

Short communication

# Hemispheric asymmetries in auditory evoked neuromagnetic fields in response to place of articulation contrasts

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## Abstract

A growing body of evidence indicates bilateral but asymmetric hemispheric involvement in speech perception. We used magnetoencephalography to record neuromagnetic evoked responses in 10 adults to consonant–vowel syllables that differ in a single phonetic feature, place of articulation. We report differential activation patterns in M100 latency, with larger differences in the right hemisphere than the left. These findings suggest that left and right auditory fields make differential contributions to speech processing. © 2002 Elsevier Science B.V. All rights reserved.

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While classical speech perception models describe language-specific, left hemisphere lateralized mechanisms for the phonetic feature extraction necessary for decoding speech [8], there is growing evidence also implicating the right hemisphere in speech perception [1,2,6,16]. In particular, auditory fields in the posterior superior temporal lobe in both hemispheres have been implicated in speech sound processing [4,5]. If both hemispheres are involved in the processing of speech, then a key issue to be addressed is whether the functional organization for speech perception entails symmetric, redundant processing mechanisms or asymmetric processing mechanisms, with differing contributions from left and right cortex.

Evidence that both hemispheres may be involved in speech perception has been provided in studies using electromagnetic methods [e.g., electroencephalography (EEG), magnetoencephalography (MEG)] [9,10,15,16]. Data from these investigations provide evidence that the right hemisphere may be performing phonetically relevant computations on the speech signal. Recent work from our

laboratory provided evidence for asymmetrical processing of speech sounds that differed in onset dynamics [3]. We reported hemispheric processing asymmetries for words with initial consonants that differed in manner of articulation, indicating that speech onsets are differentially processed as early as ~100 ms in cortical processing. Cumulatively, these data provide evidence in support of the view that both left and right auditory cortical fields play a role in speech perception, but that the contributions of the two hemispheres are asymmetric.

In the present investigation, we use MEG to measure the neuromagnetic auditory evoked field in response to within-speech contrasts. MEG, with millisecond temporal resolution, is well suited for investigating neural responses to fine-grained differences in sounds [3,13,14]. In particular, the M100, occurring ~100 ms post stimulus onset, is modulated by features at the onset of sounds (for a review, see Ref. [12]). Our goal is to exploit the sensitivity of the M100 in order to investigate early cortical responses to within-speech contrasts. We hypothesize that neural mechanisms for the early analysis of acoustic/phonetic features in speech sounds will differ in the two hemispheres. We test this hypothesis by recording the evoked response to consonant–vowel (CV) syllables that are matched for

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manner and voicing, but differ in place of articulation (/ba/, bilabial; /da/, alveolar; /ga/, velar). M100 latency and amplitude are the dependent measures. Of primary interest to us will be evidence for hemispheric processing asymmetries in M100 modulation: this may suggest that the hemispheres are performing different computations on the speech signal.

Ten right-handed healthy native English speakers volunteered to participate in the experiment. Stimulus presentation and MEG recording were performed with the approval of the institutional committee on human research. Informed written consent was obtained from each subject. Stimuli were recorded by a male speaker and matched for intensity and duration using SoundEdit™ 16 (Macromedia). Stimuli were presented binaurally using Etymotic™ ER-3A earphones and air tubes (Etymotic, Oak Brook, IL, USA) at 40 dB SL. Each stimulus was presented 200 times, interleaved in pseudorandom order, in a passive listening paradigm.

Sensor-arrays were placed over the right and left temporal lobes and neuromagnetic fields were recorded for each subject using a twin 37-channel biomagnetometer system (MAGNES-II™, BTi, San Diego, CA, USA). Epochs of 900 ms duration (100 ms pre-stimulus and 800 ms post-stimulus) were acquired around each stimulus at a sampling rate of 2083 Hz with a bandwidth of 800 Hz and a 1.0 Hz high-pass filter. Data were inspected and epochs that contained motion-related artifacts ( $>2.5$  pT,  $1 \text{ pT} = 10^{-12}$  T) were removed. Data were selectively averaged by stimulus condition and band-pass filtered using a low cut-off frequency of 1 Hz and a high cut-off frequency of 40 Hz. Root mean square (RMS) field strength across all channels was calculated for each sample point. The M100 was determined as the RMS peak across 37 channels in the interval 80–140 ms, subject to a single equivalent current dipole (ECD) model/data correlation  $r > 0.97$ , with  $Q < 50.0$  nanoampere meter (nA m), and a signal-to-noise ratio that met or exceeded a factor of 6:1.

