ORIGINAL ARTICLE

Brain electric activity during the preattentive perception of speech sounds in tonal languages

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Abstract

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The present study was intended to make electrophysiological investigations into the preattentive perception of native and non-native speech sounds. We recorded the mismatch negativity, elicited by single syllable change of both native and non-native speech-sound contrasts in tonal languages. EEGs were recorded and low-resolution brain electromagnetic tomography (LORETA) was utilized to explore the neural electrical activity. Our results suggested that the left hemisphere was predominant in the perception of native speech sounds, whereas the non-native speech sound was perceived predominantly by the right hemisphere, which may be explained by the specialization in processing the prosodic and emotional components of speech formed in this hemisphere.

Key words : speech, sound, auditory, cortex, perception, asymmetry, evoked field, low resolution electromagnetic tomography (LORETA), mismatch negativity (MMN)

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บทคัดย่อ

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คลื่นไฟฟ้าสมองในขณะที่รับฟังเสียงพูดในภาษาที่ใช้วรรณยุกต์
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งานวิจัยนี้ได้ทำการศึกษาสรีรวิทยาไฟฟ้าในการตอบรับต่อเสียงพูดของคนที่เป็นเจ้าของภาษาและของคนที่ไม่ใช่เจ้าของภาษา โดยได้ทำการบันทึกคลื่นสมองของอาสาสมัครขณะตอบรับต่อเสียงพูดที่เป็นคำโครงสร้างพยางค์เดียวในภาษาที่ใช้วรรณยุกต์ จากนั้นคลื่นสมองของอาสาสมัครก็ถูกนำไปแปรผลเพื่อดูลักษณะของคลื่นพลังงานที่เกิดบริเวณสมองที่เกี่ยวข้องกับการรับฟังเสียงพูดดังกล่าว ผลการวิจัยพบว่า สมองซีกซ้ายจะทำหน้าที่เด่นในการตอบรับต่อเสียงพูดที่เป็นเสียงของเจ้าของภาษา ผลการศึกษานี้อาจอธิบายได้ว่า สมองซีกขวาตอบสนองเฉพาะคุณลักษณะของเสียงพูดเท่านั้น แต่สมองซีกซ้ายตอบสนองทั้งคุณลักษณะและความหมายของเสียงพูดนั้น ๆ ด้วย

โครงการวิจัยชีววิทยาระบบประสาทและพฤติกรรม สถาบันวิจัยและพัฒนาวิทยาศาสตร์และเทคโนโลยี มหาวิทยาลัยมหิดล อำเภอศาลายา จังหวัดนครปฐม 73170

The mismatch negativity (MMN) component of the auditory event-related brain potential (ERP) is elicited by an infrequent change in a repetitive sound sequence (Näätänen *et al*., 1997). The MMN can be used to investigate the neural processing of speech and language (Näätänen *et al*., 1997; Alho *et al*., 1998; Näätänen, 2001; Näätänen and Winkler 1999; Pulvermüller *et al*., 2001; Shtyrov *et al*., 1998; 2000; Sittiprapaporn *et al.,* 2003; 2004) because it is considered to be a unique indicator of automatic cerebral processing of acoustic stimuli. MMN, with its major source of activity in the supratemporal auditory cortex, is a brain response elicited in an oddball paradigm where a sequence of repetitive, 'standard', stimuli is interspersed with occasional 'deviant' stimuli that differ from the standard in one or several acoustical or temporal features (Cowan *et al*., 1993; Alho 1995; Picton *et al*., 2000). MMN is thus primarily a response to an acoustic change and an index of sensory memory. Importantly, the MMN can be elicited in the absence of the subject's attention (Näätänen, 1995). It has recently been found that mismatch negativity in response to individual words is greater than for comparable meaningless word-like stimuli (Pulvermüller, 2001) and pseudoword stimuli (Shtyrov and Pulvermüller, 2002) in both amplitude and topography. This enhancement reflects cortical memory traces for words presented among either word or pseudoword standard stimuli and is best explained by the activation of cortical memory trace for words realized as distributed strongly among connected populations of neurons (Pulvermüller *et al*., 2001; Shtyrov and Pulvermüller, 2002; Pulvermüller, 1999; 2001). Moreover, these traces have been formed during the subjects' previous language experience (Näätänen, 2001; Shtyrov *et al*., 2000; Pulvermüller, 1999; 2001; Shtyrov and Pulvermüller 2002). However, one can argue that it was this lexical status difference rather than individual words' memory traces as such which contributed to the larger MMNs to words.

