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Gender differences in functional hemispheric asymmetry during processing of vowels as reflected by the human brain magnetic response

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Abstract

A number of findings indicate gender differences in language-related functional hemispheric brain asymmetry. To test if such gender-specific laterality is already present at the level of vowel-processing, the auditory evoked magnetic field was recorded in healthy right-handed male and female participants in response to the German synthetic vowels [a], [e] and [i]. Female participants exhibited stronger N100m responses than male participants over the left hemisphere. This observation was highly reliable across repeated experimental sessions. The present lateralization shows that previous findings suggesting a stronger left-hemispheric dominance for verbal material in males than in females can not be generalized to basic speech elements. Furthermore, the present results support the importance of controlling for gender ratio in studies of phonetic processing. © 2001 Elsevier Science Ireland Ltd. All rights reserved.

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A significant number of investigations attempted to elucidate gender-specific hemispheric brain asymmetries both in terms of structure and function [3,7,9,14]. One main finding that gained support from neurological and from neuropsychological evidence suggests that left-hemispheric dominance of language functions is greater in males than it is in females. This could explain why male neurological patients are more likely to suffer severe aphasia symptoms after unilateral left-hemisphere lesions than female patients (see Refs. [8,9]). Monitoring cerebral blood flow while healthy subjects listened to a human voice, Kansaku et al. [7] provided further support for gender-specific lateralization. In contrast, Inglis et al. [6] proposed an opponent concept based on Wechsler Adult Intelligence Scale (WAIS) results from 100 male and female neurological patients: Unilaterally lesioned female patients rely to a greater extent on left-hemispheric processing on the verbal and also on the performance scales of the WAIS. This finding suggests a more general left-hemispheric predominance in females and contradicts the view of a smaller hemispheric asymmetry. Other studies fail to support gender differences in functional asymmetry of language representation [3].

Some evidence suggests that processing strategies influence lateralization of speech stimuli [13,16], and that processing strategies differ for the two sexes [6,10]. Therefore it seems unfortunate that most studies of vowel or CV/CVC-syllable representation did not consider gender as a factor [1,2,4,11,15]. In the 19 peer-reviewed studies we had found in the literature, only four controlled for gender.

The present investigation aimed at revealing gender-dependent hemispheric brain asymmetry in processing speech segments which constitute a prerequisite to language representation. We hypothesized that vowels elicit lateralized brain activity which is influenced by subject's gender. Specifically, the laterality of vowel processing was expected to be greater in male subjects than in female subjects.

Fourteen subjects (seven males and seven females) with a mean age of 25.6 ± 2.27 years (M ± SD) participated in the experiment. None reported a history of neurological or otological illness. Only right-handers were included, as ascertained by the Edinburgh Handedness Questionnaire [12]. Hearing thresholds for both ears were determined individually and for each stimulus. Subjects gave informed

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Table 1
Formant frequencies of the vowels[a]

	F_1 (Hz)	F_2 (Hz)	F_3 (Hz)
[a]	780	1250	2600
[e]	370	2250	2800
[i]	250	2700	3400
[ə]	350	1400	2500

[a] Frequencies of the first three formants of all vowels are shown. Details of fixed F_0, F_4–F_6 frequencies are given in the text.

consent and were paid the equivalent of $25 for their participation.

In a target detection task, subjects listened to pseudo-random sequences of four synthetic German vowels. These were Klatt-synthesized realizations of the vowels [a] (as in 'father'), [e] (similar to 'bait' but not diphthongized), [i] (as in 'beat') and as a target a schwa-like vowel [ə]. Every subject easily identified the three non-target stimuli as the respective German vowels.

All stimuli had a duration of 600 ms and a fundamental frequency F_0 of 129 Hz that fell linearly to 119 Hz. Stimuli differed in formant frequencies F_1–F_3, as depicted in Table 1. F_4 (3900 Hz), F_5 (4700 Hz) and F_6 (5100 Hz) were held constant across stimuli, as were on- and off-set ramps (50 ms Gaussian onset, 150 ms Gaussian offset).

The vowel sequences were presented binaurally at 50 dB SPL above respective hearing threshold via a non-magnetic and echo-free stimulus delivery system. Each sequence consisted of 520 stimuli with a randomized inter-stimulus-interval of 2000 ± 200 ms and a target probability of 7%. Subjects pressed a button with their right index finger when detecting the target vowel to ensure that an active processing mode was maintained. Subjects watched silent videos to maintain a state of alertness and to avoid excessive eye movements. For the measurement a supine position was chosen, ensuring that the subject did not move.

In every subject the experiment was repeated after 1 week to assess re-test reliability and to separate source localization errors elicited through biological or environmental noise from systematic intraindividual differences.

