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ELECTROPHYSIOLOGICAL MEASURES OF AUDITORY BRAINSTEM RESPONSES TO HINDI SPEECH STIMULUS IN INDIAN ADULTS

HİNTLİ YETİŞKİNLERLERDEKİ HİNDU KONUŞMA UYARANINA KARŞI İŞİTSEL BEYİNSAPI ELEKTROFİZYOLOJİK ÖLÇÜMÜNÜN YANITLARI

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Abstract

Speech evoked auditory brainstem responses (spABR) assesses brainstem ability to encode speech. However, speech representations at brainstem are affected by acoustic properties of speech, language background and experiences. Hindi has considerable acoustic differences that may evoke dissimilar ABR pattern. Therefore, our objective was to investigate the spABR to Hindi stimulus in normal hearing adults. The 5 formants Hindi stop |da| of 40ms was synthesized to elicit ABRs from 50 normal hearing adults with mean age of 22.7 (SD=2.3) years in the age range 18-25 years. The sub-cortical response latency & amplitude to consonant and vowel portion of the stimulus were recorded. Results: The spABR elicited distinctive peaks for stimulus component. The consonant portion evoked peak V and vowel portion elicited the frequency following response (FFR). The mean, median, standard deviation, minimum, maximum and 95% confidence interval of peak latency & amplitude were measured. ANOVA was studied at 5% significance levels between the current spABR and western data. Conclusions: The obtained brainstem response timing and amplitude values of transient and sustained portion of stimulus are in line with the western reports. However, considering the acoustic differences in Indian languages, culturally & linguistically sensitive stimulus should possibly be developed and norms be established.

Keywords: Speech stimulus, Speech encoding, Speech-evoked auditory brainstem response, Transient response, Frequency following responses.

Özet

İşitsel beyin sapı uyarılmış konuşma yanıtları (spABR) konuşmayı kodlamak için beyin sapı becerilerini belirler. Ancak, beyin sapındaki konuşma simgeleri konuşmanın, dil geçmişinin ve deneyimlerinin akustik özelliklerinden etkilenir. Hindu dili, farklı işitsel beyin sapı yanıtlarını ortaya çıkarabilen hatırı sayılır derecede akustik farklılıklar içerir. Bu yüzden, amacımız normal duyabilen yetişkinlerdeki Hindu uyaranına karşı işitsel beyin sapı uyarılmış konuşma yanıtlarını (spABR) araştırmaktı. 18-25 yaş aralığındaki 22.7 yaş ortalamasındaki(SD=2.3) normal duyabilen 50 yetişkinin işitsel beyin sapını ortaya çıkarmak için 5 tane Hindu biçimlendirici durağı olan |da| sentezlendi. Gecikme süresi ve çokluğunun uyaranların ünsüz ve ünlü kısımlarına karşı korteks altı cevabı kaydedildi. Sonuçlar: İşitsel beyin sapı uyarılmış konuşma yanıtları (spABR) uyaran bileşenleri için farklı hece ortaları ortaya çıkardı. Ünsüz kısmı V hece ortasını ve ünlü kısmı da sıklığı izleyen yanıt(FFR) ortaya çıkardı. Hece ortası gecikme süresi ve çokluğunun ortalama, ortanca, standart sapma, minimum, maksimum ve %95 güven aralığı ölçüldü. Şuanki spABR ve batı dataları arasındaki %5lik önem seviyesinde ANOVA incelendi. Sonuçlar: Uyaranların uzun ve kısa süreli kısımlarının edinilen beyin sapı zamanlama ve çokluk değerleri batı datalarıyla aynı doğrultudadır. Ancak, Hint dillerindeki akustik farklılıklar göz önünde bulundurularak kültürel ve dilbilimsel olarak hassas uyaranlar imkanlar dahilinde geliştirilmeli ve normalar oluşturulmalıdır.

