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Auditory Brainstem Response Induced by the Speech Syllable /da/ in Healthy Adults with the Application of a Clinical Auditory Evoked Potential Instrument

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The purpose of this study is to explore the waveform data of speech-evoked auditory brainstem response (sABR) in normal hearing adults who speak Mandarin and to investigate the gender effect. The stimulus, synthesized consonant-vowel monosyllable /da/, was incorporated into a clinical auditory evoked potential (AEP) instrument with clinical parameter settings, such as electrode placement, stimulating, and recording parameters. Twenty bilateral young adults with normal hearing (ten males and ten females) were enrolled in this study. Their average age was 29.00 years (*SD* = 5.15, range 20–37 years old). With the electrodes placed at Fz-Earlobe-Fpz, speech syllable /da/ was presented to the subjects' better ear at 80 dB SPL with a rate of 4.3 Hz. Latencies and root mean square (RMS) amplitude of sABR peaks, periodic neural response of fundamental frequency, and composite onset measures (V–A amplitude and V–A slope) were computed and analyzed. Consistency and reproducibility were observed within the corresponding time segment of the neural response waveform. The results also show that there were no gender differences in the above measurements ($p > .05$). This indicates that a gender effect may not exist at the levels between the auditory brainstem and subcortical regions. Because the measurements of electrophysiological evaluation are susceptible to parameter-setting and individual factors, it is suggested that a norm be established before administering the procedure on subjects. This study provides a basis for applying sABR in subjects with different disorders in various disciplines, such as audiology, speech-language disorders, special education, and the neural sciences.

Keywords: *normal hearing adult, speech, auditory brainstem response*

Introduction

Accurate neural temporal transmission of the sound of speech is a key element in successful communication (Tierney, Parbery-Clark, Skoe, & Kraus, 2011). The research on speech or periodical signal evoked auditory brainstem response (sABR or ABR for complex sound, cABR) suggests that sABR serves multiple functions. For example, it can be used to identify learning and reading disorders in children (Banai, Nicol, Zecker, & Kraus, 2005; Wible, Nicol, & Kraus, 2004), serve as a physiological development marker in auditory processing and learning (Johnson, Nicol, & Kraus, 2005), determine the speech listening performance in noisy environments (Hornickel, Skoe, Nicol, Zecker, & Kraus, 2009; Russo, Nicol, Musacchia, & Kraus, 2004; Song, Skoe, Banai, & Kraus, 2011), demonstrate the influence of the experience of tonal language on auditory nerve physiology (Krishnan, Xu, Gandour, & Cariani, 2004, 2005), and assess the effectiveness of auditory training in children with language learning disabilities (Filippini, Befi-Lopes, & Schochat, 2012; Russo, Nicol, Zecker, Hayes, & Kraus, 2005). These results reveal that sABR has contributed to audiology, the treatment of speech-language disorders, and other related fields, and certify its clinical potential as an objective tool for diagnosing and assessing the effectiveness of the interventions and treatments for hearing-related impairments. However, universal standards for the complex sound evoked ABRs have yet to be established, due to the different stimulus signals, parameters, and analytical methods used in different laboratories. To date, no related studies have examined speech and complex sound evoked ABRs in Taiwan. This specific clinical application also requires further investigation worldwide. The purpose of this study was to explore the waveform data of the sABR in normal hearing Mandarin-speaking adults. It is hoped that this study will provide a basis for applying sABR in subjects with different disorders encountered in various disciplines, such as audiology, speech disorder therapy, special education, and the neural sciences.

Method

Subjects

Table 1 summarizes the basic data and statistical analyses of the age, sex, and hearing of the 20 binaural normal hearing young adults (10 males and 10 females) who participated in the study. The average age of the participants was 29.00 years (SD = 5.15), and no statistically significant differences were found between the males and females, $t(18) = 0.09$, $p = .934$. In terms of hearing, the participants' pure tone average (PTA) at 0.5, 1.0, 2.0, and 4.0 kHz in the left and right ear was 8.56 dB HL (SD = 4.14 dB) and 11.38 dB HL (SD = 4.86 dB), respectively. Because there are no consistent findings on the lateral dominance of the auditory brainstem to the subcortical pathway (Ahadi, Pourbakht, Jafari, & Jalaie, 2014; Hornickel, Skoe, & Kraus, 2009), the left and right ears were stimulated equally. The independent sample t-test results showed that there were no statistically significant differences between the 20 participants in terms of the PTA of the left ear, right ear, sABR stimulating ear, or wave V absolute latency of click evoked ABR ($p > .05$).

