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Neural Correlates of Complex Tone Processing and Hemispheric Asymmetry

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Neural Correlates of Complex Tone Processing and Hemispheric Asymmetry

Peer Review

This work has undergone a double-blind review by a minimum of two faculty members from institutions of higher learning from around the world. The faculty reviewers have expertise in disciplines closely related to those represented by this work. If possible, the work was also reviewed by undergraduates in collaboration with the faculty reviewers.

Abstract

In an effort to further explore the role of the right hemisphere in auditory processing, this study utilized brain event-related potentials (ERPs) and standardized low resolution brain electromagnetic tomography (sLORETA) in order to localize electrical brain activity of complex tone processing. Participants engaged in a diotic pitch discrimination task while ERP components were recorded from 28 electrodes on the scalp. ERPs were analyzed via individual/group average area measurements and were submitted to sLORETA for neural source localization. Results showed stronger right vs. left hemisphere activation to complex tone processing that was localized to regions of the auditory cortex. Findings support the notion that auditory cortical regions in the right hemisphere may be involved in music processing. Moreover, these findings indicate that source localization methods may be a good approach to study the complex nature of brain electrical activity during cognitive processing.

Keywords

hemispheric asymmetry, spectral processing, sLORETA, ERP, P300

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INTRODUCTION

It has been well established that functional hemispheric asymmetries exist regarding speech processing. Specifically, speech has been shown to be dominantly processed in the left hemisphere (Belin, Zatorre, Lafaille, Ahad, & Pike, 2000; Rosen et al., 2011). In contrast, music is speculated to be dominantly processed in the right hemisphere (Zatorre, Belin, & Penhune, 2002). However, there has been a wide debate about the nature of the right hemisphere involvement.

Several lines of research suggest that the right auditory cortex may play a key role in music processing. Specifically, spectral and temporal features of sounds may be crucial factors for auditory encoding and perception (Zatorre et al., 2002). For example, behavioral studies have shown spectral processing to be important for music perception, while speech perception tends to rely more on temporal processing (Warrier & Zatorre, 2002). These differences in auditory processing may be the cause of asymmetric neural activities between hemispheres during speech and music processing.

In addition, Zatorre and Belin (2001) used PET imaging to investigate auditory cortical responses to spectral and temporal variation. Findings showed that responses to spectral features were weighted toward the right hemisphere, providing evidence that right hemispheric auditory cortical areas may be specialized for spectral, and thus music perception.

The role of the right hemisphere in auditory processing has also been studied using brain event-related potentials (ERPs). For example, Greenwald and Jerger (2003) showed a right hemisphere processing bias for complex spectral tones and that the P3 brain wave may be a good indicator of hemispheric specialization. However, the

specific auditory cortical regions involved in spectral processing remains an open question.

One interesting avenue for investigating these types of issues may be found in cortical source localization methods. These methods have been developed to directly link scalp-recorded ERP potentials with cortical activation. One of the more promising source localization approaches is found in Standardized Low Resolution Electromagnetic Tomography (sLORETA) developed by Pascual-Marqui (2002). This method is a non-invasive functional brain imaging technique that estimates the electrical activity within the brain related to ERPs (i.e., current source density). For instance, Lewald & Getzmann (2011) recently published a study using sLORETA to localize electrical brain activity of auditory spatial processing, highlighting the capability of this kind of an approach.

The aim of the present study was to investigate the possible neural sources of complex tone processing (i.e., spectral processing) via the sLORETA source localization method and to further explore the right hemisphere bias for spectral discrimination. This study expands the Greenwald and Jerger (2003) study in that it seeks to detect the possible cortical sources of ERPs elicited by complex tones.

The authors hypothesize that ERPs elicited by spectrally complex tones (musical notes) will be related to auditory cortex activation. Specifically, it is expected that the right auditory hemisphere will show greater activation than the left hemisphere in young adults.