Anahtar Kelimeler: *Konuşma uyaranı, konuşma kodlaması, işitsel beyin sapı uyarılmış konuşma yanıtları, kısa süreli yanıt, sıklığı izleyen yanıtlar(FFR).*

1. Introduction

Auditory brain stem responses (ABRs) to clicks or tones are routinely employed as a metric for determining auditory thresholds in children and difficult to test population (Sininger; 1993 Hood 1998; Hall 2007) to envisage the auditory accessibility to acquire speech and language skills and to estimate the difficulty in perceiving speech. However, auditory system's ability to process speech may not be predictable from transient click or tones because they have poor approximation to behaviorally relevant complex sounds like speech (Skoe & Kraus 2010). Hence, use of speech for ABR measurement has evolved as a reliable method for underpinning the processes involved in speech perception.

Since the last decade, brainstem encoding of speech sound |da| has been investigated extensively to explore the sub cortical functioning to the acoustic- characteristics of speech stimulus with remarkable precision in normal and clinical population (Chandrasekaran & Kraus, 2009; Johnson et al, 2005, 2008; Russo et al, 2004). The poor

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speech encoding have been reported in children with language, literacy, reading, and learning deficits (Banai et al., 2009; Johnson, Nicol, Zecker, & Kraus, 2007; King, Warrier, Hayes, & Kraus, 2002). Children with known language-based learning problems reported to have delayed latencies (Johnson, Nicol, Zecker, & Kraus, 2007; King, Warrier, Hayes, & Kraus, 2002) compared to normal learning peers. Children with poor reading abilities found to have prolonged latencies, poorer waveform morphology and weaker spectral encoding compared to children with better reading abilities (Banai et al., 2009; Hornickel, Anderson, Skoe, Yi, & Kraus, 2012).

These studies have demonstrated a trend that difficulty in language, literacy, reading and effects of training on learning affects the sub cortical representation of speech. Therefore, it has been suggested that the spABR to syllable |da| can be used for clinical assessment of auditory function universally. The Bio MARK (biological marker of auditory processing) procedure has been developed as an objective tool for the assessment of speech sound processing of brainstem for the diagnosis of auditory processing disorders and learning problems.

However, Werker and Tees (1984) reported that 10 to 12 month old infants can discriminate the sounds that are linguistically relevant in their native language, suggesting that psychoacoustic discrimination of consonants are affected by language input. Moreover, the recent studies have shown that experience with language have effects in sub cortical encoding of specific elements of speech sounds (Krishnan et al, 2005, 2009). They reported that mandarin speakers encode more robust pitch patterns of mandarin sound in auditory brain stem measures that convey linguistic meaning in Mandarin than English speakers, but not in English. Furthermore, long-term music experiences selectively enhance specific stimulus features in brainstem activity (Wong et al., 2007).

Additionally, naturally produced sounds have an acoustic – phonetic difference in languages such as voice onset time (VOT) apart from temporal & spectral variations. The stop consonants such as |da| in English are produced by the vibration of the vocal folds that starts at a short lag after the release of the consonant by the articulators. In contrast, in Hindi sound |da|, voicing starts prior to the release of the consonants (for example, Hindi sound |da| has VOT of -140 to -60 ms (Lisker and Abramson 1964). These acoustic parameters delineate the distinctive features for language and speaker identification.

These observations set the theoretical foundation that the acoustic parameters of the culturally sensitive stimulus may uncover the processes involved in specific language user. We assume that the long term experience of the Hindi syllable in Hindi speakers may elicit dissimilar pattern of evoked potentials at brainstem. This may be crucial in diagnostic work up of clinical population. Therefore, the present study proposes to record ABRs with Hindi speech sound |da| in normal hearing Hindi speaking individuals and to compare with literature data.

1.1. Objective of the Study

The purpose of the study was to determine the ABRs to Hindi stimulus in normal hearing Hindi speaker adults.

2. Subjects and Methods

2.1. Research design

This prospective survey was conducted at Electrophysiological Lab of Department of Audiology. The study was accorded necessary ethical clearance from Institutional ethical board. Informed consent was obtained from all subjects.

2.2. Participants

Total 50 subjects of both the sexes in the age range 18–25 years (mean = 21.3 years, SD = 3.2 years) were recruited for the study. The subjects were right-handed native Hindi speaker with no known history of neurological, otological disease or trauma and psychiatric problem. All subjects had pure-tone thresholds ≤25 dBHL at octave frequencies from 250 Hz to 8000 Hz, speech identification score >90% at 40dBSL in both ears and normal middle ear function on Immittance evaluation (A-type tympanogram with acoustic reflexes at normal sensation levels). Subjects also required to exhibit wave V latency to 100µs click at the rate of 21.1 per sec in rarefaction polarity to the right ear within the range of normative values (mean± 1.5 standard deviations, 5.41–5.96ms at 45dBnHL).

