Interindividual and interhemispheric differences of brain function: An MEG study of auditory short-term adaptation

P. Sörös[1,2], I. Teismann[2], E. Manemann[2], N. Michael[3], B. Pfleiderer[4], B. Ross[1,5], C. Pantev[1]
[1]The Rotman Research Institute for Neuroscience, Baycrest Centre for Geriatric Care, Toronto, Ontario, Canada
Depts. of [2]Neurology, [3]Psychiatry and [4]Radiology and [5]Institute of Experimental Audiology, Münster University Hospital, Münster, Germany

Abstract

The aim of this study was to investigate the interhemispheric and interindividual differences of auditory processing using magnetoencephalography. Auditory evoked magnetic fields were recorded from both hemispheres in 26 healthy participants during the stimulation with 4 rapidly successive sounds. Our results demonstrate strong interindividual and interhemispheric differences in the auditory processing of successive sounds. The mechanisms that influence these differences in brain function are not fully understood yet.

1 Introduction

The interindividual variability of the anatomical and functional organization of the human brain is high, though not well characterized. Macro- and cytoarchitectonical studies on brain anatomy revealed strong intersubject differences regarding sulcal shape and distribution of cytoarchitectonical borders (Zilles et al. 2001). Similarly, functional neuroimaging has shown high degree of variability in brain function, especially for higher cognitive functions like memory and language (Burton et al. 2001).

Systematic studies on the inter- and intrasubject variability of sensory functions are sparse. In this study we used magnetoencephalography (MEG) to investigate the interhemispheric and interindividual differences of auditory processing. We chose a stimulation paradigm with rapidly successive speech and non-speech sounds, imitating the rhythm of spoken language or music.

2 Methods

2.1 Subjects

Twenty six subjects (11 females, 18 right-handers; 22-78 years) participated in this study. All subjects were native speakers of German and grew up in a monolingual family. They had a normal audiological status and had no history of neurologic or otologic disorders. All subjects were fully informed about the experimental procedures before the measurement and gave their informed consent to participate in the study.

2.2 Stimuli

In order to obtain a natural and clear speech stimulus the German vowel [a] was spoken by a professional speaker and recorded on digital tape. After shortening the sound using the audio software Signalyze v. 3.12, the vowel had a duration of 260 ms. Spectral analysis revealed a fundamental frequency f_0 of 234 Hz corresponding to a female voice. For the generation of a non-speech stimulus a sine tone with a frequency of 234 Hz and a duration of 260 ms was chosen. The envelope of the sine tone adopted the envelop of the vowel [a]. The goal of this processing was to make the spectral and temporal attributes of the sine tone as similar to the vowel as possible. The sine tone, however, does not contain the formants, which characterize the phonetic structure of the vowel. Trains of 4 successive vowel stimuli or 4 successive sine tone stimuli, respectively, were presented with an onset-to-onset interstimulus interval (ISI) of 450 ms. The onset-to-onset intertrain interval (ITI) was 4.5 s (randomized between 4 and 5 s). Subjects listened passively to 160 trials of the vowel condition and 160 trials of the tone condition, which were presented to the contralateral ear in a pseudo-random order. The properties of the stimuli and the experimental design are illustrated in **Fig. 1**.

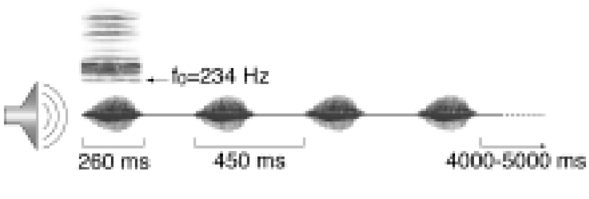

Fig. 1 Illustration of the experimental paradigm

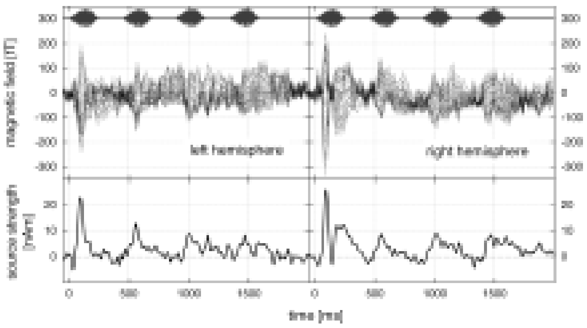

Fig. 2 Magnetic waveforms (upper panel) and the corresponding source waveform (lower panel) of one subject (vowel condition). The time course of the stimulus is illustrated on top of the figure.

2.3 Measurement

Auditory evoked magnetic fields (AEF) were recorded with a 37-channel MEG system equipped with first-order gradiometers (Magnes I, BTi, San Diego, USA) in a magnetically shielded room. The subjects laid in a left or right lateral position with their body supported by a vacuum cushion to minimize head and body movements during the measurement. They watched a self-selected silent video which was intended to attract their attention and to keep their attentional level stable. They were instructed not to move their head or body, to stay awake and to keep their eyes open. The sensor array was positioned over the auditory cortex (about 1.5 cm superior to T3 or T4 according to the 10-20 electrode system) as near as possible to the subject's head. AEFs were recorded successively from both hemispheres on the same day. The sequence of the measurements (right hemisphere first vs. left hemisphere first) was assigned randomly. Before each MEG measurement the individual hearing thresholds were determined for the vowel and the tone stimuli separately when the subject has already been placed in the shielded room. The stimuli were delivered to a silicon ear piece in the contralateral ear via speakers outside the shielded room and a plastic tube of 6.3 m in length. All stimuli were presented with an intensity of 60 dB above the individual hearing threshold.

