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Preattentive Processing of the Monosyllabic Word with Contour Tone Changes

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ABSTRACT

As both hemispheres were lateralized for speech and language, the objective of this study was to extend the investigation of how the preattentive processing of contour tone changes in monosyllabic words. Twenty-two healthy right-handed adults participated in this study. This study found that both rising-to-falling and falling-to-rising tone changes elicited mismatch negativity (MMN) between 212-244 msec with reference to the standard-stimulus event-related potentials (ERPs). The rising-to-falling and falling-to-rising tone changes elicited a strong MMN bilaterally for native and nonnative speakers. Source localization was obtained in the Middle Temporal Gyrus (MTG) of the left hemisphere and in the Superior Temporal Gyrus (STG) of the right hemisphere for both subject groups.
Keywords: Event-related potential, Sound, Tone, Contour tone, Mismatch negativity

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INTRODUCTION

In earlier studies, Chinese and English listeners did not show the same left-hemisphere (LH) lateralization as Thai listeners when making perceptual judgments of Thai tones [1-3]. In addition, Chinese and English listeners were asked to make perceptual judgments of Chinese tones, consonants, and vowels. Chinese listeners showed left-hemisphere (LH) lateralization for both suprasegmental and segmental phonological units [3]. These earlier studies suggest that functional circuits engage in early, pre-attentive speech perception of either suprasegmental or segmental units in tone languages. While it seems indisputable that language is subserved by left-hemisphere (LH) and right-hemisphere (RH) are lateralized for speech, language, or something else [1-3]. Hypotheses proposed to account for functional hemispheric asymmetries can generally be classified as either cue dependent i.e., basic neural mechanism underlie processing of complex auditory stimuli regardless of linguistic relevance [4], or task dependent, i.e., specialized neural mechanisms exist that are activated only by speech [5].

Previous event-related potential (ERP) studies at a phonetic level demonstrated that the mismatch negativity (MMN) was enhanced in Finnish subjects by their first-language (Finnish) phoneme prototype rather than a non-prototype (Estonian) [6] and that the MMN for a vowel contrast in Finnish was not generated in native Hungarian speakers with no knowledge of Finnish [7], implying that the MMN reflects language-specific memory traces formed by early and extensive exposure to a first language. However, language-specific word-related MMN components at acoustic and phonetic levels remain to be investigated in future studies. The differences between these studies provide the impetus for future investigations of duration processing and temporal integration differences across language groups.

Although the left hemisphere was selectively employed for processing linguistic information irrespectively of acoustic cues or subtype of phonological unit, the right hemisphere was employed for prosody-specific cues [5]. The propose of the present study was, thus, to use both an auditory MMN component of ERP recording and the low resolution electromagnetic tomography (LORETA) techniques to measure the degree of cortical activation and to localize the brain area contributing to the scalp recorded auditory MMN component, respectively, during the passive oddball paradigm.

MATERIALS AND METHODS

Subjects

Twenty-two healthy right-handed adults with normal hearing and no known neurological disorders volunteered for participation: eleven Native Speakers (NS), aged 23-39 (mean 25.3; six females) and eleven Nonnative Speakers (NonS), aged 23-29 (mean 27.8; nine females). The approval of the institutional committee on human research and written consent from each subject were obtained.

Stimuli and Procedure

Stimuli consisted of two pairs of monosyllabic, Thai words. Speech stimuli were digitally generated and edited to have equal peak energy level in decibels SPL with the remaining data within each of the stimuli scaled accordingly using the Cool Edit Pro v. 2.0 (Syntrillium Software Corporation). The sound pressure levels of speech stimuli were then measured at the output of the earphones (E-A-RTONE 3A, 50Ω) in dBA using a Brüel and Kjaer 2230 sound-level meter. Pairs were designed to have similar long vowel duration. Five NS listened to the synthesized words and evaluated them all as natural sounding. Two different stimuli were synthetically generated as follows:

Stimuli 1: /k^{h}aam/ - falling tone (1)
Stimuli 2: /k^{h}aam/ - rising tone (2)

The standard (S)/deviant (D) pairs for each experiment, which was randomized across subjects, were shown as follows:

