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Original Article

Gender Effects on Binaural Speech Auditory Brainstem Response

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BACKGROUND: The speech auditory brainstem response is a tool that provides direct information on how speech sound is temporally and spectrally coded by the auditory brainstem. Speech auditory brainstem response is influenced by many variables, but the effect of gender is unclear, particularly in the binaural recording. Studies on speech auditory brainstem response evoked by binaural stimulation are limited, but gender studies are even more limited and contradictory. This study aimed at examining the effect of gender on speech auditory brainstem response in adults.

METHODS: Time- and frequency-domain analyses of speech auditory brainstem response recordings of 30 healthy participants (15 women and 15 men) aged 18-35 years with normal hearing and no musical education were obtained. For each adult, speech auditory brainstem response was recorded with the syllable /da/ presented binaurally. Peaks of time (V, A, C, D, E, F, and O) and frequency (fundamental frequency, first formant frequency, and high frequency) domains of speech auditory brainstem response were compared between men and women.

RESULTS: V, A, and F peak latencies of women were significantly shorter than those of men ($P < .05$). However, no difference was found in the peak amplitude of the time ($P > .05$) or frequency domain between women and men ($P > .05$).

CONCLUSION: Gender differences in binaural speech auditory brainstem response are significant in adults, particularly in the time domain. When speech stimuli are used for auditory brainstem responses, normative data specific to gender are required. Preliminary normative data from this study could serve as a reference for future studies on binaural speech auditory brainstem response among Turkish adults.

KEYWORDS: Auditory brainstem response, auditory pathway, electrophysiology, normative data, speech stimulus

INTRODUCTION

The auditory brainstem response (ABR) is an important test to evaluate neural function in response to acoustic stimuli in the auditory brainstem.[1] Tone-burst, chirp, and click are commonly used as acoustic stimuli.[2,3] However, these simple stimuli are insufficient to examine the auditory processing of the speech sound.[3-5]

The speech ABR test gives direct data about the coding of speech sound in the auditory brainstem.[4,6-9] It can be examined with both time- and frequency-domain analyses.[10] The time-domain analysis, which consists of 7 peaks (V, A, C, D, E, F, and O), evaluates the temporal coding of the speech stimulus, whereas frequency-domain analysis, which consists of 3 peaks (fundamental frequency (F0), first formant frequency (F1), and high frequency (HF)), evaluates spectral coding of the speech stimulus of the brainstem neurons.[3,6,11-13] Artificial or natural universal syllables present in almost every language, such as /ba/ and /da/, are used to obtain the waveform. These acoustically complex syllables consist of the transient (consonant phoneme, e.g., /d/ or /b/) and sustained periodic (vowel phoneme, e.g., /a/) segments.[3,11] Encoding of the transient segment is represented by the onset response of the speech ABR waveform (peaks V and A), while that of the sustained periodic segment is represented by D, E, and F peaks (frequency following response (FFR)). Peak C symbolizes the transition to a vowel, and peak O reflects the answer to the end of the stimulus.[3,13,14] Speech ABR is being investigated in different countries and laboratories. However, there is no standardized protocol for a clinical research.[15] It is possible to obtain speech ABR using electroencephalogram recording with different methods, although

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speech ABR is sensitive to the stimuli and recording parameters, particularly the presentation mode of the acoustic stimulus (monaural or binaural).[16,17]

Speech ABR has been used to investigate the coding of speech signals in the brainstem in studies on dyslexia, autism spectrum disorder, stuttering, language-based learning problems, and special language disorders.[18-22] Most studies in the literature have recorded speech ABR with monaural stimulation,[23,24] and separate speech ABR norms for the left and right ears have been proposed owing to the advantage of the right ear.[3,25] Because binaural stimulation is more realistic than monaural stimulation, Skoe and Kraus[3] have suggested binaural stimulation in adults.[3] Other researchers reported better results in the binaural mode.[26] Moreover, Ahadi et al[16] indicated that the amplitudes of speech ABR depend on stimulus modality.[16] The superiority of binaural hearing over monaural hearing has been reported and studied for many years.[27] A tone presented as binaural is detected louder than the same tone presented as monaural. The binaural loudness summation is 6 dB. The brainstem is very important in bilateral processing.[3,28] Given that the speech ABR test is designed to investigate brainstem functions in the processing of speech stimuli in daily life, it seems that binaural stimulation may better represent real-life auditory processing, but studies on binaural speech ABR are limited in the literature.[5,14]