MATERIALS AND METHODS

Participants

Fifteen neurologically healthy undergraduate psychology students (8

women and 7 men; mean age = 21.2; SD = 1.5 years) participated in the study. All the participants were right-handed and non-musicians (less than two years of formal musical training). All procedures were approved by the CWU Institutional Review Board (IRB).

Experimental Stimuli

Participants completed a diotic (same tones presented to each ear), complex-tone discrimination task that was based on the Complex Tone Test (CTT) of Sidtis (1980). The spectrally complex tones (CT) were square waveforms with fundamental frequencies corresponding to six notes in the octave between C4 and C5 on the major scale. This includes C4 (264 Hz), D (297 Hz), E (330 Hz), F (352 Hz), G (396 Hz), and A (440 Hz). Tones were 250 msec in duration, with rise-decay times of 20 msec.

Experimental Procedures

This study used the same procedures as outlined in Greenwald and Jerger (2003). The participants were seated comfortably in a chair. Target stimuli were delivered from two phase-matched loudspeakers at ear height to either side of participant's ears. Each participant performed a diotic pitch discrimination task presented in a basic S1-S2-R design. In this paradigm a reference CT is followed two seconds later by a probe CT. The participant's task was to decide whether the pitch of the probe CT matches the pitch of the reference CT. Trials were arranged in six 25-trial blocks. Using random ordering, each block, half of the reference CT matched the probe CT.

Electrophysiological Recording

Electroencephalographic (EEG) activity was recorded from 28 scalp locations, using silver/silver-chloride

(Ag/AgCl) electrodes attached to an elastic cap (Neuromedical Supplies Inc.) and a Neuroscan amplifier/stimulator with the Neuroscan recording software. Eye movements and eye blinks were monitored via two electrodes, one positioned medially above the left eye and one at the outer canthus of the left eye. All 28 channels of EEG were referenced to linked mastoid electrodes. Individual sweeps of EEG activity, time-locked to the stimuli, were stored for off-line analysis. Each sweep was initiated by a trigger placed at the onset of each probe tone. The stored epoch encompassed 1200 msec (including a 200 msec prestimulus baseline) relative to stimulus onset.

All electrodes impedances were below 5 k Ω . Ongoing EEG activity was amplified, analog filtered from .15 to 70 Hz (1 to 100 Hz for the VEOG channel), and digitized through the Neuroscan acquisition interface system. Continuous analog-to-digital conversion of the EEG and stimulus trigger codes was performed on-line by the Neuroscan acquisition interface system. Signal averaging was conducted after off-line artifact rejection and baseline correction.

Individual epochs were examined and rejected whenever electrical activity in either VEOG channel or the frontal channels (FP1, FP2) exceeded $\pm 50\mu\text{V}$. Successfully averaged evoked potential waveforms were then digitally lowpass-filtered with zero phase-shift at 20Hz with a filter slope of -48 dB per octave in order to remove ambient electrical noise and muscle artifact.

Data Analysis

Since the latency of the P3 peak can vary widely across subjects, which in turn can attenuate the P3 peak and introduce latency jitter (Kok, 2001), individual averaged waveforms were subjected to measurement of area (amplitude integrated

over a specified time interval) between waveform and baseline. Area computation uses the extended trapezoidal rule to estimate area under the curve. That is, it sums all points except the two endpoints (which are given half-weight), and multiplies them by the sampling interval.

Area measures were made over the 300 to 900 msec latency range for the P3 component, and over the 50 to 150 msec latency range for the N1 component for all conditions. These latency ranges were chosen to ensure capture of the maximal component peaks for each individual and for group averages. In the current study, data analysis was restricted to match judgments.

Source Localization

The sources of bioelectrical activity were estimated using Standardized Low Resolution Electromagnetic Tomography (sLORETA). All computations were made using the template from Montreal Neurological Institute (MNI) with the three-dimensional solution space restricted to cortical gray matter and hippocampus, as determined by the probabilistic Talairach atlas (Lancaster, Kochunov, Nickerson, Mikiten, & Fox, 2000).