All stimuli reliably elicited an M100 evoked field response, with an underlying modeled source in auditory cortex. Data from two subjects (S5, S7) did not meet ECD correlation criterion and were excluded from further analysis. A visual inspection of the data from one subject (S10) showed a very different pattern of effect than the remaining subjects: data from this subject were excluded from further statistical analyses. The remaining seven subjects' data were analyzed using repeated measures analysis of variance (ANOVA) with an alpha level of 0.05. Individual subject within-hemisphere source localizations did not differ for the place contrasts and so are not reported due to space limitations.

**M100 Latency results:** Latency was longer in the left hemisphere (LH) ( $M = 116.1$ , S.E.M. = 2.7) than in the right ( $M = 109.5$ , S.E.M. = 4.7), although this effect just missed statistical significance ( $F_{1, 6} = 4.78$ ,  $P = 0.07$ ). Nonetheless, longer latencies in the LH were found for each subject. An

effect of place was statistically significant in the right hemisphere (RH) ( $F_{6, 12} = 3.68$ ,  $P = 0.05$ ): M100 latency was longer for /ba/ ( $M = 111.1$ , S.E.M. = 4.5) than /da/ ( $M = 109.4$ , S.E.M. = 4.7) and /ga/ ( $M = 107.9$ , S.E.M. = 5.1). Post hoc comparisons (paired  $t$ -tests) indicated that M100 latency significantly differed for the /ba/-/ga/ contrast ( $t_6 = 4.26$ ,  $P = 0.005$ ) but not for the /ba/-/da/ ( $t_6 = 1.61$ ,  $P = 0.158$ ) or the /da/-/ga/ ( $t_6 = 1.12$ ,  $P = 0.303$ ) contrasts. There was no effect of place in the LH ( $F_{6, 12} = 0.13$ ,  $P = 0.88$ ), as there was no difference between /ba/ ( $M = 115.2$ , S.E.M. = 2.9), /da/ ( $M = 116.6$ , S.E.M. = 2.5) or /ga/ ( $M = 116.4$ , S.E.M. = 4.0).

M100 latency has been described as an additive combination of a 'fixed cost' of ~100 ms plus a variable time that depends on stimulus attributes [12]. In order to clarify the size and direction of the place of articulation effect, data were normalized by subtracting latencies for /ba/ and /ga/ from the 'middle' value for /da/. Fig. 1 depicts mean normalized M100 latency for seven subjects. Individual subject data are presented in Fig. 2, depicting normalized M100 latency for the /ba/ and /ga/ contrasts for the seven subjects included in the statistical analysis as well as the eighth subject (S10), whose data were not included in the analysis.

**M100 Amplitude results:** Amplitude was slightly higher in the RH ( $M = 95.1$ , S.E.M. = 11.0) than the LH ( $M = 83.8$ , S.E.M. = 8.8), however this effect was not statistical significant ( $F_{1, 6} = 1.49$ ,  $P = 0.27$ ). The place effect was significant ( $F_{6, 12} = 7.22$ ,  $P = 0.009$ ): M100 amplitude was higher in response to /ba/ ( $M = 101.8$ , S.E.M. = 10.5) as compared to both /da/ ( $M = 83.1$ , S.E.M. = 9.3) and /ga/ ( $M = 83.4$ , S.E.M. = 8.1) in both hemispheres. This effect did not differ in the hemispheres ( $F_{1, 6} = 0.47$ ,  $P = 0.64$ ).

