P300 Topographical Maps of Tone Perception in the Tonal Speaker Brain

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Abstract: p300 components were used to investigate the processing of different sounds in the human brain function. Defining the scalp topography of the p300 components by means of reference-independent methods and identifying its electrical cortical generators by using the standardized low-resolution electromagnetic tomography (sloreta) are the aims of this study. Compared to the rare non-target tone, the rare target tone elicited a more prominent p300 occurring later than that of the rare non-target one. The rare non-target and rare target stimuli showed different scalp topography and cortical sources. Sloreta computation of the p300 responses yielded clear frontal region in both stimulus types. However, the rare non-target tone electrical filed had a more posterior distribution as compared to the rare target tone and its generators were localized in frontal area. The rare target tone produced p300 maximum over the medial frontal gyrus (mfg), whereas maximum of the p300 activated by the rare non-target tone was observed over the superior frontal gyrus (sfg). Differences in scalp topography and cortical sources suggest that two stimulus types reflect different neural processes. The findings on cortical generators are in line with the hypothesis that p3a reflects the automatic allocation of attention, while p3b is related to the effortful processing of task-relevant events.

Key words: Human Brain, Attention, Scalp Topography, Sound, Perception, Standardized Low-Resolution Electromagnetic Tomography (sLORETA).

INTRODUCTION

Human central auditory system has a remarkable ability to establish memory traces for invariant features of acoustic sounds in the environment such as human speech sound and music, in order to correct the interpretation of these natural acoustic sounds heard (Näätänen R. et al., 1978). Event-related potential (ERP) recordings have brought new insight to the neuronal events behind auditory change detection in audition of the human brain function. Theoretically, ERPs components reflect the conscious detection of a physical, semantic, or syntactic deviation from the expected sounds (Näätänen R. et al., 1978). The ERP recordings thus allow one to probe the neural processes preceding the involvement of the attentional mechanisms. The so-called “P300” is the most well known component of the brain event-related potentials (ERPs). P300 is independent of the stimulus physical properties and reflects attention/memory processes related to changes in the neural representation of the environment induced by new sensory inputs (Johnson R., 1988; Picton T. W., 1992). The oddball paradigm has frequently been used to record the P300. The P300 potential is generally recorded across the scalp and has its maxima over the midline central and parietal leads, at about 300 ms after the onset of the rare target stimulus (Volpe U. et al., 2007).

The present study compared attentional non-musician brain processes during the discrimination of the different synthesized acoustic sounds by using a modified (three acoustic sounds) auditory oddball paradigm to record P300 of ERPs in a group of healthy subjects. This study chose to record and compared the P300 elicited by these synthesized acoustic sounds, hoping to find evidence for specific brain signatures of acoustic sound processing in the non-musician brain.

MATERIALS AND METHODS

Subjects:

Eleven healthy Thai-speaking right-handed adults (eight women) and their age range: 22-26 years. They had normal hearing, corrected to normal vision and had no history of neurological or psychiatric history. In order to identify the non-musician professional, none of them had more than three years of formal musical training and none had any musical training within the past five years.

Stimuli and Procedures:

Stimuli consisted of a set of three synthesized acoustic sounds that were distinguished by frequencies (Hz). The stimuli were digitally edited using the Cool Edit Pro v. 2.0 (Syntrillium Software Cooperation) with 300 ms
duration. Three stimuli were binaurally presented through headphones at a comfortable listening level of ~85 dB, with different pitch contour: Tone 1 with high-level, Tone 2 with high-rising, and Tone 3 with low-dipping. The stimulus sequences presentation was controlled by the stimulus system (STIM2, Neurosoft, Inc. Sterling, USA). ERPs were recorded during a three-tone auditory oddball paradigm. The Tone 3 of low-dipping with 15% probability was designed as the rare target stimulus (RT), which required the subject to press a button at its occurrence; the Tone 2 of high-rising with 15% probability and Tone 1 of high-level tones with 70% probability were designed as rare non-target (RNT) and frequent non-target (FNT), respectively.

Electroencephalographic Data Processing:
EEG was recorded with a Quick-Cap equipped with 64 channels according to the international 10-20 system using Scan system (Scan 4.3, Neurosoft, Inc. Sterling, USA). Reference electrode was at mastoids. The signals were bandpass filtered at 0.05-100 Hz and digitized at 1000 Hz. The impedance of the electrode was below 5 kΩ. Eye movements were monitored with two EOG electrodes. EEG was segmented into 1000 ms epochs, including the 100 ms pre-stimulus period. The average waveforms obtained from the frequent non-target, rare non-target and rare target stimuli were digitally filtered by a 0.1 - 15 Hz band-pass filter and finally baseline-corrected. The presence of a prominent P300 was identified by measuring the integrated power amplitudes over the 40-ms time window centered on the P300 peak in the deviant and target waveforms. The brain electrical microstates technique developed by Koenig and Lehman (Koenig T. and Lehmann D., 1996) was used to obtain a reference-independent estimate of the P300 scalp topography.