Stimuli and recording parameters

The stop consonant-vowel syllable /da/ was used to stimulate the sABR, which is a widely used approach in overseas laboratories. The /da/ stimulus was produced on a Klatt speech synthesizer (Klatt, 1980) as a 170 ms syllable at a sampling rate of 20 kHz (Skoe & Kraus, 2010). The stimulus comprised an initial noise onset burst, the transition formants between the consonant and vowel, and a sustained steady-state vowel (Figure 1 top).

***Table 1.* Summary of the basic data and statistical analyses of the participants (N = 20)**

Basic data		Gender	n	M	SD	t-test	p	95 % CI LL	95 % CI UL
Age (y/o)		Male	10	29.10	5.47	0.09	.934	-4.77	5.17
		Female	10	28.90	5.11				
		Total	20	29.00	5.15				
PTA (dB HL)	Left ear	Male	10	10.38	4.86	2.13	.053	-0.05	7.30
		Female	10	6.75	2.30				
		Total	20	8.56	4.14				
	Right ear	Male	10	11.88	6.19	0.45	.660	-3.77	5.77
		Female	10	10.88	3.34				
		Total	20	11.38	4.86				
	Stimulus ear	Male	10	11.25	5.20	1.16	.263	-1.94	6.69
		Female	10	8.88	3.88				
		Total	20	10.06	4.63				
Wave V latency of click-ABR (ms)		Male	10	5.98	0.25	0.93	.363	-1.85	0.48
		Female	10	5.83	0.44				
		Total	20	5.90	0.35				

Note. CI: confidence interval; LL: lower limit; UL: upper limit; PTA: pure tone average; ABR: auditory brainstem response.

A spectrogram showed that the fundamental frequency (F0) of the syllable /da/ rose linearly from 103 to 125 Hz, and had six formant structures (Figure 1 bottom). The first formant (F1) rose from 400 to 720 Hz, while the second formant (F2) decreased from 1,700 to 1,240 Hz over the formant transition period of the stimulus. The third formant (F3) fell slightly from 2,580 to 2,500 Hz, while the fourth (F4), fifth (F5), and sixth (F6) formants remained constant at 3,300, 3,750, and 4,900 Hz, respectively (Anderson, Skoe, Chandrasekaran, & Kraus, 2010; Anderson, Skoe, Chandrasekaran, Zecker, & Kraus, 2010; Song et al., 2011).

The stimuli and recording parameters in this study were based on the results of U.S. based empirical research. The parameter setting and evaluation procedures were adopted from Anderson et al. (2010) and Skoe and Kraus (2010). The stimulus was presented monaurally with alternating polarity at 80 dB SPL through insert earphones (Etymotic Research-3A [ER-3A], Elk Grove Village, IL, USA), at a repetition rate of 4.3 times/sec. Neurophysiological responses were collected from the ipsilateral ear with a vertical montage of three Ag-AgCl electrodes (vertex, forehead ground, and ipsilateral earlobe reference). The waveforms were averaged on a SmartEP Evoked Potential Acquisition System (Intelligent Hearing Systems, Miami, FL, USA) with a 375.0 ms time window that included 187.5 ms of both pre-stimulus and post-onset. Each sABR recording comprised 3,000 sweeps and was performed twice to confirm the waveform reproducibility. Thus, the final sample comprised 6,000 sweeps. The stimulus and recording parameters are shown in Tables 2 and 3, respectively.

Procedure

The study procedure was divided into two parts: the initial general hearing test and the sABR. The initial general hearing test included an otoscopy, tympanogram, PTA, and click evoked ABR to determine the symmetric normal hearing status of all of the participants. After the initial general hearing test, the participants voluntarily chose to watch a movie with the soundtrack muted while ABR data were collected. To obtain reliable brainstem responses, the participants were required to stay quiet and relaxed during the testing. All of the procedures were approved by the National Cheng Kung University Governance Framework for Human Research Ethics (NCKU HREC107-002-2) and informed consent was obtained from all participants.

