LATERAL ASYMMETRY IN SPEECH PROCESSING AT THE BRAINSTEM: EVIDENCE FROM SPEECH EVOKED ABR

***Sujeet Kumar Sinha, & **Vijayalakshmi Basavaraj**

Abstract

Asymmetrical function of the left and right cerebral cortices is well documented. Rapidly changing auditory signals (including speech) are primarily processed in the left auditory areas while tonal stimuli are preferentially processed in the right hemisphere. Some studies suggest that response asymmetries in subcortical auditory structures do exist and may contribute to cerebral lateralization. However, the role of the subcortical auditory pathway in lateralized processing needs to be further established. 40 normal hearing subjects participated in the study. Click evoked auditory brainstem response (ABR) and speech evoked ABR were recorded. Speech evoked ABR was elicited using a synthesized /da/ stimulus. The two measures of speech evoked ABR the onset response (consist of wave V) and the frequency following responses (consist of wave D, wave E, and wave F). Additional, a fast fourier transform (FFT) of FFR also gives information regarding the amplitude of fundamental frequency of sound, the amplitude of first formant of the sound and higher harmonics of the speech sound. Results revealed that there was no difference between wave V of click evoked and speech evoked ABR for the left and the right ear. But the mean latency of wave D, E, F and O were shorter for the right ear as compared to that for the left ear. Also, the frequency following responses (FFR) revealed that mean amplitude of fundamental frequency and harmonics were larger for the right ear as compared to the left ear. The present study suggests that the right ear advantage for speech stimulus could be preserved at the brainstem level. The study adds new information in the role of auditory brainstem processing of speech sounds. These results may open up new area of research in clinical population such as learning disabled children and also the older individuals.

Asymmetrical function of the left and right cerebral cortices is well documented. Rapidly changing auditory signals (including speech) are primarily processed in the left auditory areas while tonal stimuli are preferentially processed in the right hemisphere (Zatorre, 2001). Kimura (1969) has reported that speech stimuli presented to the right ear, contralateral to the hemisphere best suited to process rapid stimuli, are preferentially processed over competing speech presented to the left ear. The cortical asymmetry of language processing has been determined by using functional imaging, electrophysiological responses, and performance on dichotic listening tasks.

The role of the subcortical auditory pathway in lateralized processing is not yet well understood. Studies of brainstem auditory evoked potentials, (Levine & McGaffigan, 1983; Levine, Liederman & Riley, 1988) reported a rightward asymmetry for monaural click-train stimulation. Stimulation of the right ear elicited larger brain stem responses than stimulation of the left ear suggesting an increased number of active neurons or increased firing synchrony in the brain stem structures along the afferent auditory path from the right ear to the left auditory cortex. The authors related the rightward asymmetry in the brain stem responses to the left hemisphere dominance for speech processing.

Smith, Marsh & Brown (1975) and Hoormann, Falkenstein, Hohnsbein & Blanke (1992) have studied subcortical lateralization of spectral encoding. It is reported that tonal (and other highly periodic) stimuli elicit a frequency following response (FFR) in which the periodicity of the response matches the periodicity of the stimulus. The FFR is thought to be generated by a series of brainstem nuclei, including the inferior

**Lecturer, Department of Audiology, , All India Institute of Speech and Hearing (AIISH), Mysore-06, email: sujitks5@yahoo.co.in, & **Director, AIISH, Mysore-06, e-mail : vbasavaraj@hotmail.com*

colliculus and lateral lemniscus, and represents the temporal coding of frequency through neural phase locking. Normalized amplitude of the FFR region in adults was reported to be significantly different for the left and right ear presentation of tone bursts (Ballachanda, Rupert & Moushegian, 1994). In comparing the right- and left-ear contributions to the binaural response to the tonal stimulus, the magnitude of the binaural response was found to be attenuated more when the left ear responses was subtracted than the right ear response, suggesting that the left ear contributed more to the binaural response for the tonal stimulus (Ballachanda et al., 1994).

Asymmetries in peripheral auditory structures have also been reported. Magnitude of active cochlear amplification, assessed by click-train--evoked Otoacoustic emissions, is reported to be greater in the right than in the left cochlea (Khalfa & Collet 1996; Khalfa, Micheyl, Veuillet & Collet, 1998). This peripheral asymmetry is also considered as an indicator of speech related asymmetries in the cerebral hemispheres.