Spatial Analysis:
The average P300 latency was defined as a moment of the global field power (GFP) with an epoch of 40-ms time window related stable scalp-potential topography (Lehmann D., 1987). The individual momentary potential measures from 21 electrodes at the P300 latency were analyzed with sLORETA to determine the P300 distribution and source loci. The three-dimensional distribution of the P300 cortical generators was analyzed for each subjects and stimulus types (rare non-target and rare target tones) using the sLORETA software (Pascual-Marqui R. D. et al., 1994).

Statistical Analysis:
The statistical significance of P300 was tested with paired-sample t-tests between the P300 amplitude and latency of the rare non-target and rare target tones. Repeated measure ANOVA was carried out on the topographic descriptors of the P300 microstate each stimulus type. In order to gather information on cortical sources specifically involved in the P300 generation, sLORETA images for rare non-target and rare target tones were compared with those for frequent non-target tones using paired t-test statistics, after logarithmic transformation of the data.

RESULTS AND DISCUSSIONS
The grand-average ERP-related components for auditory P300 for each stimulus type are shown in Fig. 1. The results of the grand-mean ERPs waveform analysis demonstrated that significantly different neuronal populations were active between 476 to 487 ms when both stimulus types were present. The mean P300 amplitudes to rare non-target and rare target tones were 0.043 (±0.003) ms and 5.706 (±0.008) ms, respectively. The paired-sample t-test revealed a significant difference between stimulus types (t(10) = -3.77; p < 0.001). The P300 component was significantly larger for rare target to ne compared to rare non-target tone in the posterior electrode sites, being maximum at Pz.

ANOVA on the GFP values yielded a significant main effect of the stimulus types (F_{1,21} = 94.28; p < 0.0001). Follow-up ANOVAs demonstrated that GFP values were higher for rare target than rare non-target tones (F_{1,21} = 97.85; p < 0.0001). Topography of the P300 elicited by rare target tones was significantly different from that of the P300 elicited by rare non-target tones (F_{1,21} = 22.97; p < 0.0001).

sLORETA t-test maps for both stimulus types are depicted in Fig. 4. The detailed summary of the t-scores and of the Talairach coordinates for the activated cortical areas is provided in Table 1 and Fig. 4. Table 1 and Fig. 4 demonstrate the xyz-values of the foci with strongest activation in Talairach space. Stronger activation for the rare target tone was found at 487 ms in the Medial Frontal Gyrus (MFG) (-5, 65, -15; t-value, 2.52), while the rare non-target tone most strongly activated at 476 ms in the Superior Frontal Gyrus (SFG) (-5, 65, -10; t-value, 2.04). Analysis of the P300 responses indicated frontal area laterality in both stimulus types (t(10) = 9.21; p < 0.001).
Fig. 1: ERPs grand average time course, displayed at vertex electrode sites; anterior (Fz, Cz) and posterior (Pz, Oz). Vertical scale: amplitude, expressed in microvolt; horizontal scale: time, expressed in milli seconds (range: -100-900 ms); Arrows point to P300 component.

The ERP segmentation procedure of rare non-target and target tones identified four brain electrical microstates (MS). The timeframe 410-700 (rare non-target tone) and 401-785 (rare target tone), corresponding to the P300 component, were selected for further analyses (see Fig. 2 and 3).

Fig. 2: Global field power (GFP) of grand average of (a) rare non-target and (b) rare target tones, with the time frames of the four identified brain electrical microstates, is shown as a solid line (Y axis: arbitrary units; X axis: time).

Table 1: Stereotaxic Coordinates of the P300 Activation Foci for the Rare Non-Target and Rare Target Tones.

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>Region of Interest (ROI)</th>
<th>Coordinates (mm)</th>
<th>sLORETA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rare Non-target</td>
<td>Superior Frontal Gyrus (SFG)</td>
<td>11 -5 65 -10</td>
<td>2.04</td>
</tr>
<tr>
<td>Rare Target</td>
<td>Medial Frontal Gyrus (MFG)</td>
<td>11 -5 65 -15</td>
<td>2.52</td>
</tr>
</tbody>
</table>

Discussion:
The main finding of this study indicates that the prominent response to both stimulus types elicited P300 peaking at 476 to 487 ms from stimulus onset. The magnitude of the acoustic difference was reflected by the P300 amplitude, showing larger P300 amplitudes in the rare target tone compared to the rare non-target one. Source analyses indicated strongest P300 responses presenting in the frontal region, possibly involving the attentional, perceptual and memory processes with a more fronto-parietal distribution. The P300 response to the rare target tone was delayed compared with that for the rare non-target one. There was a more posterior distributed P300 to the rare non-target tone than to the rare target tone.
Fig. 3: Momentary potential distribution map, location of extreme potentials and centroids of positive and negative map areas. Scalp electric potentials microstate corresponding to P300 components at 476 ms for (a) rare non-target and at 487 ms for (b) rare target tones; head seen from above, left ear left; the color scale represents positive (red) and negative (blue) electrical activity values vs. average reference. Momentary potential distribution map displayed as Equipotential line map (Equipotential lines in steps of 2.5 µV).