It is widely accepted that cortical mechanisms of speech processing are functionally asymmetrical in the human brain: the left cerebral hemisphere is traditionally considered to be dominant in the perception and production of speech in most humans, while the right one is known to be specialized in processing the prosodic and emotional components of speech (Fitch *et al*., 1997; Galaburda *et al*., 1978; Kupfermann 1991). Numerous functional (Wada and Rasmussen 1960; Zatorre *et al*., 1992) and structural (Galaburda *et al*., 1978; Koyama *et al*., 2000) studies have demonstrated the left-hemispheric predominance for language in right-handed subjects. Recently, several ERP, magnetoencephalographic (MEG), and positron emission tomography (PET) studies have suggested that the left-hemispheric predominance in speech processing is represented already at a preattentive processing level (Näätänen *et al.*, 1997; Alho *et* al., 1998; Rinne *et al.*, 1999; Koyama *et al.*, 2000; Tervaniemi *et al.*, 2000). These studies utilized MMN as an index of preattentive processing of speech sounds. Some of these studies (Näätänen *et al.*, 1997; Rinne *et al.*, 1999; Koyama *et al.*, 2000) demonstrated that the equivalent current dipole (ECD) of MMN (m) was stronger in the left than in the right hemisphere. There has been a minor interest in the long-term memory traces indexed "MMN", occurring after exposure to both native and non-native speech sounds during more complex cognitive tasks. Thus, the aim of the present study was to investigate the brain electrical activity underlying the MMNs response elicited during the preattentive processing.

Materials and Methods

Subjects

Nine healthy right-handed adult subjects (five male; aged 18-35 years) participated in the study. All subjects were native speakers of Thai with no knowledge of Chinese. All subjects had normal hearing sensitivity and gave their written informed consent before participation. None of the subjects had a history of neurological illness.

Stimuli

Natural speech stimuli of Thai were prepared, each consisting of a consonant-vowel (CV) syllable with falling tone /k^hâ/ corresponding to the identical tone of Chinese /ta^4/. In the native condition /ta^4/ was used as the standard stimulus and /k^hâ/ as the deviant stimulus. In the non-native condition, the standard stimulus was /k^hâ/ while the deviant was /ta^4/. All monosyllables in the condition were identical, thus eliminating any effects due to differences in frequency of occurrence of tones. All stimuli were digitally edited to have equal peak energy level in dB SPL with the remaining data within each of the stimuli scaled accordingly.

Acoustic Stimulation

In the native condition, the native /k^hâ/ deviant was presented among the non-native /ta^4/ standard, and the reverse was employed in the non-native condition. The stimuli were binaurally delivered at comfortable sound level (~85 dB) through earphones. The stimulus sequence was a block of 500 stimuli which contained randomized sequences of standard stimuli (P = 90%) and deviant stimuli (P = 10%). The inter-stimulus interval (ISI) was 1.25 ms (offset-onset).

Electroencephalographic Recording

Subjects were seated in an electrically and acoustically shielded chamber and instructed to read a book of their own choice and to ignore any auditory signals. During the auditory stimulation, electric activity of the subjects' brain was continuously recorded with 21 active electrodes and referred to linked earlobes. A biologic Brain Atlas system amplified (Band-pass 0.01-100 Hz), analog-digital converted (128 samples/s/channel) and stored the data.