Auditory magnetic fields (AEF) were recorded using a whole head neuromagnetometer (MAGNES 2500, 4D Neuroimaging) operated within a magnetically shielded room (Vacuumschmelze). Epochs of 1200ms (including a 200 ms pre-trigger baseline) were recorded with a bandwidth from 0.1 to 200 Hz and a 678.17 Hz sampling rate. Epochs containing button presses or excessive muscle or eye activity (indicated by peak-to-peak amplitude >3.5 pT or co-registered EOG-signal >100 μV in one of the channels) were rejected. Artifact-free epochs (250–480) remaining for every non-target vowel were averaged after off-line noise correction. A 20 Hz lowpass filter (zero phase-shift butterworth, 12 dB/oct) was subsequently applied to the average.

Further analysis was confined to the N100m component of the brain response waveform. N100m was defined as the prominent deflection in the time range between 90 and 150 ms. Additionally, isofield contour plots of the magnetic field distribution were inspected visually. N100m peak amplitude was calculated as the maximum root mean square (RMS) over 34 magnetometer channels selected to include the field extrema over the left and the right hemisphere, respectively. Peak latency was defined as the sampling point by which the RMS reached its maximum. The same channel selections were used for magnetic source imaging: An equivalent current dipole (ECD) in a spherical volume conductor was modeled at every sampling point separately for the left and the right hemisphere.

N100m source parameters were determined as the median of 16 ± 5 ECD solutions in the latency range of 30 ms before the RMS peak. To be included in median calculation, single ECD goodness of fit was required to be at least 0.90 and ECD location had to amount to at least 1.5 cm in medial-lateral direction and 3–8 cm in inferior-superior direction.

RMS N100m peak latency and amplitude and the ECD source strength were then submitted to an ANOVA with the repeated measures factors vowel type ([a], [e], [i]), hemisphere (left, right), session (first, second) and the between factor gender (female, male). Scheffé tests were used for post-hoc comparisons, *P*-values were adjusted using the Greenhouse–Geisser correction.

Two subjects were excluded from data analysis due to a very poor signal to noise ratio of the N100m. Fig. 1 depicts the grand average RMS of the vowel-elicited waveforms over the left and the right hemisphere averaged separately for gender. N100m peak latency was shorter for [a] than for the other vowels (main effect vowel type $F(2, 20) = 13.91$,

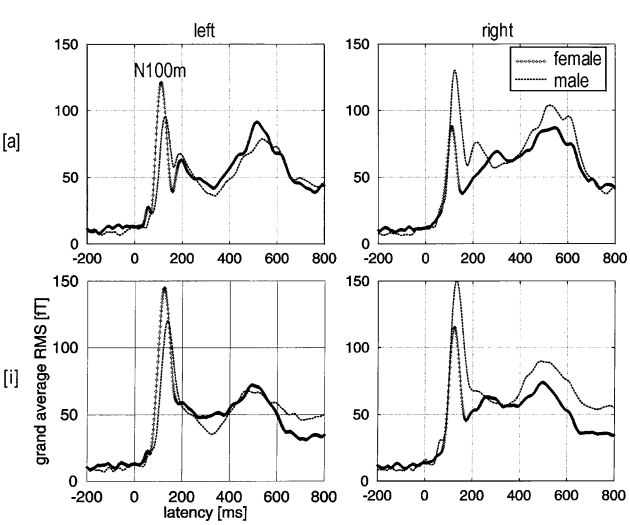

Fig. 1. Root mean squared amplitudes (RMS) over 34 channels over the left (left column) and the right (right column) hemisphere grand averaged across all female and male subjects are shown. Different line styles indicate the RMS waveforms for female and male subjects. Upper and lower row represent the results for the vowels [a] and [i], respectively.

$\epsilon = 0.81$, $P < 0.001$) but was not influenced by gender or hemisphere. Neither N100m amplitude nor ECD source strength revealed main effects of hemisphere or gender. This also held true for analysis of ECD locations that will be reported elsewhere. Irrespectively of the particular vowel, hemispheric asymmetry of the amplitude was different for male and female subjects.

Fig. 2 shows the source strength of the N100m for both sexes and hemispheres. A mean goodness of fit of 0.97 ± 0.01 confirmed the adequacy of the source model. The difference described for the N100m RMS-amplitude was corroborated by the source strength: An ANOVA calculated for the median dipole moment $|Q|$ yielded a gender × hemisphere interaction, i.e. the modulation of source strength across hemispheres was different and in this case opposite for the two hemispheres ($F(1,10) = 5.96$, $P < 0.05$). Post-hoc testing revealed that dipole sources in the left hemisphere were significantly stronger in female than in male participants ($P < 0.05$). To further investigate the hemispheric asymmetry of the strength of the evoked sources in auditory cortex, the laterality score for the dipole moment $|Q|$ was calculated as $(|Q|_{left} - |Q|_{right}) / (|Q|_{left} + |Q|_{right})$. The mean laterality score for male subjects was -0.21, indicating right-hemispheric preponderance, while female subjects scored on average $+0.16$, indicating a stronger left- than right-hemispheric activity. A consecutive ANOVA with the repeated measures factors session and vowel type and the between factor gender produced a main effect of gender ($F(1,10) = 6.55$, $P = 0.028$). This hemispheric gender difference appeared for all three vowel stimuli and across both experimental sessions. The corresponding re-test reliability is illustrated in Fig. 3.