A key issue addressed in this investigation was whether CVs that differed in a single phonetic feature would produce hemispheric processing asymmetries in early cortical processing. We report two effects: first, M100

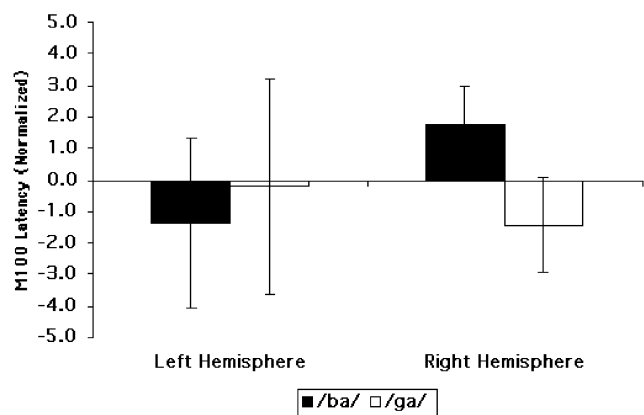


Fig. 1. Mean normalized (delta/da/) M100 latency in the left and right hemispheres for seven subjects in response to /ba/ and /ga/ (error bars represent standard error of the mean, S.E.M.).

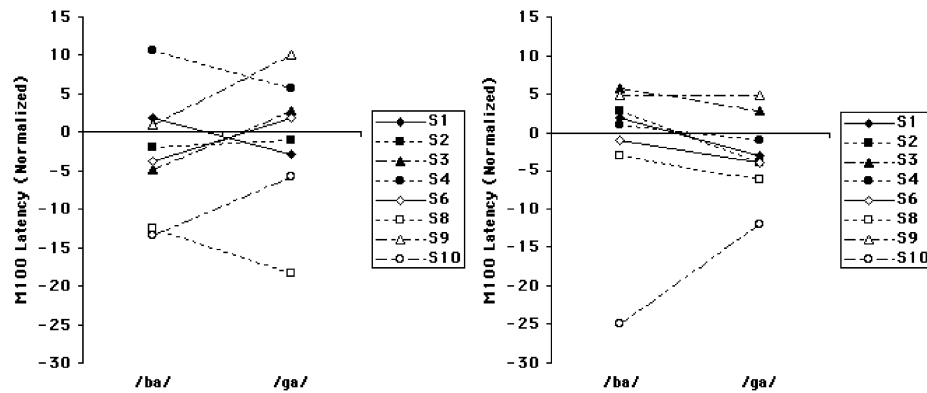


Fig. 2. Individual subject normalized M100 latency in response to /ba/ and /ga/ for the left hemisphere (left panel) and the right hemisphere (right panel). Included in the figure are data for subject S10, not included in the statistical analysis.

latency was differentially modulated in the hemispheres as a function of place of articulation. Specifically, we observed a small but consistent latency shift in the right hemisphere as a function of place, with longer latency for /ba/ as compared to /da/ or /ga/. This effect was not found in the left hemisphere, where latencies were similar across conditions. Second, we report M100 amplitude that varied as a function of the onsets of the speech sounds, with a higher amplitude for /ba/ than /da/ and /ga/. This effect was similar in the hemispheres, indicating that levels of neural activation were similar in left and right auditory fields.

While the M100 amplitude findings indicate relatively symmetric levels of activation in the two hemispheres in response to speech sounds, the latency results provide evidence for asymmetric modulation of the M100 component in the temporal domain. Previous work has provided evidence that M100 latency is modulated by stimulus attributes such as frequency, intensity, and spectral complexity [3,7,11,13]. Cumulatively, these and related findings have been interpreted to indicate that M100 latency may reflect an encoding of spectrotemporal information in sounds into the time domain [12]. Our present results provide evidence for differential temporal signatures in M100 response for within-speech contrasts. If latency modulation of the M100 reflects a dynamic re-coding of spatiotemporal information at the onsets of sounds, then our data here indicate that these coding mechanisms may not be symmetric in the two hemispheres, suggesting that left and right auditory cortical fields make differential contributions to speech processing.

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