Thus, previous studies which have reported a lateral asymmetry of the auditory brainstem responses and the otoacoustic emissions have used non speech stimulus. Subcortical laterality of speech has also been reported for a few parameters of speech using speech evoked ABR (Hornickel, Skoe & Kraus, 2009). But the study of Hornickel et al. (2009) studied a small sample of 12 normal subjects and they found significant difference for the latency two peaks of speech evoked ABR. For rest of the peaks in speech evoked ABR it reached to significance level but failed to show a significant difference. The findings of Hornickel et al. (2009) study may be due to a small sample size.

Speech evoked auditory brainstem responses consist of a transient and a sustained portions that mimics the acoustic signal (Galbraith et al., 1995). The sustained portion is also known as frequency following response (FFR). The speech evoked auditory brainstem response is considered to provide a direct electrophysiological measure of sensory processing in the auditory brainstem (Galbraith et al., 2000). More research is indicated to strengthen the evidence regarding the contribution of the subcortical auditory pathway to the cerebral asymmetry in processing speech.

Thus, limited information available in the literature shows a rightward asymmetry for non speech stimulus using a non speech stimulus such a click, at the subcortical level. However, the studies regarding the speech laterality at the subcortical level is very less. Thus, there is a need to study how speech is coded at the subcortical level (brainstem) as well, using a large data sample. The present study was undertaken with the aims of studying the right ear and left ear advantage, if any, for the speech evoked ABR to understand lateral asymmetry, if any, in speech processing at the brainstem.

Method

I. Participant

Forty student subjects (20 females, 20 males) in the age range of 18 to 30 years, with a mean age of 22 years, participated in the study. All were right-handed by self-report and as determined by the Edinburgh Handedness Inventory (Oldfield, 1971). All participants had pure tone thresholds of <20 dBHL from 250 Hz to 8000 Hz for air conduction and from 250Hz to 4000 Hz for bone conduction in both the ears. A normal middle ear functions was for all the subjects were determined by tympanometry and reflexometry evaluations. Prior to the study, consent was obtained from all the participants.

II. Test Stimulus:

The test stimulus which was used for speech evoked ABR in the present study was a synthesized /da/ syllable (King, Warrier, Hayes & Kraus, 2002). The stimulus available in BIOLOGIC NAVIGATOR PRO evoked potential system with the BioMARK protocol was used. The /da/ stimulus available with the BioMARK protocol is a 40 ms synthesized speech syllable produced using KLATT synthesizer (Klatt, 1980). This stimulus simultaneously contains broad spectral and fast temporal information's characteristic of stop consonants, and spectrally rich formant transitions between the consonant and the steady-state vowel. Although the steady-state portion is not present, the stimulus is still perceived as being a consonant-vowel syllable. The fundamental frequency (F0) linearly rises from 103 to 125 Hz with voicing beginning at 5 ms and an onset noise burst during the first 10 msec. The first formant (F1) rises from 220 to 720 Hz, while the second formant (F2) decreases from 1700 to 1240 Hz over the duration of the stimulus. The third formant (F3) falls slightly from 2580 to 2500 Hz, while the fourth (F4) and fifth formants (F5) remain constant at 3600 and 4500 Hz, respectively. Figure-1 shows the time domain waveform of the stimulus used in the present study.