[Experiment 1] Standard (2) – Deviant (1)
[Experiment 2] Standard (1) – Deviant (2)

The sounds were presented binaurally via headphones (Telephonic TDH-39-P) at 85 dB. The inter-stimulus interval (ISI) was 1.25 second (offset-onset). Deviant stimuli appeared randomly among the standards at 10% probability. Each experiment included 125 trials (10% D). The stimuli were binaurally delivered using SuperLab software (Cedrus Corporation, San Pedro, USA). Electroencephalogram (EEG) signal recording was time-locked to the onset of a word. Subjects were instructed not to pay attention to the stimuli presented via headphones, but rather to concentrate on a self-selected silent, subtitled movie.

Electroencephalographic Recording

For EEG/ERP recording, the standard 20 locations of the 10-20 system, EEG was recorded via an electrocap (Electrocap International) from 20 active electrodes (Fp1, Fp2, F7, F3, Fz, F4, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, Oz, O2) positioned according to the 10-20 International System of Electrode Placement, plus Oz and Ground are applied, pre-mounted in an elastic Electro-Cap. Reference electrodes were manually applied to left and right mandibles, where the Fp1 and Fp2 electrodes are used for ocular artifact detection. Horizontal eye movements were monitored with electrodes at the left and right outer canthi and vertical eye movements were monitored at Fp1 and Fp2. EEG was amplified with a gain of 30,000 and filtered with a bandpass of 0.1-30 Hz. EEGs were acquired as continuous signals and were subsequently segmented into epochs of 1s (a 100 msec pre-stimulus baseline and a 900 msec post-stimulus epoch).

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EEG Data Processing

The recordings were filtered and carefully inspected for eye movement and muscle artifacts. 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. Epochs with voltage variation exceeding ±100 µV at any EEG channel were rejected from further analysis. The MMN was obtained by subtracting the response to the standard from that to the deviant stimulus. All responses were recalculated offline against average reference for further analysis.

Spatial Analysis

The average MMN latency was defined as a moment of the global field power with an epoch of 40-ms time window related stable scalp-potential topography [8]. The low-resolution electromagnetic tomography (LORETA) was applied to estimate the current source density distribution in the brain, which contributed to the electrical scalp field [8]. Maps were computed with LORETA. LORETA computed the smoothest of all possible source configurations throughout the brain volume by minimizing the total squared Laplacian of source strengths.

Data Analysis

During the auditory stimulation, electric activity of the subjects' brain was continuously recorded. The MMN was obtained by subtracting the response to the standard from that to the deviant stimulus. The statistical significance of MMN was tested with one sample *t*-test. An across-experiment ANOVA was carried out so as to make cross-linguistic comparisons.

RESULTS

The grand-averaged ERPs showed that both rising-to-falling and falling-to-rising tone changes perception elicited MMN between 212-244 msec with reference to the standard-stimulus ERPs. An ANOVA comparing MMN amplitudes of the S and D were not significant (e.g., $F_{(3,40)} = .62$, $P = 0.55$ in Experiment 1, n.s. and $F_{(3,40)} = 0.23$, $P = 0.82$ in Experiment 2, n.s., for the main effect of conditions). The result showed that rising-to-falling and falling-to-rising tone changes elicited a strong MMN bilaterally for NS and NonS (see Table 1). Furthermore, an across-experiment ANOVA demonstrated no interaction and main effects. The significant difference in MMN amplitudes was not observed between groups across experiments ($F_{(7,80)} = 0.12$, $P = 0.955$, n.s.).

Table 1: Mean amplitude (µV) ±S.D. of MMN elicited by a contour tone change perception in Native Speaker and Non-Native Speaker.

Tone Changes	Native Speaker	Non-Native Speaker
Rising-to-Falling	-3.03±0.87	-3.13±1.08
Falling-to-Rising	-2.92±0.95	-2.99±0.70

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Source localization analyses were performed using LORETA [8]. Table 2 demonstrates the xyz-values in Talairach space as calculated with LORETA in the time window 212-224 msec. In Experiment 2, a single source was estimated to be located in the Middle Temporal Gyrus (MTG) of each hemisphere for both groups. In Experiment 1, sources were obtained in the MTG of the LH and in the Superior Temporal Gyrus (STG) of the RH for both groups. No hemispheric difference was discovered in this study (see Table 2 and Figure 1 – Figure 4).