Speech ABR can be affected not only by stimulus and recording parameters but also by many other factors (particularly individual factors).[3,12,29,30] Literature review reveals that studies are usually conducted with specific clinical populations (such as autism and stuttering), and there are a few studies investigating the existence of individual factors, which affect speech ABR.[18,21] In previous studies, although there is almost a consensus that certain factors (e.g., age) affect speech ABR, there is none to the effect of gender, owing to the limited number of studies conducted.[14,31,32]

Significant differences have been shown between women and men in ABR with traditional stimuli, such as clicks.[33] Women have shorter peak latencies compared to men.[34] A gender effect may also be expected in ABR using speech stimulus; however, it is not entirely clear which part of speech ABR responses are affected from a limited number of gender-focused studies.[12] Particularly, studies in the literature that address the relationship between speech ABR and binaural stimulation are extremely limited, and data from the studies are inconsistent.[12,29] Further studies should clarify and document the parts of the binaural speech ABR response with the gender effect. If there is a significant gender impact, it will become important to have gender-specific normative data for clinical practice. Therefore, this study aimed to determine whether or not gender has an effect on the time or frequency domain of binaural speech ABR in adults.

MATERIALS AND METHODS

Participants

Overall, 30 healthy young adults (15 females/group I and 15 males/group II) participated in the study. They had normal hearing. Adults were right-handed and native Turkish speakers. The age range (in both groups) was 18 and 35 (mean: 26.20 years for females and 24.93 years for males). The exclusion criteria for the groups were (1) having abnormal otorhinolaryngology examination, (2) presence of abnormal middle ear function, (3) presence of systemic, metabolic, or neurological disease, and (4) presence of learning disabilities. Also, attention was paid not to include any participants with professional or amateur music experience in the study. The inclusion criteria for the groups were (1) without a history of hearing loss and (2) having normal hearing. The study was approved by the Ethics Committee of the Hacettepe University (no: GO16/363-15). Written informed consent was obtained from the subjects who participated in this study.

Audiological Assessment

The pure-tone audiometry thresholds were determined using the Grason Stadler device (Model 61; Grason Stadler Inc., Eden Prairie, Minn, USA) and TDH-49P supra-aural headphones (Telephonic; Farmingdale, NY, USA). A hearing screening was performed at 0.5, 1, 2, and 4 kHz frequencies and 20 dB HL intensity. Contralateral–ipsilateral reflex measurement and tympanometric evaluation were performed at the same frequencies with an Interacoustic AZ26 (Interacoustics; Assens, Denmark) clinical impedance meter and 226 Hz probe tone. Individuals who passed the hearing screening and had type A tympanogram and reflex thresholds in the normal range[35] were considered to have normal hearing[36] and were included in the study.

Stimuli and Electrophysiological Recordings

The /da/ syllable with 40 ms duration and 5 formants was used in the study. This stimulus contains an initial noise burst and formant transition between the consonant (/d/) and the vowel (/a/). The F0 and the first 3 formants (F1, F2, and F3) vary linearly (F0 from 103 to 125 Hz, F1 from 220 to 720 Hz, F2 from 1700 to 1240 Hz, and F3 from 2580 to 2500 Hz). The last formants, F4 and F5, are constant at 3600 Hz and 4500 Hz, respectively.[37,38] For the speech ABR recordings, a preliminary study was carried out using a system prepared by the researchers without using the BioMARK module. In this preliminary study, for 35 people, 250 electroencephalography (EEG) recordings were made, and the parameters were modified to finalize the procedure. The prepared system contains 2 laptops (for recording and analysis), System Plus Evolution computer software program (Micromed, Mâcon, France) (compatible with EEG systems), the 32-channel SAM 32 RFO fc1 model Headbox (Brain Quick Brain spy, Micromed, Italy), A Universal Serial Bus (USB) interface (BQ USB EXPRESS, Micromed, Italy), MATLAB R2014a program (The MathWorks, Inc., Natick, Mass, USA) and the audio file and Sennheiser HDA 200 (Sennheiser Electronic Corporation, Wennebostel, Germany) model supra-aural headphones. These earphones may induce artifacts as reported, but we have not had such a problem.[17] All recordings were made in a test room with a Faraday cage while participants were sitting in a comfortable seat. Electrodes were placed (positive, on the forehead; negative, on the right earlobe; and ground electrode, on the left earlobe). The stimulus was presented binaurally to each participant using supra-aural headphones with a repetition rate of 10.9/second at 80 dB SPL and alternating polarity in quiet. The sampling rate of 4000 Hz, ISI of 51 ms, and 1000 sweeps × 5 sessions (5000 total sweeps) were preferred. The impedance of electrodes was <5 kΩ, and the artifact rejection level was >20 μV.