2.3. Stimulus and recording parameters

The Hindi stop voiced phoneme of consonant-vowel (CV) combination |da| of 40 ms duration consisting of 5-formants was synthesized (Ansari & Rangasayee 2015) to elicit ABRs. The speech sound consisted of an initial burst of 10ms and a formant transition of 30ms between the consonant and the vowel. The F0 and the first three formants (F1, F2, F3) change linearly over the duration of the stimulus: F0 from 113 to 147, F1 from 240 to 770, F2 from 1670 to 1350, and F3 from 2680 to 2550 Hz. F4 & F5 remain constant at 3700 & 4600 Hz respectively.

The spABR were acquired from the subjects sited comfortably on the reclining chair through Ag-AgCl electrodes with surface contact impedance of < 5 kΩ, positioned centrally on the scalp, at Cz, behind the right mastoid (reference) and on the forehead (ground). The syllable |da| were presented into the right ear at a rate of 11.1 per sec at comfortable listening level of 65 dBSL relative to the threshold at 1000 Hz through ER-3 insert earphones. The sampling rate was 20000 Hz and responses were online band passed filtered from 100 to 3000 Hz at 12 dB/octave. Trials with eye-blinks or other motion artifacts greater than ±35 µV were rejected online. Two traces of 2000 sweeps were collected at alternating polarity. The recording window was 50 ms starting 10 ms prior to stimulus onset. Waveforms were averaged online in Intelligent Hearing Systems (IHS) Smart EP software (version 2.39).

2.4. Analysis

The obtained waveforms were subjected for peak identification by two experienced observers who had experience in spABR recording and analysis. The stimulus used for recording sub-cortical responses was blinded to observers. The two observers who independently agreed on individuals peaks were analyzed and peak at which disagreement occurred was discarded from data pool.

The identified peaks were labeled as V, A, C, D, E, F, & O. Their absolute latencies & amplitude were analyzed. Waves V and A reflected the onset of the response, wave C the transition region, waves D, E, and F the sustained region (i.e., the frequency following response), and wave O the offset of the response. V-A complex was analyzed for latency, amplitude and slope (VA amplitude/VA duration).

The peak values were descriptively analyzed. The mean, median, standard deviation, minimum, maximum and confidence interval values of individual peak were calculated. One way ANOVA was studied at significance levels of 5% ($P < 0.05$) to compare the mean latency & amplitude values of individual peak between the present study and studies reported in literature.

3. Results

The study used Hindi stop voiced phoneme of consonant-vowel (CV) combination |da| to obtain neurophysiologic responses of brainstem in Hindi speaking adults. All 50 participants exhibited spABR. Figure 1 showing speech evoked auditory brainstem responses with Hindi stimulus |da| in one of the subject.

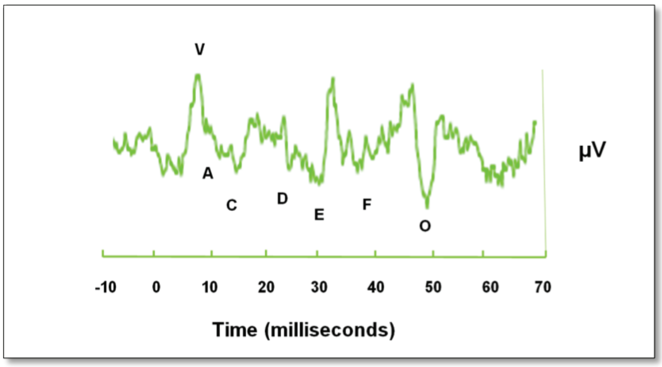

Figure 1. Waveform of speech evoked auditory brainstem responses with Hindi stimulus |da| in one of the subject.

Table 1: Showing mean, standard deviation (in parenthesis), median, minimum and maximum and 95% confidence values of sub cortical responses peaks latencies and amplitudes in Indian adults.

