and compared the results with that from separate visual / auditory stimulus.

II. MATERIALS & METHODS

A. Subjects

Seven right-handed healthy college students (4 male, 3 female; mean age of 21.9 years) participated in the study after giving written informed consent. Each participant had normal or corrected-to-normal vision and normal hearing.

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B. *Experiment design*

The experiment was conducted in a soundproof chamber having a background sound level of 31 dB and a background luminance with intensity of 2 cd/m2. The subjects were asked to sit on a comfortable chair positioned at a viewing distance of 60 cm to the CRT monitor, be relaxed, focus attention, keep head still, and with eyes staring at the center of the monitor during the experimental session. Error reaction data caused by head and eye movements were excluded.

The experiment equipment for stimulation is the Neuro Scan STIM2 system applying Oddball paradigm[9], the key point of this paradigm is two different kinds of stimulation are applied on the same sensory channel, but the probability of one stimulus is larger, such as 85%, the other is smaller, such as 15%. Visual (V) and auditory (A) stimulus was delivered respectively, both include target and non-target modality. Visual stimulus were green solid round with diameter of 3cm as target V, and red solid round with diameter of 3cm as none-target V', both last on the center of the CRT monitor for 60ms. Auditory stimulus was a 60ms, 80 dB 2 kHz target pure tone A and a 60ms, 80 dB, 1 kHz non-target pure tone A', delivered from a speaker. Eight different stimuli combinations were presented in random order on each block of trials, which included uni-modal auditory stimulus of pure A or pure A', unimodal visual stimulus of pure V or pure V', and bimodal stimuli combinations included AV, AV', VA', and A'V'. Fig. 1 is the schematic diagram of combined stimuli.

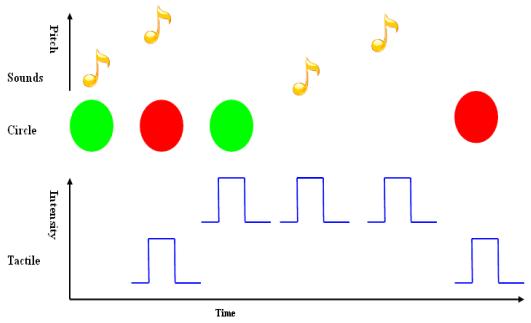

Fig.1 Diagrammatic drawing of different stimuli configurations

The stimuli were delivered in 5 blocks with 150 trials. Each of the eight stimuli combination occurred on each block in a randomized sequence. All stimuli appeared with the probability as 10%, 20%, 10%, 20%, 10%, 10%, 10%, and 10%, and were presented at irregular intervals of 2 ms. All subjects had prior experience before the experiment with 50 trials. The subject was required to make a judgment as soon as they perceived target stimuli after each stimulation, to press down the button on the reaction box with the right forefinger, and also to count the number of target stimuli. Simultaneously, reaction time, correct or not, the EEG data were recorded.

C. *Electrophysiological data recordings and preprocessing*

The EEG data were recorded from 64 surface electrode sites using Neuroscan system in seven normal subjects throughout the experimental session. The electrodes were located according to the 10-20 system. Reference electrode was at the parietal lobe. Electrode impedances were kept below 5 kOhm (Fig.2), and the bandpass was 0.05-100 Hz. The EEG data was filtered at 0.05-30 Hz, and stored for later analysis. The EEG epoches weer averaged from 200 ms before to 800 ms after stimulation onset. Artifact caused by eye movements, blinks, or amplifier blocking was rejected from each sweep, and baseline correction (-200 ms ~ 0 ms) was performed before source analysis so that the mean of the 200 ms prestimulus voltages was zero. Data from the eight kind stimuli were averaged accordingly.

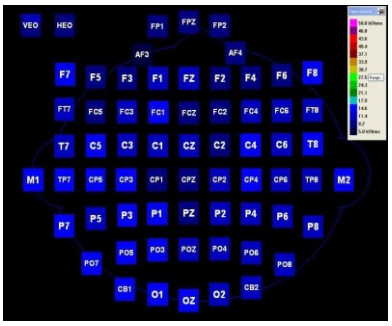

Fig.2 Position of the 64 electrodes on the spherical head model

Fig.3, Fig.4 and Fig.5 were the averaged EEG of one subject recorded from 64 electrode sites with unimodal auditory (A), visual (V) stimulus and bimodal auditory-visual (AV) stimuli respectively. In these figures, the reference electrode is the average reference, and the time window is the interval between 200 ms before the stimulation and 1000 ms after the stimulation. Blue waveforms in each figure are the EOG (HEO or VEO) and bilateral mastoid potentials, yellow waveforms are the potentials from the other electrodes for source analysis, red waveforms are mean global field power (MGFP), the time period for source analysis can refer to the peak time of MGFP with 75% of peak MGFP as the boundaries.

