
ORIGINAL ARTICLE

Auditory preattentive processing of Thai vowel change perception in consonant-vowel (CV) syllables

**Chittin Chindaduangratn¹, Wichian Sittiprapaporn²
and Naiphinich Kotchabhakdi³**

Abstract

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Event-related potential (ERP) responses to infrequently presented spoken deviant syllables /pi/ among repetitive standard /pɔ/ syllables were recorded in Thai subjects who ignored these stimuli while reading books of their choices. The vowel across-category changes elicited a change-specific mismatch negativity response (MMN). The across-category change perception of vowels in consonant-vowel (CV) syllables was also assessed using low-resolution electromagnetic tomography (LORETA). The LORETA-MMN generator appeared in the left auditory cortex, emphasizing the role of the left hemisphere in speech processing already at a preattentive processing level also in CV-syllables.

Key words : brain, event-related potential (ERP), low-resolution electromagnetic tomography (LORETA), mismatch negativity (MMN), vowel, categorical perception, lateralization, hemisphere, speech

¹M.Sc.(Physiology), Asst. Prof., MD., ²Ph.D.(Neurosciences), ³Ph.D.(Neuro-Behavioural Biology), Assoc. Prof., Neuro-Behavioural Biology Center, Institute of Science and Technology for Research and Development, Mahidol University, Salaya, Nakhon Pathom 73170, Thailand.

Corresponding e-mail: stwst@mahidol.ac.th, grecd@mahidol.ac.th

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บทคัดย่อ

จิตตินทร์ จินดาดวงรัตน์ วิเชียร สิทธิประภาพร และ นัยพินิจ คงภักดี
กลไกทางสมองในขณะที่รับฟังเสียงสาระในคำโครงสร้างพยางค์เดียว
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คลื่นสมองบริเวณส่วนที่ตอบรับต่อเสียงสาระในคำโครงสร้างพยางค์เดียว คำว่า “ปี” และ “ป้อ” ได้รับการบันทึกในอาสาสมัครคนไทย ด้วยวิธีการเบี่ยงเบนความสนใจในการรับฟังเสียงสาระที่อ่านหนังสือ คลื่นสมองของอาสาสมัครทั้งหมดได้นำมาวัดหาค่าแอนปลิจูด และนำค่าเฉลี่ยของคลื่นสมองมาแสดงบริเวณสมองส่วนที่เด่นในการตอบรับต่อเสียงสาระในคำโครงสร้างพยางค์เดียวโดยเทคนิค โลเรโซซูชั่น โถโนกราฟี ผลการวิจัยพบว่า บริเวณส่วนของสมองส่วนที่รับรู้เกี่ยวกับเสียงสาระประกายอยู่ในบริเวณสมองซีกซ้าย ซึ่งสมองซีกซ้ายนี้มีกลไกสำคัญในการตอบรับต่อเสียงสาระในคำโครงสร้างพยางค์เดียว

โครงการวิจัยชีววิทยาระบบทรรประสาทและพฤติกรรม สถาบันวิจัยและพัฒนาวิทยาศาสตร์และเทคโนโลยี มหาวิทยาลัยมหิดล ตำบลคາลายา อำเภอพุทธมณฑล จังหวัดนครปฐม 73170

Mismatch negativity (MMN), an index of preattentive processing of speech sounds, is an ERP component elicited by deviant stimuli sequences of repetitive auditory stimuli (Näätänen *et al.*, 1978). The MMN component appears as a frontocentrally negative wave usually peaking between 100 and 300 ms from the onset of stimulus deviation. The MMN, with its major source of activity in the supratemporal auditory cortex, can be used to investigate neural processing of speech and languages (Näätänen *et al.*, Sittiprapaporn *et al.*, 2003). The MMN(m) in response to speech sounds could be classified into within- and across-category change of phonemes. The former is the change detection of physical feature(s) within the same phoneme boundary, such as changes in pitch, duration, and intensity. The latter is the change detection between independent phonemes. For example, Thai language can be divided into either front (e.g., /i/, /e/, /ɛ/, /æ/) and back (e.g., /u/, /o/, /ɔ/, /ɑ/) vowels or rounded (e.g., /u/, /o/, /ɔ/) and unrounded (e.g., /i/, /e/, /ɛ/, /æ/, /ɑ/) vowels and the change detection between any combinations of these (e.g., /ɔ/ vs. /i/) is considered across-category change detection.

Results of reaction time (RT) studies on the categorization and discrimination of speech sounds demonstrated that vowels were categorically coded (Pisoni, 1973; Polka 1995) indicating clearly peaks

at the category boundary. This indicates that across-category discrimination performance is more accurate than within-category discrimination. Recently, it was investigated whether the left hemispheric predominance of MMN(m) for speech sounds is specific to the across-category change detection of phonemes or merely reflecting the processing of language-related stimuli. It was also hypothesized that the dominance of the left auditory cortex in the preattentive speech processing might occur only at the level of perception of vowel across-category change (Kasai *et al.*, 2001). However, the above-mentioned study (Kasai *et al.*, 2001) utilized only simple Japanese vowels but did not address the issue of whether the CV syllables are specific to the level of perception of vowel across-category change. To address this issue, we investigated the across-category discrimination of vowel in CV syllables by means of MMN paradigm. Additionally, the low-resolution electromagnetic tomography (LORETA), a tomographic method that is also Talairach based, was used to localize the mismatch response of vowel across-category change in CV syllables.