DISCUSSION

Both rising-to-falling and falling-to-rising tone changes perception elicited MMN between 212-244 msec with reference to the standard-stimulus ERPs. The rising-to-falling and falling-to-rising tone changes elicited a strong MMN bilaterally for native and nonnative speakers of Thai. Source localization analyses performed using LORETA demonstrated that sources were obtained in the Middle Temporal Gyrus (MTG) of the left hemisphere and in the Superior Temporal Gyrus (STG) of the right hemisphere for both groups. The same results were obtained in magnetoencephalogram (MEG) studies using both tone and Japanese words [9, 10]. The present results, then, parallel the finding in previous studies [9,10]. The present study, the detection of vowel duration and tone changes was most likely acoustically driven rather than semantically driven, such that the stimuli were processed without any access to semantic information. The acoustic aspect in the absence of phonetic or higher-order properties may account for why NonS had similar neuronal responses to NS subjects. This suggests that at the point of stimulus disparity or thereafter, change detection of vowel lengthening is somehow compromised. It is reasonable to speculate that the continued auditory processing required for the longer vowel interferes with or masks the detection mechanism underlying the MMN [9]. In contrast, the current findings contradict previous tone studies that reported a clear MMN elicited by both duration increments and decrements [11] and a larger MMN elicited by increments than decrements [12]. The MMN component was also found to be more sensitive to tone falling than rising and leveling for both subject groups.

Table 2: Stereotaxic coordinates of activation foci during the contour tones change perception.

Tone Changes	Coordinates (mm)			BA	*t* values
	x	*y*	*z*		
Native Speakers (NS)					
Rising-to-Falling					
	-45	-67	15[a]	39	5.91
	53	-60	15[b]	22	4.69
Falling-to-Rising					
	-59	-32	1[a]	21	5.73
	46	-67	8[c]	37	4.64
Nonnative Speaker (NonS)					
Rising-to-Falling					
	-52	-67	15[a]	39	1.82
	53	-60	15[b]	22	1.12
Falling-to-Rising					
	-45	-67	15[a]	39	1.10
	46	-67	8[c]	37	1.06

[a] Left middle temporal gyrus (MTG)
[b] Right superior temporal gyrus (STG)
[c] Right middle temporal gyrus (MTG)