Hindi Speech Stimulus - Evoked ABRs									
	Peaks	N	% of peak detection	Minimum (ms)	Maximum (ms)	Median (ms)	Mean (SD) (ms)	95% Confidence Level Minimum	95% Confidence Level Maximum
L	V	50	100	5. 77	10. 96	7. 03	6.78 (0.24)	6. 18	7. 73
A	A	50	100	6. 79	12 .09	7.55	8. 04 (0.35)	7.24	8 .19
T	C	50	100	14.01	20.23	17.01	18.81 (0.97)	16.01	19.21
E	D	45	93	19.67	24.26	21.11	22.78 (0.85)	20.10	22.16
N	E	45	94	26.37	33.81	30.06	31.82 (0.20)	29.16	32.21
C	F	50	98	34.3	41.73	37.34	39.48 (0.51)	36.35	40.02
Y	O	47	99	43.1	49.23	47.31	49.03 (0.68)	45.27	49.01
(ms)	V-A	50	100	1.01	1.98	1.23	1.46 (0.19)	1.31	1.69
Slope	V/A	50	100	0.87	1.34	0.91	1.21 (0.37)	0.87	1.27
A M	V	50	100	0.16	0.63	0.28	0.29 (0.15)	0.21	0.48
p	A	50	100	-0.93	-0.13	-0.47	-0.37 (0.31)	-0.93	-0.13
L	C	50	100	-0.36	-0.21	-0.36	-0.37 (0.26)	-0.36	-0.21
I	D	45	93	-0.89	-0.16	-0.50	-0.31 (0.17)	-0.60	-0.39
T	E	45	94	-1.06	-0.01	-0.37	-0.34 (0.23)	=0.48	-0.24
U D	F	50	98	-0.39	-0.07	-0.31	-0.30 (0.23)	-0.39	-0.07
E	O	47	99	-1.06	-0.01	-0.31	-0.33 (0.18)	-0.01	-0.47
(µV)	V-A	50	99	0.50	1.38	0.51	0.38 (0.25)	0.80	1.06
Area	VA	50	100	0.28	1.18	0.43	0.71 (0.26)	0.59	0.83

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The results indicated that the onset (wave V and A) and the transition (peak C) were observed in all the participants (100%). The FFR (peak D, E and F) were present in 93.3% and the offset response (peak O) was detected in 99% of participants. The latencies and amplitudes of discrete peaks (see Table 1) and sustained components (see Table 2) of the brainstem response to speech stimulus were measured.

3.1. Discrete Peak Measures of the Hindi Speech stimulus-evoked ABRs

The latencies and amplitudes of spABR discrete peaks V, A, C, D, E, F and O as well as the latency, amplitude, area, and slope between waves V and A (known as the V/A complex) were calculated. Table 1 showing mean, standard deviation (in parenthesis), median, minimum, maximum and 95% confidence values of sub cortical responses of individual peak latencies and amplitudes in adults.

Table 2: Showing Mean, standard deviation of (A) Stimulus-to-response correlations (B) spectral amplitude measures of Hindi stimulus in native Hindi speaker

	Number	Mean	Standard Deviation
A) Stimulus–response correlations			
SR corr (r)	50	0.28	0.06
SR lag (ms)	50	7.98	3.42
B) Spectral amplitudes (µV)			
RMS amp	50	2.32	0.02
F0 amp	49	16.13	7.12
F1 amp	45	6.46	4.35
HF amp	44	0.36	0.12

3.2. Sustained Portion of the Hindi Speech stimulus-evoked ABRs measures

The response between waves C and O comprises the sustained portion or FFR (peaks D, E and F), occurs approximately between 10 and 40 ms after the onset in response to the vowel portion of the syllable. Responses to formant transitions of stimuli were analyzed using, Stimulus-Response Correlation, Frequency Fourier Transform (FFT) and Root Mean Squares (RMS) measures (depicted in Table-2). These measures provide information about the overall magnitude of sustained neural activity and phase-locking capabilities of the neural population in auditory system (Krishnan 2002; Russo et al. 2004; Johnson et al. 2005).