Materials and Methods

Subjects

Ten healthy right-handed monolingual native

speakers of Thai (7 females; aged 18-35 years) participated in the study. The mean (\pm s.d.) age was 24.35 (\pm 4.95) years. All subjects had normal hearing sensitivity and gave their written informed consents before participation in the study.

Stimuli and Procedure

A pair of speech stimuli of central Thai, each consisting of CV syllable was prepared to elicit MMN in response to an across-category vowel change (standard, with back rounded articulation, /pɔ/; deviant with front unrounded articulation, /pi/; both with a 500 ms duration). All stimuli were spoken by a native central Thai speaker and digitally edited to have an equal peak energy level in dB SPL. The sounds were presented binaurally via headphones at a comfortable listening level of \sim 85 dB. The /pi/ deviant (10%) was presented among the /pɔ/ standard (90%) in random order. The inter-stimulus interval (ISI) was 1.25 second (offset-onset).

Electroencephalographic Recording

Subjects were seated in an electrically and acoustically shielded chamber, instructed to read a book of their own choices 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 mastoids. 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 later

ERPs were obtained by averaging epoch, which started 100 ms before the stimulus onset and ended 900 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. For each experiment subject, the averaged MMN responses contained at least 125 accepted deviant trials.

Spatial Analysis

ERP voltages were transformed into reference-independent values by re-computing the voltages vs. average reference. The latency was defined as a moment of the peak GFP with an epoch of 40-ms time window (Lehman, 1987). The individual momentary potentials at the latency mismatch responses were analyzed with LORETA (Pascual-Marqui *et al.*, 1994).

Statistical Analysis

The statistical significance of MMN (deviant-minus-standard difference) was tested with one sample *t*-test. This was done by comparing the

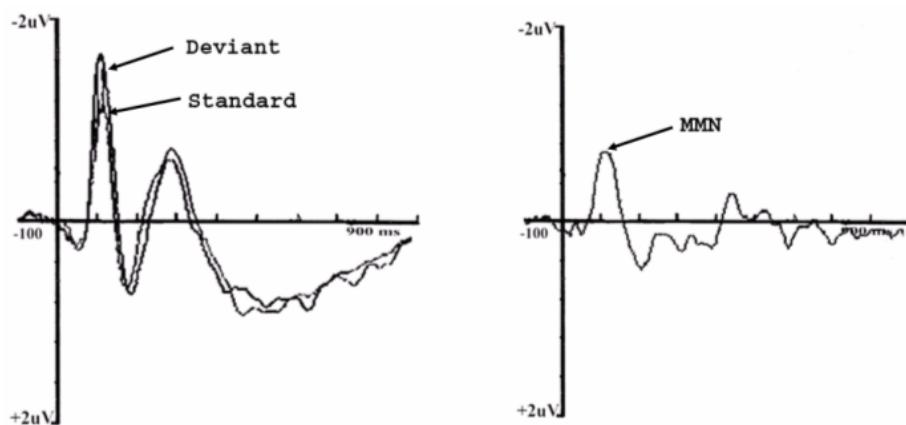


Figure 1. Grand-average ERPs elicited by standard and deviant stimuli (Left), and deviant-minus-standard difference waves (MMN) (Right) at Fz for across-category Thai vowel change: /pɔ/ - /pi/ condition.

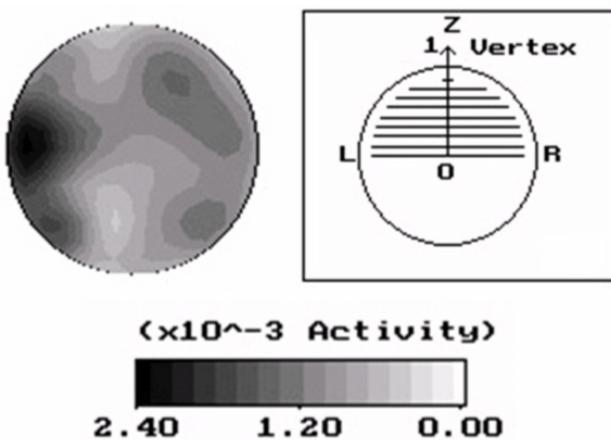


Figure 2. Current densities distribution of mismatch response localizing dominant active area in the left temporal lobe (Upper Left) for the across-category Thai vowel change: /pɔ/-/pi/ condition.

mean MMN amplitude against a hypothetical zero at the frontal (Fz) electrode site, where the MMN is most prominent. LORETA was also calculated, resulting in three-dimensional *t*-statistic images.