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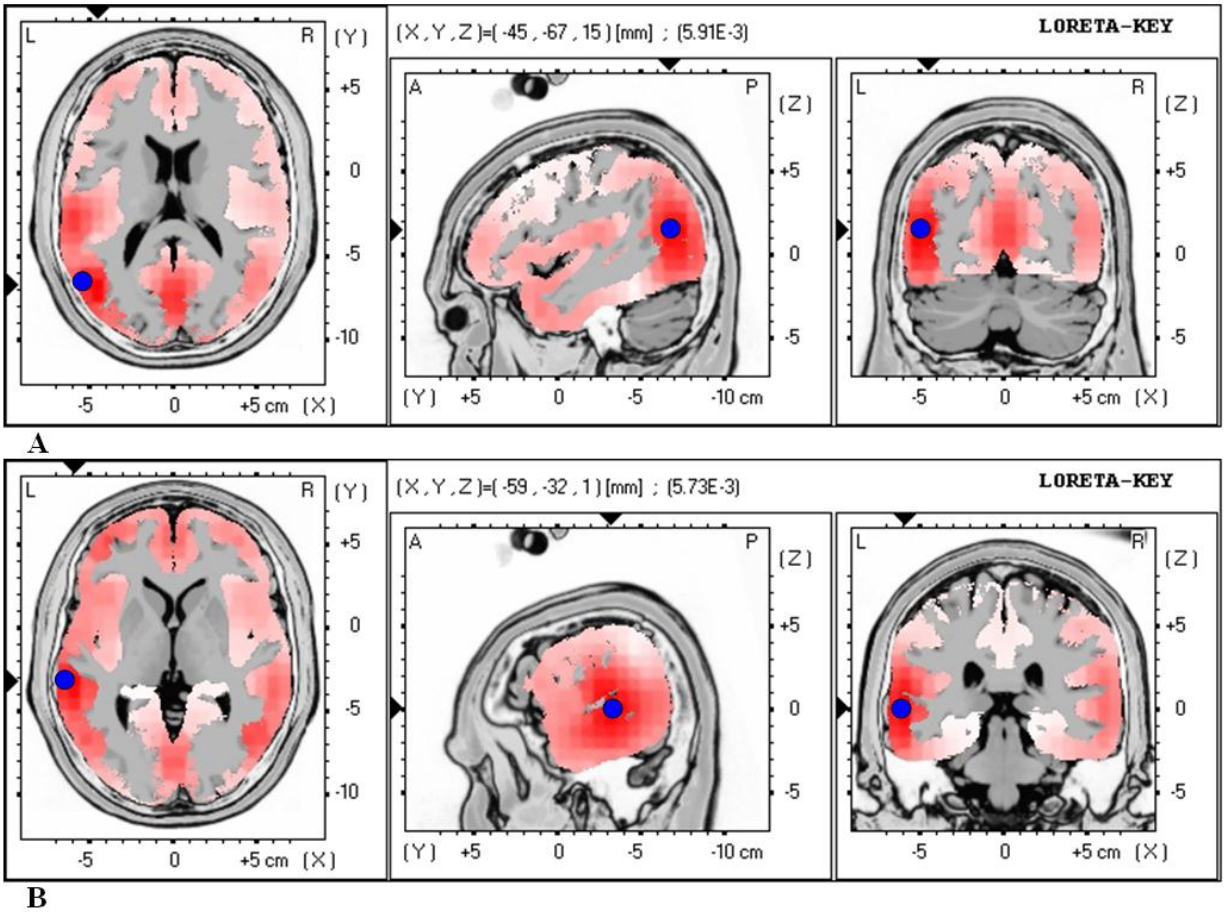

Figure 1: Graphical representation of the low-resolution electromagnetic tomography (LORETA) *t*-statistic comparing the event-related potentials (ERPs) for mismatch negativity (MMN) responses at the time point of the individual peak over Fz for the rising-to-falling (A) and the falling-to-rising (B) tone changes occupied by the long vowel duration of native speaker (NS) activated in left hemisphere (LH). Red color indicates local maxima of increased electrical activity for across- and within-category of vowel change responses in an axial, a saggital and a coronal slice through the reference brain. Blue dots mark the center of significantly increased electric activity.