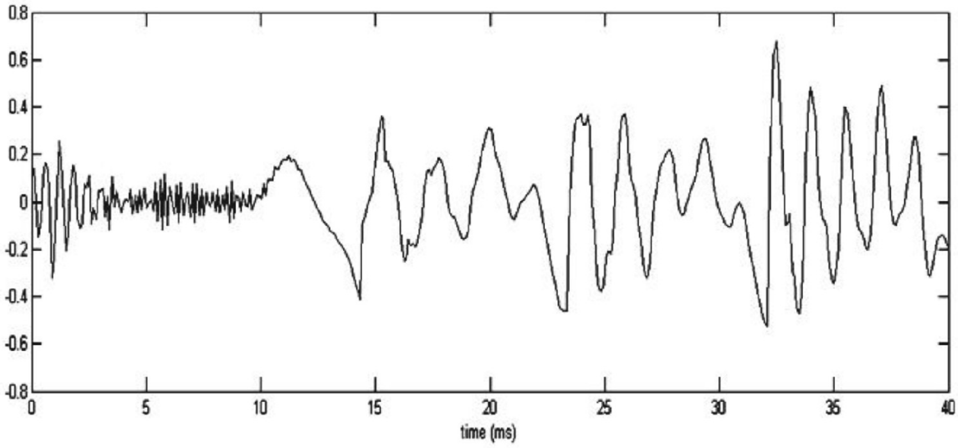

Figure -1. Time domain waveform of the stimulus /da/ available in the Biologic Navigator Pro EP system

III. Instrumentation:

A calibrated (ANSI S3.6-1996), two channel clinical audiometer Madsen OB922 with TDH-39 headphones housed in Mx-41/AR ear cushions were used for pure tone audiometry. Radioear B-71 bone vibrator was used for measuring bone conduction threshold. A calibrated middle ear analyzer, (GSI Tympstar) using 226 Hz probe tone was used for tympanometry and reflexometry. BIOLOGIC NAVIGATOR PRO evoked potential instrument was used for recording click evoked and speech evoked auditory brainstem responses.

IV. Procedure:

All the participants underwent puretone audiometry and tympanometry to ensure the subjects selection criteria. Participants were also subjected to click evoked auditory brainstem responses (ABR) and Speech evoked ABR. Click evoked ABR and Speech evoked auditory brainstem responses were recorded with the protocol shown in table-1

Table 1: Recording parameters for the click and speech evoked auditory brainstem responses.

	Stimulus	Click	/da/
Stimulus parameter	Duration	0.1 msec	40 msec
	Intensity	80dB SPL	80 dB SPL
	Polarity	Alternating	Alternating
	Repitition rate	11.1/sec	9.1/sec
	Total no. of stimulus	2000	3000
Acquisition parameter	Analysis time	10 mec	74.67 ms time window that included 15 ms of pre-stimulus and 59.67 ms of post-onset activity.
	Filter setting	100 to 3000 Hz	100 to 3000 Hz
	Electrode Montage	Noninverting(+ve):Vertex, Inverting(-ve) : Test ear mastoid, Ground: Non test ear mastoid	Noninverting(+ve):Vertex, Inverting(-ve) : Test ear mastoid, Ground: Non test ear mastoid
	Transducer	Biologic Insert	Biologic Insert

ABR were recorded twice for both the ears to ensure the reliability of the waveforms and also to get a weighted add waveform for the speech stimulus. For the speech stimulus the two waveforms was added together using weighted add option in the BIOLOGIC EP instrument. This waveform was converted to ASCII format using the software called 'AEP TO ASCII'. ASCII format data was then analyzed using 'BRAINSTEM TOOLBOX' developed at Northwestern University. This software runs on MATLAB platform and does the FFT of the waveform and analyses the FFR.

V. Data analysis

Data analysis was done as described by Russo et al. (2004), Wible et al. (2004). The seven peaks of the response to /da/ (V, A, C, D, E, F, O) were identified. Frequency following response for frequency encoding was analyzed using a Fourier analysis 11.4–40.6 ms time window. To increase the number of sampling points in the frequency domain, the time window was zero-padded to 4096 points before performing a discrete Fourier transform. Average spectral amplitude was calculated for three frequency ranges: fundamental frequency (F0) 103–120 Hz, first formant (F1) 455–720 Hz, and high frequency (HF) 721–1154 Hz.

out to obtain the mean and the standard deviation of (i) latencies of peaks V of click evoked ABR and wave V, A, C, D, E, F& O of speech evoked ABR (ii) amplitude of F0, F1 & HF of speech evoked ABR only. Paired 'T' test was applied to analyse the significance of difference between the latencies of peak V for the left and the right ear for the click evoked ABR and also to find out a Significance of difference between the latencies of peak V, D, E, F & O for the left and the right ear for the speech evoked ABR. Paired T test was also applied to find out a significance of difference between the amplitude of F0, F1 & HF for the left and the right ears.