EEG Data Processing

ERPs were obtained by averaging epoch, which started 100 ms before the stimulus onset and ended 400 ms thereafter; the – 100 – 0 ms interval was used as a baseline. The MMN was obtained by subtracting the response to the standard from that to the deviant stimulus. The averaged MMN responses contained at least 125 accepted deviant trials in each condition. The data were analyzed with LORETA (Pascual-Marqui *et al.*, 1994) to estimate the current source density distribution in the brain, which contributes to the electrical scalp field. The scalp electric potential power or 'global field power' (GFP) (Lehmann and Skrandies, 1980) was calculated.

Statistical Analysis

The statistical significance of MMN was tested with one-sample *t*-tests by comparing the mean MMN amplitude at the frontal (Fz) electrode site, where the MMN is most prominent.

Results

There was MMN and it was significant in both conditions. The average latency value (±s.e.m.) for both conditions was 174±30 ms. The native (/k^{h}â/deviant) condition yielded higher MMN amplitudes than the non-native (/ta^4/deviant) condition (respective mean amplitude -2.41 µV; GFP = 1.00 and -0.98 µV; GFP = 0.56, respectively). The current densities distribution for the non-native condition demonstrated a predominant activity in the right temporal cortex (RT-ROI): *locx, locy, locz* = 0.033, -0.217, 0.215; 1.74 µA/mm^2 while the native condition was predominant in the left temporal cortex (LT-ROI): *locx, locy, locz* = -0.020, 0.113, 0.215; 2.61 µA/mm^2. In analysis of the scalp voltage field distribution, the two conditions differed in amplitude and scalp voltage distribution of the response from each other (Figure 1).

Discussion

The present study focuses on the estimation of the electrical activity in the brain contributing to the electrical scalp field of the auditory MMNs response. The main finding of our study was that the cerebral predominant pattern in the speech sound change perception differed significantly between the native or non-native speech sounds in a tonal language. The MMN generators of native speech sound located predominantly in the left auditory cortex whereas the right auditory cortex was dominant in the non-native speech sound. An explanation for the results may be that the relatively predominant contribution of the left hemisphere in the preattentive speech processing may occur at the level of the language experience, while the non-native speech sound was analyzed as a specialization in processing its prosodic components of speech, thus, predominantly activating the right hemisphere. In both conditions eliciting electric sources of MMNs response, not only the native but also the non-native condition; it was possible for a subject to detect the difference between the deviant and standard stimulus already at the stimulus onset. This fact is likely to affect the difference in hemispheric predominance, because left hemisphere has been demonstrated predominantly in the perception and production of speech, whereas right hemispheric predominance has been shown to be specialized in processing its prosodic and emotional components.

Our results support the previous studies (Näätänen, 2001; Shtyrov, *et al.*, 2000; Pulvermüller, 1999; 2001; Shtyrov and Pulvermüller, 2002) that the activation of cortical memory traces for spoken words has been formed during the subjects' previous linguistic experience by demonstrating the left-hemispheric activity placed in a subjects' native context than and right-hemispheric activity in a non-native context. These results clearly demonstrate that the presence of the subjects' previous linguistic experience of the perception play a major role in electric source of the MMNs response. Considering the scalp voltage field distribution, the native Thai listeners showed the scalp voltage field distribution of MMNs response in the fronto-central regions to the native context because pitch variations were perceived by native Thai listeners as phonologically significant at the lexical level in their language. However, when the same Thai listeners were presented with homologous pitch contours in a non-native context, they did not show similar electric source of MMNs response in fronto-central regions, but in centralized regions. Both electric source and scalp voltage field distributions are probably caused by the activation of pre-existing long-term memory traces for spoken word stimuli. These traces, presumably, had been formed during the subjects' previous language experiences.