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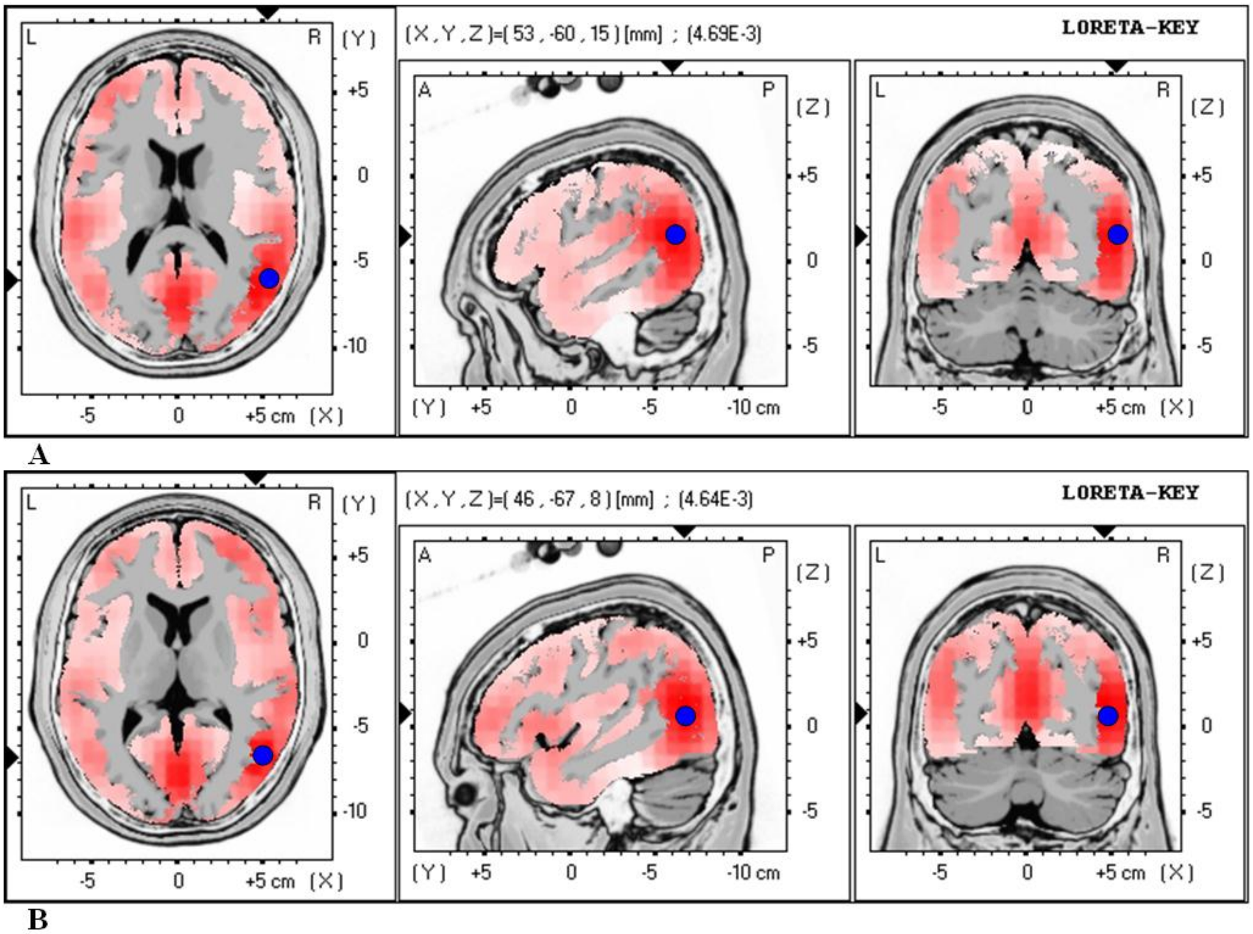

Figure 2: Graphical representation of the low-resolution electromagnetic tomography (LORETA) *t*-statistic comparing the event-related potentials (ERPs) for mismatch negativity (MMN) responses at the time point of the individual peak over Fz for the rising-to-falling (A) and the falling-to-rising (B) tone changes occupied by the long vowel duration of NS activated in right hemisphere (RH). More details are shown in figure 1.