The sLORETA images represent the standardized electric activity at each voxel in neuroanatomic MNI space as the exact magnitude of the estimated current density. Anatomical labels as Brodmann areas are reported using MNI space, with correction to Talairach space (Brett, Johnsrude, & Owen, 2002). The full description of the method can be found in Pascual-Marqui (2002).

sLORETA images corresponding to the ERP waveforms were defined as the mean current density values for the interval of the N1-P3 brain wave complex.

RESULTS

Behavioral

Accuracy score data were collected during ERP testing to ensure that the participants understood and were able to perform the tasks. Since the main focus of this study was not to evaluate possible differences between subject's responses to match and mismatch stimuli, only responses to the match experimental conditions were evaluated. In order to assure high accuracy, subjects were instructed to be as accurate as possible when responding to the stimulus. Thus, no response latency was recorded. The mean accuracy score for correct responses of the participants for the diotic CTT was 98.2% (SD: 1.3).

Event-Related Potentials

The N1-P3 waveform complex obtained in response to matching complex tones is shown in Figure 1. This waveform complex was maximal at the CPZ electrode site. The mean area latency of averaged individual responses for the N1 was -111.2 (SD: 112.2) and -2663.4 (SD: 1190.7) for the P3 component. A negative difference indicates greater waveform on the right hemisphere, thus the P3 component showed a maximal right hemisphere asymmetry at the CPZ electrode. Figure 2 shows the topographic distribution of the N1-P3 brain waveform. Note that the topographic distribution of the response is clearly in the direction of the right hemisphere in the region of the centro-parietal electrodes.

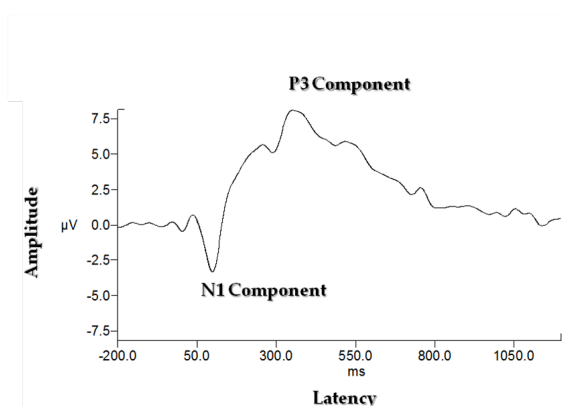


Figure 1. Grand Average ERP Waveform at the CPZ electrode showing the N1-P3 waveform complex.

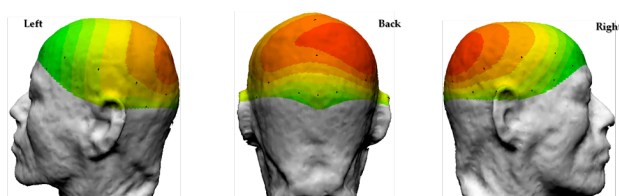


Figure 2. Topographic scalp distribution of the P3 waveform. Red color indicates maximal ERP signal.

sLORETA

Figure 3 shows the results of the sLORETA analysis of the N1-P3 complex. sLORETA estimates current source density across the brain volume by computing the set of voxel dipole strengths and orientations that account for the obtained scalp topography. The maps shown in Figure 3 are essentially statistical maps of current density at each voxel summarized across time. Processing CT's produced widespread activation in the auditory cortex and temporo-parietal cortical regions.