Results

I. Descriptive analysis of click ABR responses:

The click ABR was recorded reliably for all the 40 subjects. Since speech evoked ABR were available only for 34 subjects, the data of click ABR of only those 34 subjects were considered for analysis. Table-2 shows the mean and standard deviation (S.D) of the latency of click evoked ABR for the left and the right ear presentations.

Paired 't' test revealed no significant difference between the left and the right ear peak V latencies for

Table-2: Mean and standard deviations (S.D) of the wave V latency (msec) of click evoked ABR

	Left ear		Right Ear	
Latency (msec)→	Mean	S.D	Mean	S.D
Peak V	5.75	0.11	5.70	0.12

The first formant of the stimulus ramps from 220 to 720 Hz over the 40-ms syllable. The F1 frequency range used for FFR analysis accounts for the time lag and the corresponding F1 frequency ramping between the onset of the stimulus and the periodic formant transition that elicits the FFR. The HF range corresponded to the 7th through 11th harmonics of the F0 of the stimulus, a frequency range between the first and second formants. All the analysis for the FFR was computed with "brainstem toolbox".

Statistical analyses:

Statistical analysis was done using SPSS software version 15. Descriptive analysis was carried click evoked ABR [t (33) = 1.52, p>0.05]. The results of click evoked ABR indicate that the processing of click stimulus was similar for both the ears.

II. Descriptive analysis of speech evoked ABR

Speech evoked ABR could be recorded reliably in 34 out of 40 subjects for the left and the right ear. In 6 subjects in the recorded waveform at around 10 msec had a large positive peak either in one or both the ears which is consistent with the latency of post-auricular muscle artifact. Hence the data of these subjects were not considered for analysis. An example of such a waveform is shown in figure-2.

Figure -2: A positive peak in the speech ABR waveform around 10 msec

The peak 'C' was not included for analysis as it was present in only 60% of the subjects. Figure-3 shows speech evoked ABR sample.

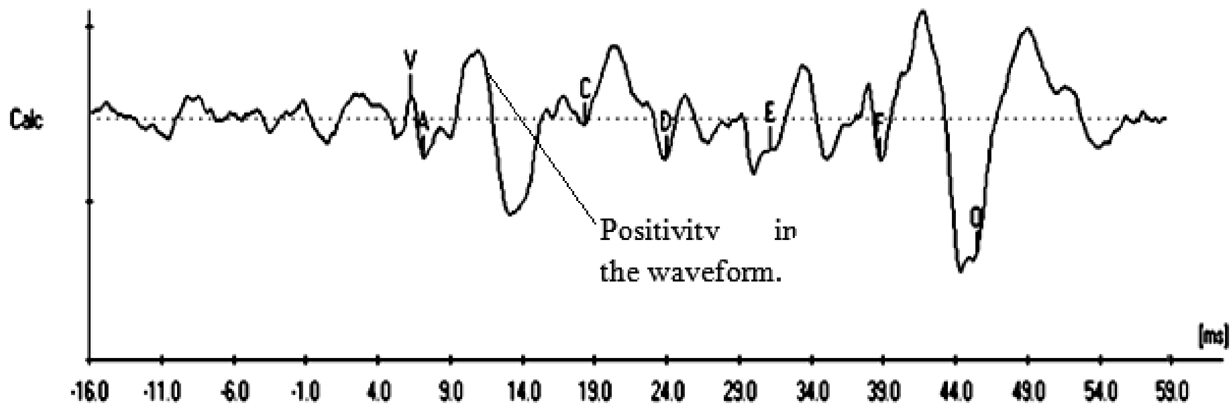

Figure-3: Sample of a Speech evoked ABR of a normal hearing subject

Table-3 represents the mean and standard deviations of the latencies (msec) of wave D, E, F and O and amplitude(µv) of fundamental frequency, first formant frequency, and high frequency. The 't' values and the level of significance of right and left ear comparisons are also shown in table-3. As it can be seen from table-3 that mean latencies for wave D, E, F and O were longer for the left ear as compared to that of the right ear. It can also be seen that mean amplitudes of the fundamental frequency, first formant frequency, and high frequency were smaller for the left ear as compared to that of the right ear.