The stimulus-to-response correlation (SR corr) and the amount of stimulus-to-response delay or shift (SR lag) were calculated to determine timing (latency) of the FFR. FFT analysis was performed to calculate the magnitude of the neural response over the entire period of the stimulus (RMS amp) as well as the magnitude of spectral components in narrow frequency regions surrounding the stimulus fundamental frequency (F0 amp: 113 to 147 Hz), the first formant (F1 amp: 475 to 740 Hz), and a higher frequency region (HF amp: 760 to 1375 Hz). Timing of the FFR is indicated by S–R correlation and the magnitude of the response was evaluated with RMS, F0, F1 and HF amplitudes. The greatest amount of energy is present in the F0 region (see Figure 2).

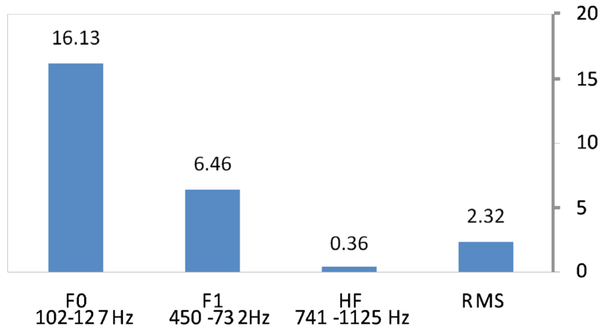

Figure 2: Showing greatest amount of energy is concentrated around F0 area

4. Discussion

The study used Hindi syllable to trace brainstem neurophysiologic responses in Hindi speaking adults. The 96% of subjects evidenced responses by the peak observers. It is reported that the response structures at brainstem level are organized to encode the stimulus with extreme accuracy (Musiek, 1991). The two measures i.e. transient and sustained component of spABR are used to describe the neural activity for temporally & spectrally distributed Hindi syllable.

The transient portion of spABR, exhibited presence of an initial wave V at a mean latency of 6.78 ms analogous to the wave V elicited by a click stimulus. However, this is more than the documented mean latency between 5 and 6 ms of peak V for click stimulus (Jacobson T, 1985). The latencies of the later peaks were calculated with reference to wave V. Peak A appeared at negative trough immediately after wave V at a mean latency of 7.55 ms, wave C emerged at a mean latency of 18.81 ms, wave D occurred at a mean latency of 22.78 ms, wave E crop up at a mean latency of 31.82 ms, wave F was visible at a mean latency of 39.48ms and wave O was visible at a mean latency of 49.03ms. These latencies are similar to the earlier findings (Johnson et al, 2005; Russo et al, 2004).

Fast Fourier analysis was applied between 10 ms and 40 ms of response to analyze the amplitude of F0 and F1. The F0 had larger amplitude as compare to the F1. This may be due to the acoustic characteristics of |da| stimulus which has greater energy at the F0 region compared to its harmonics, and greater energy stimulus components are represented better at the neuronal level. Also, the F0 has a lower frequency compared to its harmonics and it is reported that lower frequency produces better phase locked neuronal responses (Russo et al, 2004). These findings are in the line of previous reports and imply that the rapid timing changes of consonant and vowel portion of the Hindi stimulus |da| are faithfully represented and preserved in normal auditory system (Karawani & Banai, 2010; Johnson et al, 2005; Russo et al, 2004).

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4.1. Comparison of Hindi stimulus evoked ABRs values with Western data

Another goal of the study was to compare the obtained spABR to Hindi stimulus |da| with the values reported in literature. The major finding of comparisons between the Hindi sample and previous literature values are on timing measures. Table 3 showing mean (SD) along with minimum and maximum bounds at 95% confidence interval (CI) of the test sample in the left column, Israeli and US norms in middle column and right-most column respectively. The overlap among Hindi, Israeli and US CIs (Table-3) is equivalent to an insignificant result of a t-test with p value at 0.05.

Table 3: Comparisons of mean latency values obtained in the present study with the study by Russo et al. (2004) and Karwani & Banai (2010).