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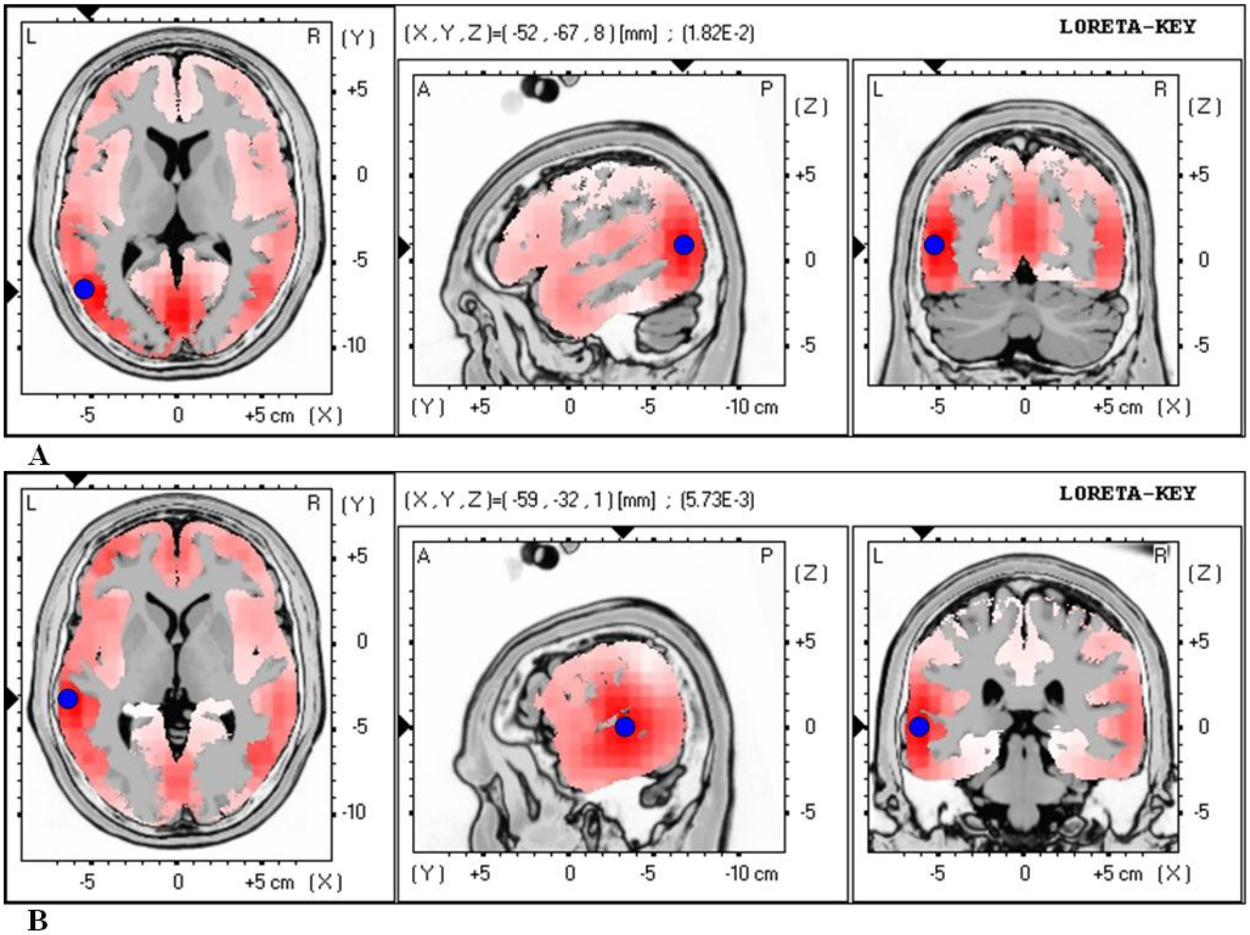

Figure 3: Graphical representation of the low-resolution electromagnetic tomography (LORETA) *t*-statistic comparing the event-related potentials (ERPs) for mismatch negativity (MMN) responses at the time point of the individual peak over Fz for the rising-to-falling (A) and the falling-to-rising (B) tone changes occupied by the long vowel duration of NonS activated in left hemisphere (LH). More details are shown in figure 1.