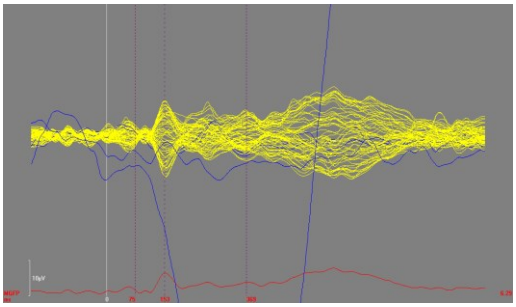

Fig.3 The averaged EEG of one subject recorded from 64 electrode sites with unimodal auditory (A) stimulus

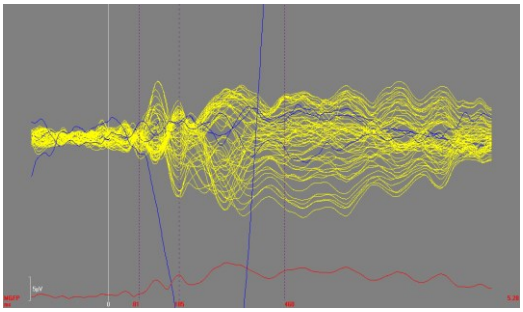

Fig.4 The averaged EEG of one subject recorded from 64 electrode sites with unimodal visual (V) stimulus

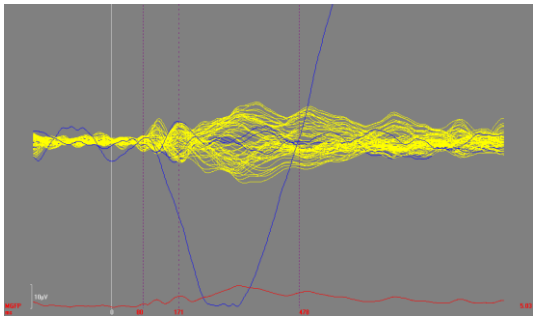

Fig.5 The averaged EEG of one subject recorded from 64 electrode sites with bimodal auditory-visual (AV) stimuli

D. Source analysis

Dipole source analysis was performed on the average ERP data of five applicable subjects using CURRY 6.0 software.It has been extensively used to model brain generators of surface-recorded evoked potentials, epileptiform activity, and ERP[11]. This method offers a noninvasive approach to the localization of areas in the brain that generate surface recorded electrophysiologic signals. By calculating potential variation of brain surface when the neurons was excited, the position and intensity of equivalent dipole can be found[10]. To determine the accuracy of the dipole position, and whether the brain electrical activity is concentrated in practical application, the measurement of related variance and neurophysiology were analyzed[12,13].

In the experiment, an average human model was used to obtain the thickness of brain, skull and scalp surface by virtue of average MRI on the basis of three balls model[13]. A fixed dipole method was applied in which the position of the dipoles was constrained while their orientation and strength remained free. The applied coordinate system was PAN (R, A, S), namely the X axis point to the right end across left and right mastoid, the Y axis points to the tip of the nose, the Z axis is up.

III. RESULTS

Fig.6 is averaged evoked potentials with bimodal auditory-visual stimuli at electrode site FCz from one of the subjects. The time windows were defined by means of global field power (MGFP). Dipoles were fit to the time intervals around the peaks in MGFP using a 75% of peak GFP criterion[11].

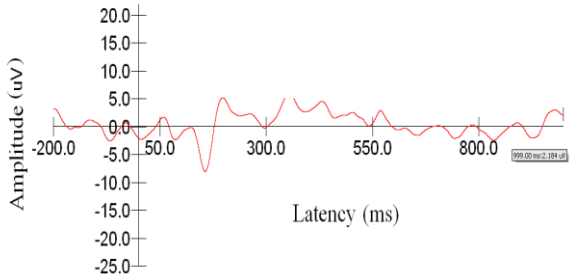

Fig. 6 The averaged evoked potentials in response to bimodal auditory-visual target stimulus recorded from electrode FCz of one subject