Peaks	PRESENT INDIAN STUDY data at 95% CI		US (RUSSO 2004) data at 95% CI	Israeli (Karawani, 2010) data at 95% CI	p-value at 0.05
	Mean (SD)	Min Max	Min Max	Min Max	
V	6.78	6. 38	6.63	6.50	0.141
	(0.24)	6. 88	6.74	6.66	
A	7.55	7.24	7.51	7.43	0.071
	(0.35)	7 .69	7.68	7.69	
C	18.81	18.31	18.35	18.35	0.415
	(0.97)	19.01	18.67	18.52	
D	22.78	20.10	22.62	22.37	0.621
	(0.85)	22.16	23.00	22.88	
E	31.82	29.16	30.90	30.88	0.354
	(0.20)	32.21	31.15	31.13	
F	39.48	36.35	39.45	39.36	0.153
	(0.51)	40.02	39.69	39.50	
O	49.03	47.27	48.14	48.06	0.519
	(0.68)	51.01	48.36	48.35	
VA slope (µV/ms)	0.77	-0.83	-0.43	- 0.42	0.452
	(0.36)	-0.57	- 0.36	-0.31	

The obtained electrophysiological results do not support our assumption that culturally & linguistically sensitive stimulus may exhibit dissimilar ABR pattern in Hindi speakers. The comparable findings can be argued on two fronts. Firstly, the sub cortical structures may not be able to represent subtle acoustic differences existed in the languages and the system may be responsive to gross durational aspects of the stimulus. Secondly, though the subjects in the current study were native Hindi speaker but were also exposed and had equivalent basic reading and writing skills in other languages including the English.

Further, the Indian basic educational program has compulsory three to four language exposure & learning and it is likely that their auditory systems may have maturational tuning to represent gross/ common features of acoustic stimulus of variants of stimulus |da|. The linguistic and psychoacoustic aspects of these differences may be operated by the higher order auditory function in listeners. However, a systematic investigation is required to address this point.

5. Conclusions

The study provides neural encoding of acoustic aspects of Hindi stimulus in term of latency and amplitude. The latency measures of response provide information about the precision with which the brainstem nuclei synchronously respond to acoustic stimulus while amplitude measures furnish information about robustness of the response of the brainstem nuclei for the acoustic stimulus. The major characteristics of ABR to Hindi sound |da| in adults are in similar lines to non tonal language speakers reported in literature.

The comparable latency values of spABR entails that the ABR also reflects various acoustic properties of Hindi syllable in normally perceiving auditory system suggesting that similar results are expected in the population and languages where this stimulus will be present. Therefore, alterations in peak latency measures may indicate a difference in conduction speed along the dendrites and axon projections, or a difference in kinetic channels of neurons, or even differences in the synchronization of the response generators in clinical population. Hence, it can be suggested that Hindi stimulus can also be used for recording ABR in speakers of Indian languages.

However, the growing body of literature reveals that brainstem encoding of specific elements of speech sounds in Mandarin speakers encode pitch patterns more robustly than English speakers that convey linguistic meaning in Mandarin, but not in English (Krishnan et al, 2005, 2009). Therefore, we would like to emphasize a point here that India is multicultural and multilingual society also have tonal language speakers. Therefore, the acoustic-phonetics variations among the various languages in India may play a crucial role in diagnostic work-up of clinical population. Hence, unlike any other language based speech test, appropriate speech stimulus and norms may be more meaningful in assessment and categorization of clinical population.

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7. Declaration of conflict of interest

The corresponding author is doing Ph D under the guidence of second author on same topic.

References

Ansari, M.S., Rangasayee, R. (2015). Development of Hindi speech stimuli to elicit auditory brainstem responses: Necessity & acoustic-phonetic considerations. *Journal of Hearing, Balance and Communication, 13*, 118-125.

ANSI. (1989). Specifications for Audiometers (ANSI S3.6-1989). New York: American National Standards Institute.

Banai, K., Hornickel, J., Skoe, E., Nicol, T., Zecker, S., Kraus, N. (2009). Reading and sub cortical auditory function. *Cerebral Cortex, 19*, 2699–2707.

Bradlow, A.R., Kraus, N., Nicol, T.G., Mcgee, T.J., Cunningham, J., Zecker, S.G., Carrell, T.D. (1999). Effects of lengthened formant transition duration on discrimination and neural representationof synthetic CV syllables

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NÖRODAVRANIŞ BİLİMLERİ DERGİSİ

by normal and learning-disabled children. *Journal of Acoustic Society of America, 106,* 2086–2096.

Chandrasekaran, B., & Kraus, N. (2009). The scalp-recorded brainstem response to speech: Neural origins and plasticity. *Psychophysiology, 47*, 236 – 246.