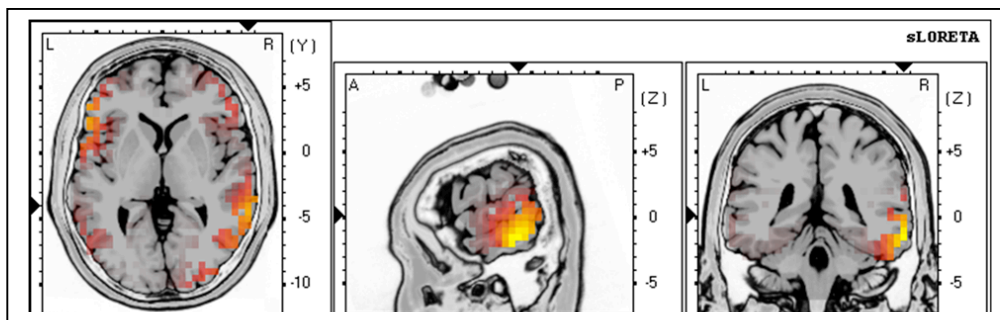


Figure 3. sLORETA source location of the N1-P3 ERP complex superimposed on horizontal, sagittal, and coronal slices of the MNI brain. Colors represent the electric activity at each voxel in neuroanatomic Talairach space. Yellow color indicates maximal activation.

Moreover, the cortical activation was more pronounced in the right hemisphere. Cortical activation for the N1-P3 waveform was maximal in the middle temporal gyrus and temporal-parietal lobe (Brodmann's area 21) of the right hemisphere. For clarity, Figure 4 shows a cortical model created by sLORETA of the maximal current source density in the right hemisphere.

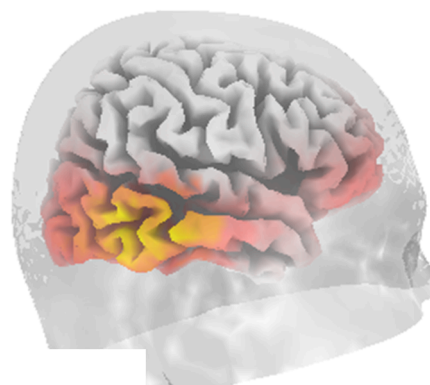


Figure 4. MNI cortical model of the N1-P3 ERP complex neural sources in the right cerebral hemisphere.

DISCUSSION

The results of the current study are in concordance with other neuroimaging methods, and indicate a right hemisphere asymmetry for spectral processing. Our results are consistent with the notion that the cerebral hemispheres are differentially specialized for processing different aspects of auditory information (i.e., temporal vs. spectral).

Specifically, the findings of this study show that complex tone processing has a right hemisphere bias with maximal activation in the temporal cortical regions in non-musicians. Moreover, the findings of this study enhance a previous study of complex tone processing (Greenwald & Jerger, 2003) by providing the possible neural correlates of spectral processing in the brain.

To our knowledge, there have been no prior studies of sLORETA and complex tone processing, and this study shows the utility of cortical source localization methods in investigating hemispheric asymmetries.

A limitation of this study is that it only investigated the responses to correct matches of complex tone pairs and did not view incorrect responses. Future research may want to compare the differences in hemispheric asymmetries to the different types of responses in order to gain a more complete understanding of complex tone processing. In addition, future investigations could also include neural source comparisons between spectral and temporal aspects of sounds processing. For example, an fMRI study (Jamison, Watkins, Bicho, & Mathews, 2006) showed that there are some hemispheric differences in processing of temporal versus spectral information. Utilizing a method like sLORETA could be another avenue to further probe the various auditory processing regions of the brain. Finally, the results of this study only address complex tone processing in non-musicians, and further studies are warranted to explore the complex tone processing of musicians.

Using the well-established complex tones test, the present study clearly shows that the spectral aspect of sound is dominantly processed in the right hemisphere. Since spectral processing is an important factor in music processing (Warrier & Zatorre, 2002), the results of the current study also shed some further insight

into the nature of right hemisphere involvement in the processing of music. For instance, results indicate that the middle temporal gyrus and temporal-parietal lobe regions appear to be involved in music note processing (complex tones).

In conclusion, the observations of the current study strongly support the hypothesis that the human auditory cortex of the right hemisphere has strong spectral resolution capabilities (Zatorre & Belin, 2001; Warrier & Zatorre, 2002) and contribute to the overall understanding of hemispheric asymmetries of the human auditory cortex function.

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