Table-3: Mean and Standard deviations (S.D) of latency (msec) of wave V, D, E, F, O and amplitude (µv) of F0, F1 and HF

		Left Ear		Right Ear		't' Values
		Latency (msec)				
		Mean	**S.D**	**Mean**	**S.D**	
Onset response	**V**	6.54	0.23	6.50	0.26	1.27##
	A	7.39	0.35	7.36	0.37	0.60##
Frequency Following responses	**D**	22.68	0.58	22.07	0.69	4.39**
	E	30.94	0.55	30.58	0.54	3.60**
	F	39.45	0.45	39.02	0.53	6.01**
Offset response	**O**	47.90	0.57	47.43	0.96	3.75**
		Amplitude(µv)				
Fundamental Frequency(F0)		4.28	1.45	5.24	1.72	3.84**
First Formant Frequency(F1)		0.86	0.55	1.06	0.68	2.88**
High Frequency(HF)		0.31	0.16	0.41	0.17	4.17**

Figure-4 represents the data of 34 subjects in error bar graph. It can be seen from figure -4 that there is no much difference in the latency of wave V for the left versus the right ear, however, the latencies of peaks D, E, F are shorter for the right ear as compared to that of the left ear.

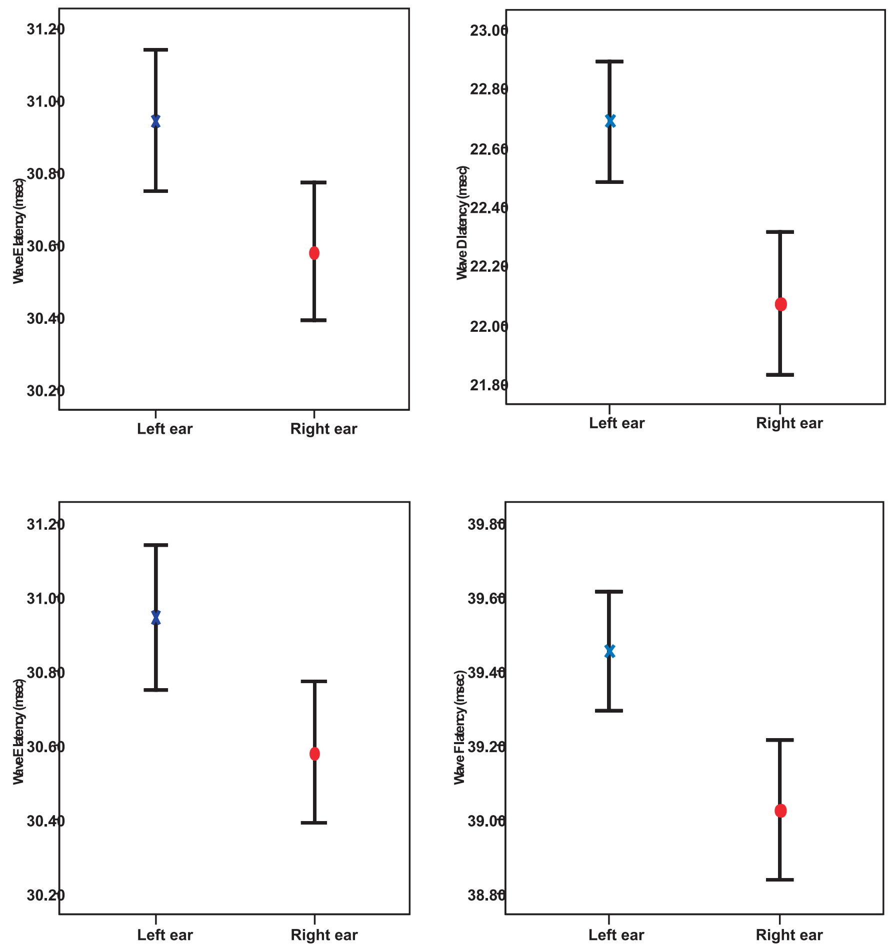

Figure 4: Shows the error bar graph of latency for [a] wave V [b] wave D [c] wave E, [d] wave F of speech evoked ABR

Discussion

The aim of the present study was to explore any indications for subcortical lateralization, if any, for processing the speech. The speech evoked ABR was recorded reliably in 33 subjects. In 6 subjects there was a positive peak present in the wave form at around a mean latency of 10 msec. This positive peak was suggestive of post auricular muscle response as described by Purdy, Agung, Hartley, Patuzzi & O'Beirne (2005), who reported a mean latency of 10.31 msec for the post auricular muscle response. Hence the 6 subjects were excluded from the data.