Conclusion

The present study was intended to use electrophysiological investigations to elucidate the difference in cerebral lateralization between the auditory preattentive perception of native and non-native speech sounds in tonal languages. This

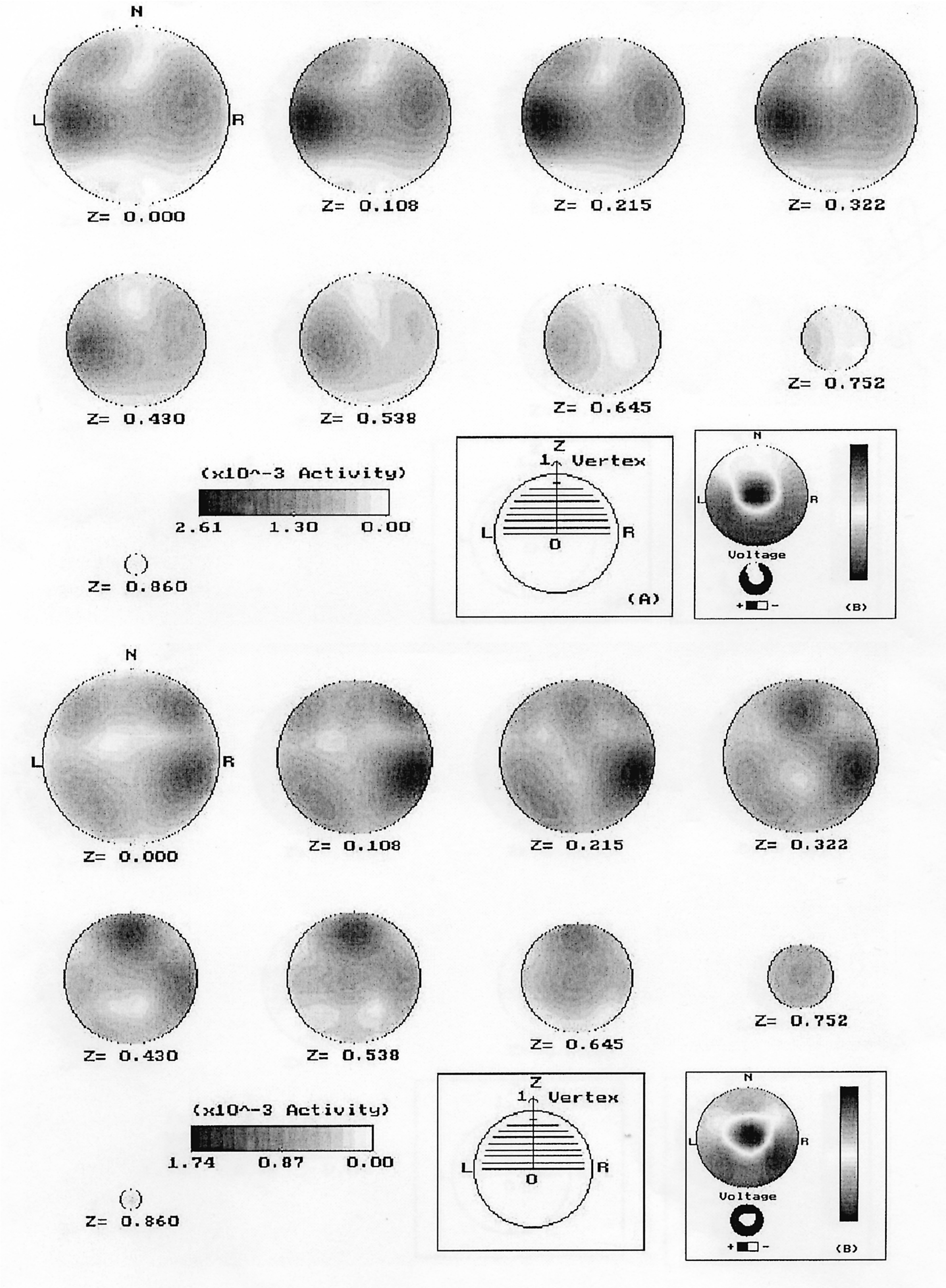

Figure 1. Schematic representation of mismatch negativity (MMN) regions of interest (ROI): (Top) Native condition; (Bottom) Non-native condition.

revealed that spoken words from the subjects' native language elicited electric sources of mismatch responses, indicating a source contribution in the left auditory cortex and in the right auditory cortex for non-native speech sounds. These responses can be activated in the absence of active attention to the auditory input and are probably available at the early stages of cerebral speech processing.

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