2.4 Data Analysis

After excluding artifact-contaminated epochs, the magnetic waveforms were averaged. Signals were filtered within a band-pass of 0.01-40 Hz and baselines corrected. The root mean square of the amplitudes (rms) was calculated for a time window of 0–2000 ms for visual inspection and for comparison of the waveforms. Single equivalent current dipoles (ECDs) were computed every 2 ms. The location and orientation of the dipole representing the peak of the first N1 response was determined. These parameters were used to calculate

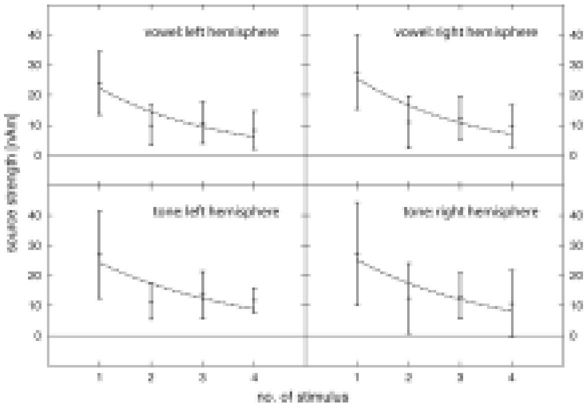

Fig. 3 Source strength of the N1 (mean±SD) of all 4 sounds in the sequence. The results for vowels (upper panel) and tones (lower panel) are plottted separately. A curve is fitted to the mean N1 values using an exponential function.

the source waveform (a spatio-temporal dipol-fit) over the entire epoch. The source waveform represents the strength of a current dipole at a fixed location and with fixed orientation over time. The latency and source strength of each P1, N1 and P2 component were determined.

3 Results

In all subjects, auditory evoked responses were found around 100 ms after stimulus onset for all 4 sounds of the sequence. While the latency of the components was comparable in most subjects, the course of the activation differed between subjects and hemispheres. Magnetic field waveforms and the corresponding source waveforms of a single subject are displayed in **Fig. 2**. In this subject, the later components of the first response (around 250 ms) differ between the hemispheres.

In **Fig. 3** the mean source strength is plotted separately for both hemispheres and for the stimulation with vowels and tones. There are no significant differences between vowels and tones regarding the individual values of source strength and the interindividual differences. The decrease of activation during the stimulation sequence is also similar between conditions.

Fig 4. shows the grandaverage and the standard deviation of the source waveforms for all participants. It is obvious that the value of the standard deviation remains nearly the same for all 4 responses.

The correlation coefficients (-0.29-0.75) between the hemispheres of different subjects displays strong interindividual variability. The interhemispheric correlation coefficients (0.20-0.85) similarly varied from subject to subject. These differences were found in both stimulus conditions, in the vowel and in the sine tone paradigm, in an analogous manner.

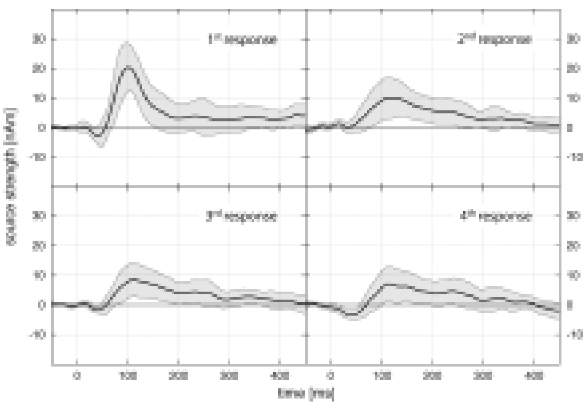

Fig 4. Mean (bold line) and standard deviation (grey shading) of the source waveform for all 4 sounds in the sequence (left hemisphere, vowel condition).

4 Discussion

We compared the cortical activation during stimulation with rapidly successive vowels and tones between the hemispheres of single subjects and between subjects.

The stimulation with the sequences of 4 vowels and with the sequences of 4 tones resulted in very similar cortical activation patterns regarding the absolute value of the source strength of the N1 and the course of the activation in both hemispheres. A previous study on vowel and tone processing demonstrated differences between conditions in the sustained field in the latency range of 400-600 ms, but not in the latency range of the N1 (Eulitz et al. 1995). The lateralization of speech vs. non-speech sound processing is a controversial issue. Szymanski et al. (1999), in contrast to the study of Eulitz et al. (1995), found a stronger response for vowels in the left compared to the right hemisphere, particularly between 150 and 400 ms post stimulus onset. Most probably, the different durations and physical parameters of the stimuli used in these studies and in our study account for the divergent results.

The results of our study demonstrate strong inter-individual differences in the auditory processing of rapidly successive vowels and tones. These results are in line with studies of cortical anatomy and higher cognitive functioning. The mechanisms that determine the extent of inter- and intraindividual variability are not fully understood yet. Two mechanisms are most likely to play an important role: genetic determination and environmental modulation of cortical function. The strong influence, eg. of extensive training on individual brain (re)organisation has been demonstra-ted in musicians (Pantev et al. 1998). The possible genetic influence on brain anatomy and function has mostly been studied in anatomical and behavioural twin studies. The sulcal shape and the gross brain anatomy are influenced by genetic mechanisms (Lohmann et al. 1999). Nevertheless, the relative importance of genetic and environmental factors for the explanation of individual brain function has yet to be determined.

5 Literature

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