Data Analysis

Electroencephalography data obtained from the sessions were analyzed after the end of the recording. MATLAB was used for the peaks (V, A, C, D, E, F, and O) in the time domain, and these peaks

were visually identified and marked manually. Each peak was separately identified by 2 audiologists, and amplitude and latency values of these peaks were determined for each adult. The peak collection criteria listed by Krizman et al[23] were used. The peaks F0, F1, and HF of the frequency domain were determined by Fourier analysis.[3] Fourier analysis was performed on the 11.5-46.5 ms of the recorded waveform. For each participant, the amplitude sizes of these peaks were defined.

Statistical Analysis

Data processing was done in MATLAB. Analyses were completed after data were transferred to the IBM Statistical Package for the Social Sciences Statistics 24 program (IBM SPSS Corp.; Armonk, NY, USA). *t*-Test was used to compare the measurement data of both groups if the parametric test conditions were met. *P* value of <.05 was accepted.

RESULTS

Speech ABR was successfully recorded from all adults. V-A and O (onset and offset peaks) were 100% and peak C was 90%. Significant differences in the latency of the transient (peaks V and A) and sustained response (only peak F, not D-E) of binaural speech ABR were found between females and males. These peak latencies of female participants were found to be significantly earlier than those of men ($P < .05$). Also, no significant difference in the latency of peak O was found ($P > .05$). In addition, there was no statistical difference between the groups in peak amplitudes of the time domain ($P > .05$).

The mean, minimum, and maximum values for latencies and amplitudes of the time domain peaks of groups are shown in Table 1. Also, Figure 1 displays grand average binaural speech ABR waveforms for females and males.

Peak amplitudes of F0, F1, and HF of the frequency domain were not affected by sex ($P > .05$). The mean and standard deviation values for amplitudes of speech ABR spectral measures in groups are shown in Table 2.

DISCUSSION

This study aimed to analyze and compare the coding responses in the auditory brainstem of binaural speech sound (syllable/da/) between the sexes in adult groups. The analysis was aimed at time and frequency domains of speech ABR.

In our study, significant gender disparities were found at peaks V, A, and F in the time domain of binaural speech ABR. The differences were only in the latencies, while no difference was found in the peak amplitudes; women had earlier peaks latencies than men, but the magnitude of response was not affected by gender. In addition, no significant gender difference was found in the peak amplitude in the frequency domain (peaks F0, F1, and HF).

Ahadi et al[29] were the first to report the sex effect on speech ABR with the binaural mode. Ahadi et al[29] showed that women have earlier V and A peak latencies than men, but there is no difference in the 7 peak amplitudes between the sexes. Although their study is similar to our study in this aspect, the larger F0, F1, and HF peak amplitudes that they obtained in women were not found in this study. Monaural stimulation was not used in their study. Jalaei et al[14] were the first to examine gender relationships and both modes of stimulation

Table 1. Mean, SD, Minimum–Maximum, and *P* Values of the Time Domain Peaks of Binaural Speech ABR in Native Turkish Speakers

	Group I (n = 15)				Group II (n = 15)				All Participants (n = 30)				
	Latency (ms)												
Peaks	**Mean**	**SD**	**Min.**	**Max.**	**Mean**	**SD**	**Min.**	**Max.**	**Mean**	**SD**	**Min.**	**Max.**	***P***
V	7.05	0.57	6.59	9.03	7.69	0.72	6.84	9.28	7.37	0.63	6.59	9.28	.042**
A	10.23	0.38	9.52	10.74	10.57	0.41	10.01	11.47	10.40	0.43	9.52	11.47	.028**
C	17.71	1.28	16.11	20.26	17.91	0.93	16.36	19.78	17.81	1.11	16.11	20.26	.653
D	25.19	0.49	24.66	26.61	25.68	0.73	24.90	26.86	25.40	0.64	24.66	26.86	.067
E	33.56	0.34	32.96	34.18	33.90	0.76	32.23	35.16	33.73	0.60	32.23	35.16	.126
F	42.15	0.28	41.75	42.72	42.70	0.82	41.02	44.43	42.43	0.67	41.02	44.43	.021**
O	50.47	0.65	48.58	51.51	51.00	0.90	49.07	52.73	50.74	0.82	48.58	52.73	.073
	Amplitude (μV)												
Peaks													
V	0.12	0.07	0.03	0.25	0.13	0.05	0.07	0.21	0.13	0.06	0.03	0.25	0.784
A	−0.24	0.09	−0.49	−0.12	−0.21	0.06	-0.34	-0.13	−0.22	0.08	-0.49	-0.12	0.263
C	−0.09	0.05	−0.17	−0.03	−0.08	0.05	−0.17	−0.02	−0.09	0.05	−0.17	−0.02	0.341
D	−0.16	0.06	−0.27	−0.06	−0.19	0.05	−0.27	−0.08	−0.17	0.06	−0.27	−0.06	0.284
E	−0.22	0.08	−0.36	−0.09	−0.26	0.07	−0.37	−0.13	−0.24	0.08	−0.37	−0.09	0.205
F	−0.16	0.09	−0.33	−0.03	−0.19	0.09	−0.42	−0.06	−0.17	0.09	−0.42	−0.03	0.379
O	−0.23	0.1	−0.44	−0.06	−0.18	0.05	−0.27	−0.09	−0.20	0.09	−0.44	−0.06	0.070