The onset response (i.e. wave V) did not show any significant differences for the left and the right ear presentations for both the click as well as speech stimulus. The result of the present study in consonance with the study by Hornickel et al. (2009), where they also did not get the significance difference for the wave V for the click and speech stimulus. The similarity between the two studies is because an identical protocol was used in both the studies. Also, Song, Banai, Russo & Kraus, (2006) have reported that peak V of click evoked and speech evoked ABR are highly correlated with each other. Thus, it may be hypothesized that the auditory system processes the speech as well as the non speech stimulus similarly with respect to the onset response.In the present study the latency differences attained statistical significance for the frequency following responses (i.e. for the waves D,E and F) and also the offset response, were longer for the left ear presentation as compared to the right ear presentation, suggesting that the frequency following responses (FFR) may be encoded earlier at the brainstem for the right ear presentation as compared to that of the left ear presentation. It may be noted that this asymmetry in FFR is evident even when there is no difference in the onset response for the speech evoked ABR. It is possible that brainstem processes the onset of the stimulus differently and the periodicity of speech stimulus differently. This is supported by the reports which suggest that FFR to speech operate via different mechanisms/pathways than the onset response (Hoormann et al., 1992; Kraus & Nicol, 2005; Song et al., 2006; Akhoun et al., 2008). It is also possible that the right-ear/left hemisphere pathway contains a more efficient phase locking network that results in interaural latency differences during the FFR region but not for the onset or click responses (Hornickel et al.2009).

The results of the present study showed that the amplitude of the fundamental frequency was larger for the right ear presentation as compared to that of the left ear presentation. The larger fundamental frequency representation for the right ear has also been reported by Hornickel et al. (2009). This is in contrary to the reports that there is left ear advantage for tonal perception (i.e of F0) which is crucial for pitch perception. Scheffers (1983) hypothesized that the auditory system extracts the pitch of a sound on a moment-to- moment basis and uses the pitch value to direct voice segregation. Thus, the duration of the stimulus might play an important role in pitch encoding. Since the stimulus used in the present study was of only 40 msec duration, it is possible that it was too transient to enable a valid pitch encoding, and therefore the amplitudes were better for the right ear as compared to that of the left ear.

Another important finding was that the amplitude of the harmonics (first formant and the high frequency harmonics) was more for the right ear presentation as compared to the left ear. This may be expected as these two are very important aspect of speech and thus simply may be processed better through the right ear as compared to the left ear. One more observation to be noted here is that the amplitude for the high frequency harmonics is less as compared to that of the first formant frequency. The lesser amplitude of the high harmonics can be justified as the efficiency of the brainstem structures to phase locking better for the low frequencies compared to that for high frequencies (Rose, Hind, Anderson & Brugge, 1971).

Conclusions

The present study suggests that the processing of speech is faster through the right ear as compared to the left ear. Frequency following responses specially shows a faster processing through the right ear compared to the left ear. The results of present study are encouraging as it may open up new areas of research in clinical population. These findings suggest lateralization of speech processing in the auditory brainstem for selective stimulus components and support the existence of right ear advantage for speech and speech-like stimuli. These results may have clinical implications in studying children with language based learning disorders, who tend to have particular difficulty with phonemic contrast since they have delayed brainstem responses relative to their normal learning peers (Banai et al., 2005; Wible et al., 2004). The study may also have clinical implications in older individuals, as Bellis, Nicol and Kraus (2000) have reported that there is a lack of typical hemispheric asymmetry in the neural representation of speech sounds in older individuals at the cortical level. It would be interesting to see whether such a decrement in speech processing occurs at the level of brainstem also in older individuals.