Results

The results of the grand-mean difference waveform analysis demonstrated that significantly different neural populations were active between 100-140 ms when across-category change of vowels was present. The paired-sample *t*-test showed that the mean MMN amplitudes revealed

a significant affects of condition ($t(9) = 2.58; p < 0.05$). The mean MMN amplitude was $-0.41 \mu\text{V}$, S.D. = ± 0.24 (Figure 1).

The current density distribution of across-category change of vowel demonstrated an activity in the left temporal cortex (LT-ROI: *locx*, *locy*, *locz* = $-0.020, 0.113, 0.215; 2.40 \mu\text{A/mm}^2$) (Figure 2).

In addition to the left temporal cortex, the activation of across-category change of vowel occurred in the left inferior frontal gyrus (IFG) (BA 44/45: *x*, *y*, *z* = $-52, 24, 22; t = -3.13$) (Figure 3).

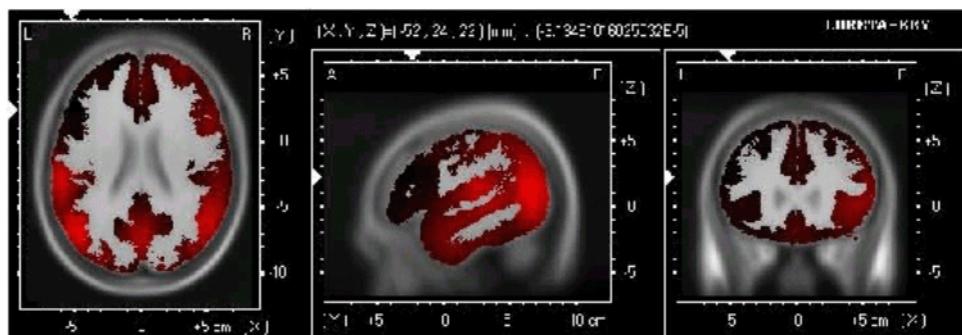


Figure 3. LORETA computation at the mismatch response to across-category Thai vowel change. Images display maximal *t*-statistics with corrected thresholds shown in three orthogonal brain slices (horizontal, sagittal and coronal).

Discussion

The main finding of our study indicates that the prominent response to across-category change of vowel in CV syllable elicited MMN peaking at 100-140 ms from stimulus onset. The result in LORETA suggested that the LORETA-MMN generator of across-category vowel change appeared in the left auditory cortex. The contribution of the left hemisphere was able to obtain at the preattentive level of the vowel across-category-change perception in CV syllables, indicating that the preattentive discrimination of speech sounds in CV syllables may be a part of the left-hemispheric neural networks. The present finding is in line with those of previous studies using Finnish (Näätänen *et al.* 1997; Rinne *et al.*, 1999; Tervaniemi *et al.*, 1999) Japanese (Kasai *et al.*, 2001; Koyama *et al.*, 2000) and English subjects (Alho *et al.*, 1998) that reported a left-hemisphere dominance of MMN (m) source strength for speech sounds. However, also contradicting evidence was recently found in previous reports on in Japanese subjects (Kasai *et al.*, 2001; Imaizumi *et al.*, 1998). Firstly, employing verbs rather than simple vowels as stimuli, Imaizumi (Imaizumi *et al.*, 1998) did not find a left-hemisphere dominance of mismatch response to speech sounds. It has been suggested that syntactic factors of verbs might modulate the hemispheric balance of mismatch response (Zatorre *et al.*, 1994). One possible explanation may be that prosodic changes of stimuli may have an effect. This is consistent with previous study indicating that prosodic aspects of spoken language are functionally processed by the right hemisphere (Zatorre *et al.*, 1994). Therefore, the preattentive prosodic processing might modulate the laterality of mismatch response in their study.

Secondly, the duration of speech stimuli in our study (500 ms) was considerably longer than those of previous studies (Tervaniemi *et al.*, 1999; Aaltonen *et al.*, 1994). These studies using relatively shorter duration (100 ms (Aaltonen *et al.*, 1994) and 200 ms (Tervaniemi *et al.*, 1999) did not show the left hemispheric predominance of mismatch response to vowel across-category change

perception. Kasai, *et al.* (2001) estimated that isolated semisynthetic vowels with short duration in a repetitive manner tended not to be processed fully as phonemes in the subject's brain.

Thirdly, another possible reason for the discrepancy between our study and previous studies is dipole source analysis. Our study estimated only one source analysis for mismatch response and located in the left hemisphere. Anatomical location of active sources was revealed by projection of LORETA solutions into grey matter structures model and evaluated the effects of vowel across-category change perception in CV syllables on these source distribution.

Conclusion

The present study was conducted to determine the preattentive processing of MMN generator for vowel across-category change perception in CV syllable. The vowel across-category-change perception in CV syllable elicited MMN peaking at 100-140 ms from stimulus onset and appeared in the left auditory cortex as assessed by LORETA, emphasizing the role of the left hemisphere in the auditory preattentive processing of vowel across-category-change perception in CV syllables.

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