**$P < .05$.

SD, standard deviation; ABR, auditory brainstem response.

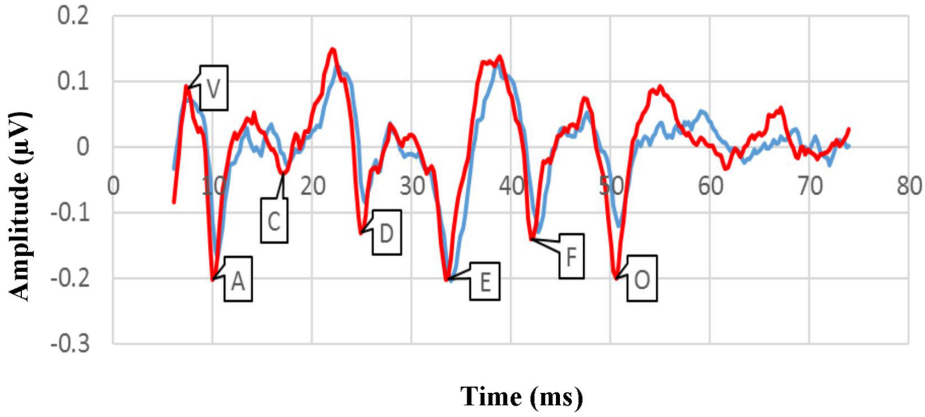

Figure 1. Representation of electrophysiological response to syllable /da/; grand average waveform obtained from women (red line) and men (blue line) of the speech ABR in time domain. V, A, and F wave peak latencies of women were found to be significantly shorter than those of men. ABR, auditory brainstem response.

in speech ABR. While both modes of stimulation were reported to reveal significant gender differences, the binaural stimulation produced more pronounced gender disparities in the onset amplitudes (peaks V and A) of speech ABR, in line with the present study. The gender differences were more prominent in the FFR portion of speech ABR (peaks D, E, and F) for the monaural stimulation. Besides, we could not compare our results because the analysis of the F0, F1, and HF peaks of the speech ABR could not be performed due to technical issues in their study.[14] Our literature review revealed no binaural speech ABR study based on the gender effect other than those mentioned. For both studies, significant gender disparities were noted in most results of the binaural speech ABR, but these results are inconsistent. On the other hand, in terms of the onset response, our data are similar to the studies of Krizman[23] and Liu,[31] carried out in the monaural stimulation mode. Consistent with these aforementioned studies, in our study, V and A peak latencies of women were significantly shorter than those of men. In other words, temporal encoding of the stimulus onset in the brainstem region is notably earlier in women. Faster timing reflects more synchronous neural activity in women in response to the acoustic stimulus.[23]

Recall that peaks D, E, and F represent temporal coding of fundamental frequencies and harmonics of the speech stimulus.[3,6,11-13] The early latency we obtained only at peak F (no difference at 3 peak amplitudes) shows that gender almost does not affect the phase-locking ability, that is, there is no significant difference in temporal coding of F0 and harmonics of the speech sound between men and women. These outcomes are consistent with the findings from studies by Ahadi[29] and Krizman[23] but not with those from the study by Jalei et al.[14,23,29] In addition, peaks C and O were unaffected by gender, and our findings are in line with the outcomes of the previous studies.[23,29]

The mechanisms underlying the gender differences of speech ABR are not clear. The first factor that may explain the latency difference in the onset response we obtained between genders is the different head sizes. Women have smaller head sizes compared to men. In the study of Jalaei and Zakaria, the mean head circumference was significantly higher in male than female groups ($P < .001$). Their study showed significant gender disparities that were noted in the transient component (Peaks V and A) but not in the sustained component of speech ABR. Female participants produced statistically shorter latencies of peaks V and A than males, in line with the present study.[12] Another noteworthy factor that may explain differences between genders is sex hormones. Liu et al[31] showed that speech ABR values correlated with hormone (estradiol and testosterone) levels in adults.[31] Liu et al[39] divided individuals into age groups of 6-12 and 24-34 years in their other study and found no difference between genders in school-age children, but with the advancement of age in girls, peak latencies were shortened, and amplitudes increased. Significant differences appeared between women and men during adulthood. According to them, this change may be due to the effect of hormones.[39] It is not clear which of the above factors is the main factor to explain gender disparities in speech ABR results; however, our results may be explained by factors, such as less brain volume, less skull thickness, short cochlear ducts, and shorter fiber tracks in women and differences in body temperature, middle ear transfer function, and sex hormones.[12,23,29]