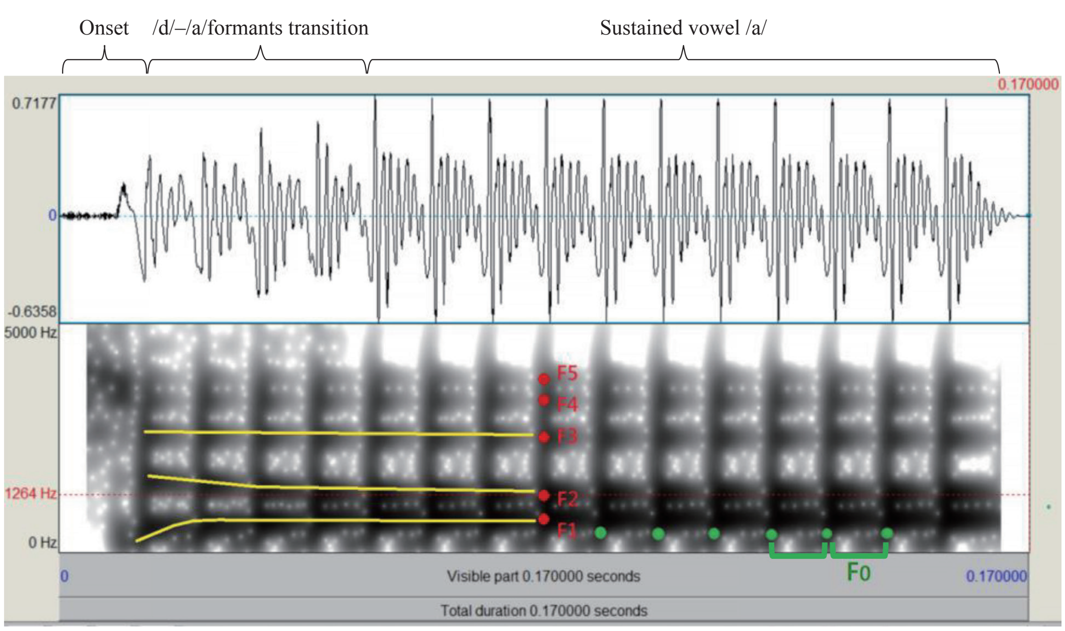

Figure 1. **Waveform (top) and spectrogram (bottom) of the 170 ms consonant-vowel (CV) syllable /da/.**

Table 2. **Stimulus parameters of the click and speech syllable /da/ evoked ABR**

Stimulus parameters	Click-evoked ABR	Speech /da/-evoked ABR
Stimuli	Click	CV syllable /da/
Duration	100 μs	170 ms
Intensity	80 dB nHL	80 dB SPL
Stimulus mode	Each single ear	Single ear
Rate and ISI	31.4 times/sec	Rate = 4.3 times/sec, ISI = 62.5 ms
Polarity	Alternating	Alternating

Note. ABR: auditory brainstem response, CV: consonant-vowel, ISI: inter-stimulus interval.

Table 3. **Recording parameters of the click and speech syllable /da/ evoked electrical potentials**

Recording parameter	Click-evoked ABR	Speech /da/-evoked ABR
Electrode (vertical montage)	Active: Fz Reference: A1/A2 Ground: Fpz	Active: Fz Reference: A1/A2 Ground: Fpz
Impedance (between two electrodes)	< 5 kΩ (< 2 kΩ)	< 5 kΩ (< 2 kΩ)
Sampling rate (1,024 points)	40,960 times/sec	2,730.67 times/sec
Digital band-pass filter (6 dB/octave)	100 ~ 3,000 Hz	70 ~ 2,000 Hz
Averaging sweeps (sum twice)	1,024 (2,048)	3,000 (6,000)
Epoch	Pre-stimulus: -12.5 ms; Post-stimulus: 12.5 ms	Pre-stimulus: -187.5 ms; Post-stimulus: 187.5 ms
Artifact rejection	> ± 20 μV	≧ ± 35 μV

Note. ABR: auditory brainstem response.

Data processing and waveform analysis

The waveform analysis focused on the initial 0–60 ms sABR, which comprised the onset burst period and the formant transition period. The absolute latencies and root mean square (RMS) amplitude of the speech-ABR peaks, periodic neural responses of the fundamental frequency, and composite onset measures (V–A amplitude and V–A slope) were collected, computed, and analyzed. The consistency and reproducibility of the data were also checked within the corresponding time segment of the neural response waveform.