Gorga, M., Abbas, P., Worthington, D. (1985). Stimulus calibration in ABR measurements. In: Jacobsen J, editor. The Auditory Brainstem Response. San Diego: College-Hill Press, 49–62.

Hall, J.W. (2007). New handbook of auditory evoked responses. Boston Mass: Pearson.

Hood, L.J. (1998). Clinical Applications of the Auditory Brainstem Responses. San Diego, USA: Singular Publishing Group, Inc.

Hornickel, J., Anderson, S., Skoe, E., Yi, H., & Kraus, N. (2012). Sub cortical representation of speech fine structure relates to reading ability. *NeuroReport, 23*, 6-9.

Johnson, K.L., Nicol, T.G., Kraus, N. (2005). Brainstem response to speech: A biological marker of auditory processing. *Ear & Hearing, 26,* 424-34.

Johnson, K.L., Nicol, T.G., Zecker, S.G., & Kraus, N. (2007). Auditory brainstem correlates of perceptual timing deficits. *Journal of Cognitive Neuroscience, 19*, 376-385.

Johnson, K.L., Nicol, T.G., Zecker, S.G., Kraus, N. (2008). Developmental plasticity in the human auditory brainstem. *Journal of Neuroscience, 28,* 4000-7.

Karawani, H., & Banai, K. (2010). Speech-evoked brainstem responses in Arabic and Hebrew speakers. *International Journal of Audiology, 00,* 1–6.

King, C., Warrier, C.M., Hayes, E., Kraus, N. (2002). Deficits in auditory brainstem pathway encoding of speech sounds in children with learning problems. *Neuroscience Letter, 319,* 111–15

Kraus, N., & Nicol, T. (2005). Brainstem origins for cortical ‘what’ and ‘where’ pathways in the auditory system. *Trends in Neuroscience, 28,* 176 – 181.

Kraus, N. (2007). Sensory-based learning disability: Insights from brainstem processing of speech sounds. *International Journal of Audiology, 46,* 524 – 532.

Krishnan, A. (2002). Human frequency - following responses: representation of steady-state synthetic vowels. *Hearing Research, 166,* 192-201.

Krishnan, A., Xu, Y., Gandour, J., Cariani, P. (2005). Encoding of pitch in the human brainstem is sensitive to language experience. *Cognitive Brain Research, 25,* 161 – 168.

Krishnan, A., Swaminathan, J., & Gandour, J.T. (2009). Experience-dependent enhancement of linguistic pitch representation in the brainstem is not specific to a speech context. *Journal of Neuroscience, 21,* 1092 – 1105.

Musiek, F.E. (1991). Auditory evoked responses in site-of lesion assessment. In: W.F. Rintelmann (ed.), Hearing Assessment. Austin: PRO-ED, 383 – 427.

Liberman, A.M., Cooper, F.S., Shankweiler, D.S., & Studdert-Kennedy, M. (1967). Perception of the speech code. *Psychological Review, 74,* 431-461.

Palmer, A., & Shamma, S. (2004). Physiological Representations of Speech. In S. Greenberg, W. A. Ainsworth, A. N. Popper, R. R. Fay (Eds). Speech Processing in the Auditory System: Springer Handbook of Auditory Research (Vol, 18, pp- xiv, 476). New York: Springer.

Russo, N., Nicol, T., Musacchia, G., Kraus, N. (2004). Brainstem responses to speech syllables. *Clinical Neurophysiology, 115,* 2021–2030

Sininger, Y.S. (1993). Auditory brain stem response for objective measures of hearing. *Ear & Hearing, 14,* 23-30.

Song, J.H., Banai, K., Russo, N.M., & Kraus, N. (2006). On the relationship between speech- and non-speech-evoked auditory brainstem responses. *Audiology & Neurootology, 11*, 233 – 241.

Wong, P.C., Skoe, E., Russo, N.M., Dees, T., Kraus, N. (2007). Musical experience shapes human brainstem encoding of linguistic pitch patterns. *Natural Neuroscience, 10,* 420 – 22.

Werker, J.F., & Tees, R.C. (1984). Developmental changes across childhood in the perception of non-native speech sounds. *Canadian Journal of Psychology, 37,* 278–28.

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