Table 2. Mean and SD Values of the Frequency-Domain Peaks of Binaural Speech ABR in Native Turkish Speakers

	Group I (n = 15)		Group II (n = 15)		All Participants (n = 30)		
	Amplitude (μV)						
Peaks	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	***P***
F0	0.430	0.138	0.410	0.204	0.420	0.172	.747
F1	0.104	0.030	0.104	0.043	0.104	0.037	.988
HF	0.019	0.006	0.019	0.005	0.019	0.006	.811

$P < .05$.
SD, standard deviation; ABR, auditory brainstem response; F0, fundamental frequency; F1, first formant frequency; HF, high frequency.

Speech ABR data obtained using 40 ms /da/ stimulus in the literature are highly variable in individuals with normal hearing. For example, in a study conducted with 60 Portuguese individuals between the ages of 18 and 35, the results showed the latency of V wave = 7.59 ms (SD = 2.17 ms) and A wave = 9.28 ms (SD = 2.86 ms), while in another study with 29 Malaysian participants aged between 19 and 30 years, the latency of V wave was 6.11 ms (SD = 0.17 ms) and the A wave was 6.94 ms (SD = 0.16 ms) (very early).[12,40,41] In our study, the mean latency of the V Wave was 7.37 ms (SD = 0.63 ms) and the A wave was 10.40 ms (SD = 0.43 ms). Significant differences in latency and amplitude values obtained in the mentioned and other studies[14,16,23,29] may be due to head size and other anatomical factors. Zakaria et al[30] found that the speech ABR results of the 2 ethnic groups of Asian origin (Malay and Chinese) were similar, but when these results were compared with the results of the study of Krizman et al[23] involving individuals from the Caucasian race, almost all speech ABR peak amplitudes of the Asian group were determined to be larger and the peak latencies were shorter. While the researchers noted that speech ABR results may be similar due to the anatomical similarity between Asian groups (Malay and Chinese) and similar head size, they reported that Asians may have higher amplitudes and shorter latencies because they have smaller bodies and heads than Caucasians. ABR amplitudes and latencies are known to be affected by anatomical factors, particularly head diameter and cochlear length.[30]

Another factor that may affect values of latency and amplitude may be the equipment and software used during recording. Speech ABR is being investigated in different countries and laboratories. However, there is no consensus regarding a certain clinical protocol or a particular value-set of the protocol settings.[15] While Navigator Pro (Biologic, Natus, Pleasanton, Calif, USA) and NeuroScan (Compumedics, Inc., Charlotte, NC, USA) are the most well-known equipment, BioMARK (Biological Marker of Auditory Processing, Natus Medical, Inc.) and NeuroScan Stim2 (Compumedics, Inc.) are the most frequently preferred software packages.[15] As in our study, it is possible to obtain speech ABR responses with EEG recording with the use of different methods. In studies, the equipment and techniques used were shown to cause different latency and amplitude values.[41]

CONCLUSION

Our study shows a significant difference between males and females in neural encoding of the transient portion (onset peaks V and A) of the speech stimuli in the binaural speech ABR. In other words, female participants had earlier latencies of V and A peaks than male participants. On the other hand, significant gender disparities were not found in neural encoding of the sustained portion (peaks D, E, and F) of speech stimuli and in frequency-domain analysis (peaks F0, F1, and HF). Therefore, gender-specific normative data are recommended when using speech stimuli in the binaural presentation mode for ABR. Having gender-specific normative data can be useful when recording speech ABR for clinical evaluations and research; however, as for using normative data in the same way, detailed information, such as that on the characteristics of the subject group in which the data were collected, the collection method, parameters used, and analysis methods have to be obtained.

As a result, gender can affect speech ABR interpretation; therefore, clinicians and researchers should consider gender. Moreover, our study is the first to assess speech ABR of native Turkish speakers and provides speech ABR normative data for future applications involving Turkish adults.

Ethics Committee Approval: The study was approved by the Ethics Committee of the Hacettepe University (no: GO16/363-15).

Informed Consent: Written informed consent was obtained from the subjects who participated in this study.

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