Results and Discussion

The average latencies of all of the sABR waves are summarized in Table 4. Figure 2 shows the gender differences in the 0–60 ms sABR waveform induced consonant-vowel (CV) syllable /da/. For waves V, A, C, and F, a trend of shorter latency and larger amplitude can be observed in the female group. However, the independent *t*-test and multiple-comparison correction results showed that there were no significant gender differences in the V and A waves of the sABR. In addition, the frequency following response (FFR) stage of the C, D, E, F waves showed no differences in latency between genders. In general, there were no significant gender differences in the absolute latencies of the sABR waves. The different components of the amplitude of sABR are listed in Table 5. No significant differences were found in gender variability for the V–A amplitude, RMS amplitude at the formant transition, or V–A slope. The above data were analyzed with one-way analysis of covariance (ANCOVA). In the FFR periodic analysis, recurrent periodic characteristics were found in waves D, E, and F, as shown in Figure 2 and Table 4. Overall, the observed ABR was able to reflect the periodic component characteristics of the speech /da/ stimuli.

Several studies have pointed out the age effect in the sABR (Anderson, Parbery-Clark, White-Schwoch, & Kraus, 2012; Liu, Fu, Wang, Li, & Wang, 2016; Mamo, Grose, & Buss, 2016). Therefore, we recruited

Table 4. **Latency and statistical analysis of the speech-evoked auditory brainstem response (sABR) waveform**

Wave	Gender	Latencies (ms)				95 % CI	
		M	*SD*	*t*	*p*	LL	UL
V	Male	7.80	0.75	-0.72	.482	-0.72	0.35
	Female	7.98	0.29				
	Total	7.89	0.56				
A	Male	9.41	1.30	-0.89	.387	-1.48	0.60
	Female	9.85	0.87				
	Total	9.63	1.10				
C	Male	17.72	1.61	1.76	.095	-0.23	2.65
	Female	16.52	1.45				
	Total	17.12	1.62				
D	Male	23.77	1.30	1.31	.206	-0.42	1.81
	Female	23.07	1.06				
	Total	23.42	1.21				
E	Male	33.73	0.27	1.80	.088	-0.07	0.95
	Female	33.29	0.72				
	Total	33.51	0.58				
F	Male	43.87	0.98	2.43	.026	0.11	1.51
	Female	43.07	0.39				
	Total	43.47	0.83				
D–E interval	Male	9.96	1.33	0.15	.879	-1.55	1.80
	Female	10.22	1.21				
	Total	10.09	1.24				
E–F interval	Male	10.14	0.96	0.78	.445	-0.64	1.42
	Female	9.78	0.67				
	Total	9.96	0.83				

Note. CI: confidence interval; LL: lower limit; UL: upper limit.

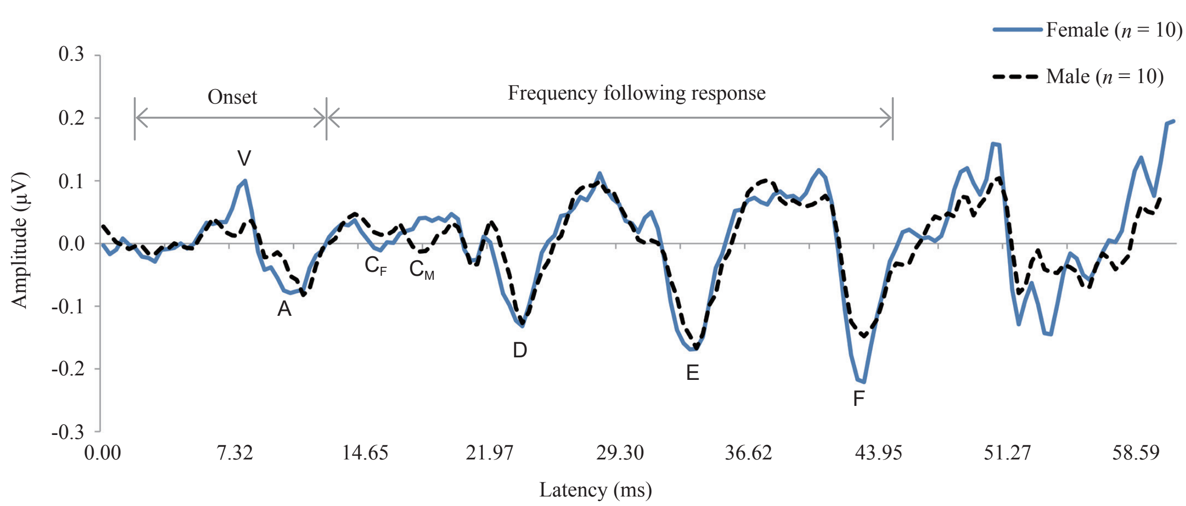

Figure 2. **Speech /da/ -evoked ABR waveforms (0–60 ms) for different genders.**

Note. Subscript F denotes the female C-wave mark position, and subscript M denotes the male C-wave marker position