Fig. 4: Graphical representation of the sLORETA $t$-statistic comparing the P300 responses at the time point of the individual peak for the (a) rare non-target (476 ms) and (b) rare target tones (487 ms). The scales on the right show negative (blue) and positive (yellow) $t$-values. Positive values (yellow) represent significantly increased electrical activity for rare non-target (a) and rare target (b) in an axial, a sagittal and a coronal slice through the reference brain.

Several studies have reported that attended to (rare target) and ignored infrequent (rare non-target) stimuli elicit different P300 components, i.e., P3a and P3b components, reflecting different attentive and integrative processes (Volpe U. et al., 2007; Brazdil M. et al., 2005; Knight R. T., 1984; Squires N. K. et al., 1975). P3a reflects a stimulus-driven attentional shift, while P3b reflects the process of effortful attentional allocation and stimulus evaluation for task relevance (Debener S. et al., 2002; Goldstein A. et al., 2002; Patel S. H. and Azzam P. N., 2005; Polich J, 1989; Polich J, 2003). The present findings are in the line with the hypothesis that P3a reflects automatic allocation of attention which generated in fronto-parietal regions, the cerebral network for the orienting of attention (i.e., a shift of attention towards new and/or unexpected stimuli (Friedman D. et al., 2001). In the mean time, the P3b is largely independent from response selection and mainly reflects stimulus categori-
zation activity (Volpe U. et al., 2007). Regarding to the time course analyses, the present findings are in line with previous studies indicating that frontal area showed an early peak and a subsequent decrement of activation. Moreover, several brain imaging studies indicate the involvement of a more posterior and distributed neural network with respect to P3a, including associative cortices implicated in attentional, perceptual and memory processes, and support the view that P3b represents effortful processing of task-relevant events (Bledowski C. et al., 2004; Clark V. P. et al., 2000; Kiehl K. A. et al., 2001; (Kirino E. et al., 2000; Opitz B. et al., 1999). Furthermore, both frontal lesion studies (Knight R. T., 1984; Kiehl K. A. and Liddle P. F., 2003) and dipole studies (Friedman D. et al., 2001; Opitz B. et al., 1999) have clearly shown that the orienting response requires a frontal lobe engagement, confirming the relationship between frontal activity and the P3a component.

sLORETA source analysis demonstrated that both stimulus types produce P300 components involving similar brain sources. The rare target tone elicited a P300 component with maximum amplitude at the superior frontal gyrus (SFG), whereas in the rare non-target tone, the P300 component was maximal at the medial frontal gyrus (MFG). The source analysis suggested P300 sources to be in the vicinity of the frontal area with a more posterior distribution for the rare non-target tone. It may be that the different topographies of the neurophysiological brain response reflect differential cortical distributions of the underlying neuronal assemblies. Several previous fMRI studies have been reported that a wide fronto-parietal network could represent the neurophysiological substrate of P3a (Volpe U. et al., 2007; Bledowski C. et al., 2004; Clark V. P. et al., 2000; Kiehl K. A. et al., 2001; Kiehl K. A. and Liddle P. F., 2003). Moreover, some previous fMRI studies, dealing with P3b component arising from an oddball auditory stimulation, reported that its generators were located in frontal, parietal, cingulated and temporal areas (Brazdil M. et al., 2005; Clark V P, Fannon S. et al., 2000; Cahloun V. D. et al., 2006; Horn H. et al., 2003; Linden D. E., 2005; Stevens M. C. et al., 2006), along with the contribution of insular (Horn H. et al., 2003; Linden D. E. et al., 1999), subcortical (Brazdil M. et al., 2005), and cerebellar activations (Clark V. P. et al., 2000; Kiehl K. A. and Liddle P. F., 2003). Therefore, the present study about the source activities underlying a target detection task are consistent with those reported in recent studies by Mulert and colleagues (Mulert C., et al., 2004) and Volpe and colleagues (Volpe U. et al., 2007) who also used similar LORETA source analysis.

**Conclusion:**
The ERP-related components of P300 is more sensitive to the rare target sound rather than to the rare non-target one. Automatic detection of the target sound may be a useful index of auditory memory traces of music sound attention and cognition in the human auditory cortex.

**REFERENCES**