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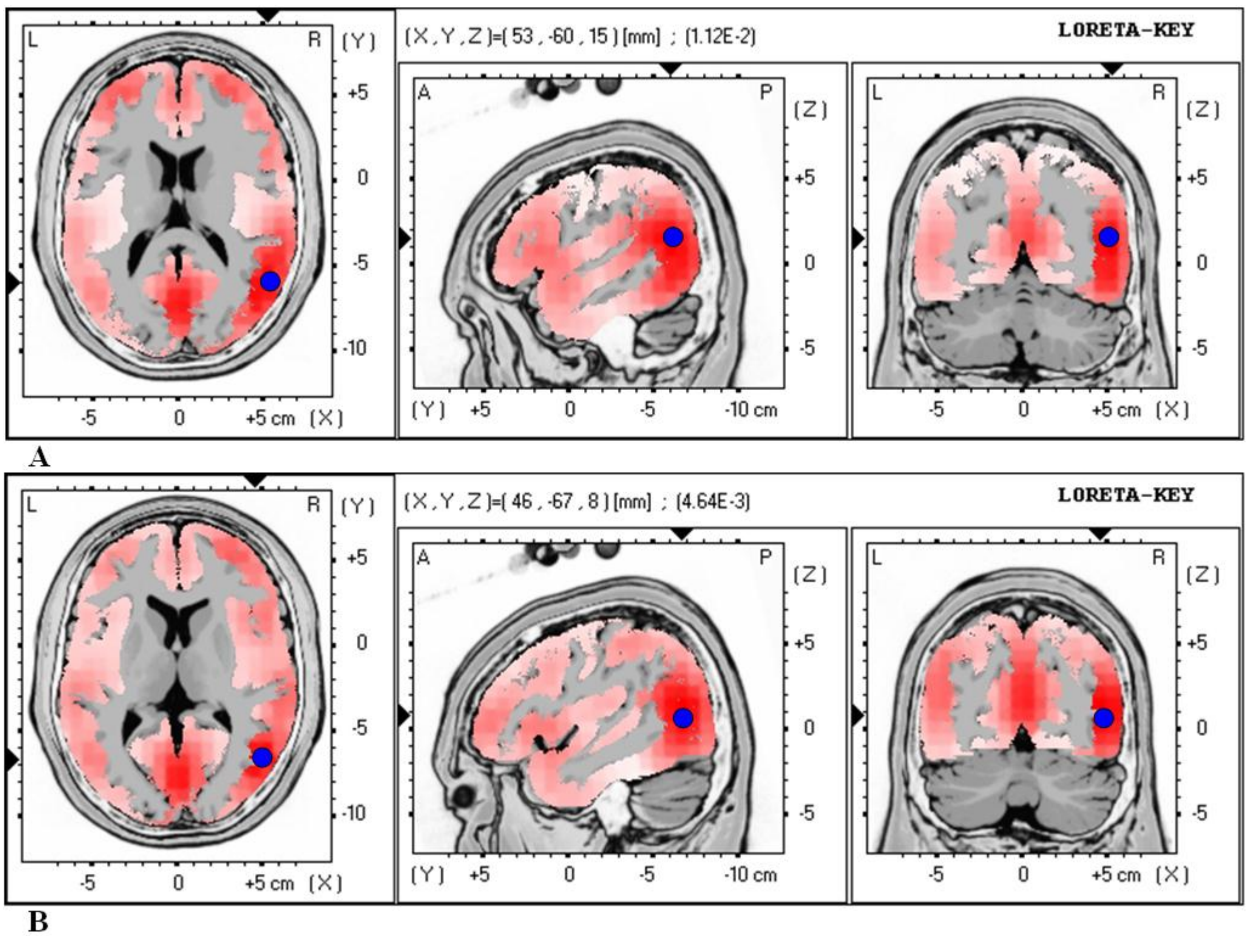

Figure 4: Graphical representation of the low-resolution electromagnetic tomography (LORETA) *t*-statistic comparing the event-related potentials (ERPs) for mismatch negativity (MMN) responses at the time point of the individual peak over Fz for the rising-to-falling (A) and the falling-to-rising (B) tone changes occupied by the long vowel duration of NonS activated in right hemisphere (RH). More details are shown in figure 1.

One might expect language-specific effects on the elicitation of the MMN in speech, since Thai is a tonal language and English is a stress-accent language. Although a tendency towards stronger MMN in NonS is observed, the current findings do not support such an expectation in that no statistically significant difference in MMN amplitudes was found between subject groups at an acoustic level. Previous ERP studies at a phonetic level demonstrated that the MMN was enhanced in Finnish subjects by their first-language (Finnish) phoneme prototype rather than a non-prototype (Estonian) [1] and that the MMN for a vowel contrast in Finnish was not generated in native Hungarian speakers with no knowledge of Finnish [7], implying that the MMN reflects language-specific memory traces formed by early and extensive exposure to a first language. However, language-specific word-related MMN components at acoustic and phonetic levels remain to be investigated in future studies.

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CONCLUSION

Both rising-to-falling and falling-to-rising tone changes perception elicited MMN between 212-244 ms with reference to the standard-stimulus ERPs. The rising-to-falling and falling-to-rising tone changes elicited a strong MMN bilaterally for native and nonnative speakers of Thai. Source localization analyses performed using LORETA demonstrated that sources were obtained in the Middle Temporal Gyrus (MTG) of the left hemisphere and in the Superior Temporal Gyrus (STG) of the right hemisphere for both subject groups. Automatic detection of changes in vowel shortening and pitch falling is then a useful index of language universal auditory memory traces.

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