Individual laterality scores (pooled across vowels) in the first session are plotted against the scores in the second session. The strong and highly significant correlation ($r_{Spearman} = 0.93$, $P < 0.0001$) indicates that the type of hemispheric laterality reappears consistently, even on different days of testing.

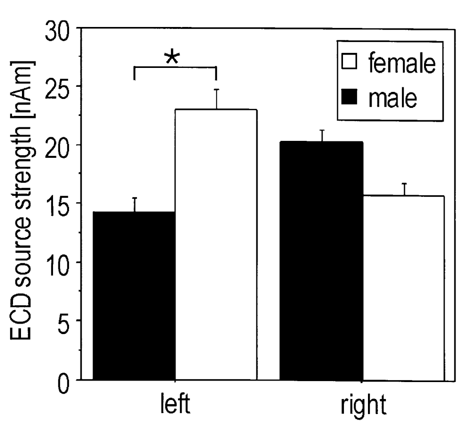

Fig. 2. Mean source strength (±SEM) of the equivalent current dipole (ECD) is shown separately for both hemispheres and subject's gender. Significant post-hoc tests are indicated by an asterisk.

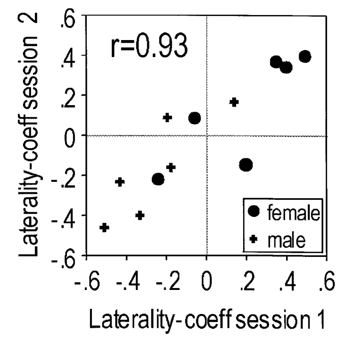

Fig. 3. Individual laterality coefficients (pooled across vowels) of the first experimental session are plotted against those of the second experimental session. Male subjects are represented by crosses, female subjects by circles. Note the high re-test reliability of the lateralization pattern.

The main rationale of this analysis was to reveal the influence of gender on lateralized vowel processing. As outlined above, most of previous studies did not control for gender ratio. The present data suggest gender differences in the lateralized processing of vowels. However the pattern of asymmetry we observed cannot readily be derived from reports of greater left-lateralized language processing in male subjects [7–9]. Despite a rather small sample size a clear statistical outcome demonstrated a highly reliable pattern of gender-specific lateralization whereby female participants produced larger activity in the left hemisphere than male participants (Figs. 1–3). This relationship between subject's gender and hemisphere was confirmed when comparing the strength of ECD sources evoked in auditory cortex. In the measured signal amplitude, error variance is introduced through interindividual differences in exact sensor-to-head position which may obscure experimental effects.

To our knowledge, this type of gender-specific lateralization of speech processing has not been reported previously. A recent MEG study (personal communication with M. Haerle and B. Rockstroh) demonstrated a similar lateralization pattern in male and female subjects in a language production task. The left ear advantage in male participants observed by Meinschaefer et al. [10] points in the same direction – although they examined processing of syllable structure, a task that was expected to trigger right-hemispheric dominant activity.

It is possible that the stronger right-hemispheric activity in men results from a more sound-based processing [5] whereas the reversed pattern in female listeners [6] can be explained if we assume that females may prefer verbal strategies. In this context, it is noteworthy that this particular set of vowels can be categorized and subdivided on a phonological level (thereby assuming that vowel discrimination is based on the extraction of phonological features) as well as on a non-linguistic acoustic level, i.e. by merely extracting spectral envelope information. A discrimination strategy relying on one or the other mechanism would lead to the same behavioral response in the present study but would produce different degrees of brain hemispheric asymmetry.

The classic view of greater left-lateralized language processing in males [8,9] is mainly based on clinical observations and lesion studies. The common interpretation of these studies links damaged brain structures to functional deficits in a deterministic mono-causal fashion. However a considerable body of evidence shows that structural damage in one hemisphere also affects functioning in the other unlesioned hemisphere (see Ref. [11] for a review). Consequently, the results of the lesion studies might be confounded by changes in the functioning of the unlesioned hemisphere.

In summary, the results show that hemispheric language asymmetry as reflected by processing of vowels is influenced by subject's gender: female but not male subjects exhibited stronger left-than right hemisphere activity. The results also revealed a surprisingly high re-test reliability across experimental sessions. Vowel processing constitutes a prerequisite for further decoding and processing speech content, and language-related brain asymmetry is consequently influenced. The present findings underline the importance of considering gender as a variable even when exploring basic levels of speech processing.

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