Table 5. **Amplitude and statistical analysis of the speech-evoked auditory brainstem response (sABR) composite waveform**

sABR	Gender	*M*	*SD*	*F*	*p*
V–A composite amplitude (μV)	Male	0.19	0.06	1.07	.316
	Female	0.22	0.09		
	Total	0.20	0.08		
20–60ms RMS amplitude (μV)	Male	0.10	0.03	0.77	.394
	Female	0.11	0.04		
	Total	0.11	0.03		
V–A composite slope (μV/ms)	Male	0.13	0.05	0.05	.825
	Female	0.13	0.04		
	Total	0.13	0.05		

Note. RMS: root-mean-square.

normal hearing young adults whose ages were matched to the literature for comparison and discussion purposes (Hornickel, Skoe, & Kraus, 2009; Krizman, Skoe, & Kraus, 2012). In comparison with the literature, the latency of each sABR wave in this study was relatively delayed and the amplitude was rather small. However, the wave peaks and troughs still appeared in the range of latency corresponding to a typical sABR waveform. The differences in the data may have come from changes in the stimulus and recording parameters. Hornickel, Skoe, and Kraus (2009) and Krizman et al. (2012) used a 40 ms /da/ as the stimuli material. This type of short stimulus usually achieves synchronous neural discharge in a shorter time. As a consequence, the latency of the 40 ms-/da/-evoked sABR was shortened and the amplitude increased. In addition, the electrode location of Cz in recording the vertical potential would have produced a greater amplitude than the Fz location. These observations help explain the differences between the results of this study and those in the literature. However, the distribution of values in this study was quite large, which may be a result of the differences in the intrinsic factors of the participants, such as ethnicity (Zakaria, Jalaei, Aw, & Sidek, 2016), language (Krishnan et al., 2005), and other personal factors. To sum up, in this study, a clinical instrument with specific settings was able to evoke ABR with speech /da/ and the response was similar to that reported in the literature, i.e., a consistent response waveform in relative time segment. However, because the results are likely to have been affected by the parameter settings of the electrophysiological test, the test environment, and individual factors of the participants, it is necessary to establish a norm reference dataset for domestic use.

Furthermore, the literature suggests that the wave V latency of theoretically click-evoked ABR should be shorter in females than males and that the amplitude should be greater in females than males (Jalaei, Zakaria, Mohd Azmi, Nik Othman, & Sidek, 2017; Krizman et al., 2012; Liu et al., 2016). However, these gender effects were not observed in this study. In fact, the results in the literature are not consistent. The gender difference in the sABR may be caused by physiological differences in gender (head circumference, skull thickness, and cochlear length) and/or endocrine system changes with growth, although it is still not conclusive which factors dominate these differences. In this study, no significant gender differences were observed for the 170 ms speech /da/ induced ABR.

Conclusions

The ABR was induced by the speech syllable /da/ in healthy adults with the application of a clinical auditory evoked potential (AEP) instrument. For specific settings, the clinical instrument was capable of evoking reproducible neural responses in Mandarin native language and binaural normal hearing young adults. The evoked ABR was similar to that reported in the literature.

The results also showed that there were no gender differences in the above measurements ($p > .05$). This indicates that gender effects may not occur between the auditory brainstem and subcortical regions. Compared to the short stimulus sound, i.e., click or tone burst, speech stimulation provides more neural synchronization and temporal processing information to reflect how the speech is processed by the auditory neural pathway. However, because the measurements used in electrophysiological evaluations are susceptible to the parameter settings and individual factors, it is suggested that a norm be established before administering the paradigm on subjects. This study provides a basis for applying speech-evoked ABR in subjects with different disorders in areas such as audiology, speech therapy, and special education.