Dipole modeling was performed within the time window of each wave (Table 1). For the 80-95 ms time window, the auditory and visual electrophysiological results were best explained by one pair of bilateral dipoles localized in the middle temporal gyrus (MTG) and inferior occipital gyrus (IOG), respectively. Under auditory-visual stimuli, the electrophysiological results were best explained by two pairs of bilateral dipoles localized in the thalamus and middle occipital gyrus (MOG) with an explained variance of around 85%. For the 160-190 ms time window, the visual electrophysiological results were best explained by one pair of bilateral dipoles localized in the superior temporal gyrus (STG) , that of visual were best explained by two pairs of bilateral dipoles localized in the lobulusparietalisinferior (LPI)and the middle occipital gyrus (MOG), and that of auditory-visual were best explained by two pairs of bilateral dipoles localized in the gyrus frontalis inferio (IFG) and middle temporal gyrus (MTG) with an explained variance of above 90%. Finally, for 380-420 ms time window, the electrophysiological results were best explained by two pairs of bilateral dipoles localized in the hippocampus (HP) and thalamus under auditory stimulus, in the thalamus and middle temporal gyrus (MTG) under visual stimulus. The scalp cerebral activities were best explained by 5 dipoles, with one pair of bilateral dipoles localized in the gyrus frontalis superior (SFG), one pair in the thalamusnd, and one in the precuneus.

Table 1. Averaged dipole modeling of event-related potentials of five subjects with unimodal audio/visual and bimodal audio-visual stimuli

Stimulus Type	Time Window (ms)	Optimal Time (ms)	Explained Variance (standard) (%)	Cerberal area
A	80-95	89	84.22	(R)(L) MTG
V		88	86.60	(R)(L) IOG
AV		87	96.91	(R)(L)Thalamus (R)(L)MOG
A	160-190	171	95.78	(R)(L) STG
V		179	97.19	(R)(L) LPI (R)(L)MOG
AV		173	96.26	(R)(L)IFG (R)(L) MTG
A	380-420	400	96.93	(R) (L) HP (R)(L)Thalamus
V		407	97.94	(R)(L)Thalamus (R)(L)MTL
AV		400	98.04	(R)(L)SFG (R)(L)Thalamus (L)Precuneus

Cerberal area: MTG--middle temporal gyrus; STG--superior temporal gyrus; IOG--inferior occipital gyrus; MOG--middle occipital gyrus; HP--hippocampus; PLI--lobulusparietalisinferior; SFG--gyrus frontalis superior; IFG--gyrus frontalis inferior; MTL-- middle temporal lobe. L--left, R--right.

IV. DISSCUSSION & CONCLUSION

The present study aimed at comparing the dipoles source of auditory and visual between umimodal and bimodal conditions at the electrophysiological level. For the early time period of 80-95 ms, we observed that auditory activity was best explained by one pair of bilateral dipoles localized in the middle temporal gyrus namely auditory area, and visual

activity source labeled C1 component was in the occipital lobe namely visual area[14], whereas the auditory-visual bimodal was in the thalamus and occipital lobe, which demonstrated bimodal source was not the simple addition of the unimodal conditions. Driver, Ghazanfar stated that the channel integration function of thalamus, with the result that the occipital lobe was derived from the feedback of thalamus to visual under auditory-visual stimuli[2, 5, 15]. Their results gave us new clue to understand the multi-modal l internal interaction mechanism.

At the 160-190 ms period, the auditory electrophysiological source labeled N1/P2 component were located in the superior temporal gyrus, the visual source in the parietal lobe and the occipital lobe, which was both the ventral and dorsal streams bifurcated from primary visual cortex[13], whereas the auditory-visual bimodal source was in the parietal lobe and frontal lobe. The results indicated bimodal source was not the simple addition of the unimodalsource. Ghazanfar reported the channel integration function of frontal lobe[2], thus reflects the source of parietal lobe was the feedback of frontal lobe to auditory.

Finally, from late dipole source analysis results about the 380-420 ms period, auditory component (namely P3) was related to cognitive, memory and other brain activities, and the effect source was located in the hippocampusand thalamus, consistent with those obtained by Tarkka and Horovitz[16, 17]. The visual source were located in the hypothalamus and temporal lobe, similar to the late visual source analysis by Yamazaki and Bledowski[13,18]. The auditory-visual bimodal source was in the thalamus, the frontal and occipital lobe, it once again demonstrated that bimodal source was not the simple addition of the unimodal source, they had same sources, and may be considered as the negative feedback from thalamus and frontal lobe to occipital lobe.

In summary, we have observed the different electrophysiological sources with unimodal of audio and visual stimuli and auditory-visual stimuli which suggests the presence of auditory-visual interaction area. This research may provide the basis of the promoting effect of bimodal stimuli for brain computer interface, and present a new tool for the study of multi-modal interaction.

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