References

Akhoun, I., Gallego, S., Moulin, A., Menard, M., Veuillet, E., Berger-Vachon, C. et al. (2008). The temporal relationship between speech auditory brainstem responses and the acoustic pattern of the phoneme /ba/ in normal-hearing adults. *Clinical Neurophysiology, 119,* 922-933.

American National Standards Institute. (1996). *"Specifications for audiometers".* ANSI S3.6-(1996). New York: American National Standards Institute.

Ballachanda, B. B., Rupert A., & Moushegian, G. (1994). Asymmetric frequency-following responses. *Journal of the American Academy of Audiology,* 5,133–137.

Banai, K., Hornickel, J., Skoe, E., Nicol, T., Zecker, S., & Kraus N(2008). Reading and Subcortical Auditory Function. *Cerebral Cortex,* 19, 2699-2707.

Banai, K., Nicol, T., Zecker, S., & Kraus, N. (2005). Brainstem timing: Implications for cortical processing and literacy. *Journal of Neuroscience, 25 (43),* 9850 - 9857.

Bellis, T.J., Nicol, T., & Kraus, N (2000). Aging affects the hemispheric asymmetry in the neural representation of speech sounds. *Journal of Neuroscience, 20,* 791-797.

Eldredge, L., & Salamy, A., (1996). Functional auditory development in preterm and full term infants. *Early Human Development, 45,* 215–228.

Galbraith, G. C., Threadgill, M. R., Hemsely, J., Salour, K., Songdej, N., Ton, J., et al. (2000). Putative measures of peripheral and brainstem frequency following frequency following in humans. *Neuroscience Letters, 292,* 123-127.

Galbraith, G.C.A., Paul, W., Branski, R., Comerci, N., & Rector, P.M. (1995). Intelligible speech encoded in the human brain stem frequency-following response. *Neuroreport, 6,* 2363–2367.

Hoormann, J., Falkenstein, M., Hohnsbein, J., Blanke, L. (1992). The human frequency-following response (FFR): Normal variability and relation to the click-evoked brainstem. *Hearing Research, 59,* 179-88.

Hornickel, J.M., Skoe, E., & Kraus, N (2009). Subcortical lateralization of speech encoding. *Audiology and Neurotology,* 14, 198-207.

King, C., Warrier, C.M., Hayes, E., Kraus, N (2002). Deficits in auditory brainstem encoding of speech sounds in children with learning problems. *Neuroscience Letters, 319*, 111–115.

Khalfa, S., & Collet, L. (1996). Functional asymmetry of medial olivocochlear system in humans. Towards a peripheral auditory lateralization. *Neuroreport, 7(5),* 993--996.

Khalfa, S., Micheyl, C., Veuillet, E., & Collet, L. (1998). Peripheral auditory lateralization assessment using TEOAEs. *Hearing Research,* 121(1-2), 29--34.

Kimura, D. (1969). Spatial localization in left and rights visual fields. *Canadian Journal of Psychology, 23,* 445–458.

Klatt, D. (1975). Software for cascade/parallel formant synthesizer. *Journal of the Acoustical Society of America,* 67,971-975.

Kraus, N., Nicol, T. (2005). Brainstem origins for cortical .what. and .where. pathways in the auditory system. *Trends Neuroscience, 28* (4), 176-181.

Levine, R. A., & McGaffigan, P. M. (1983). Right-left asymmetries in the human brain stem: auditory evoked potentials. *Electroencephalography and Clinical Neurophysiology, 55* (5), 532--537.

Levine, R. A., Liederman, J., & Riley, P. (1988). The brainstem auditory evoked potential asymmetry is replicable and reliable. *Neuropsychologia, 26* (4), 603--614.

Oldfield, R. C. (1971): The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia, 9 (1),* 97-113.

Purdy, S. C., Agung, K. B., Hartley, D., Patuzzi, R. B., & O'Beirne, G. A.(2005). The post auricular muscle response: An objective electrophysiological method for evaluating hearing sensitivity. *International Journal of Audiology, 44,* 625-630.

Rose, J.E., Hind, J.E., Anderson, D.J., & Hind, J.E. (1971). Some effects of the stimulus intensity on response of the auditory nerve fibers in the squirrel monkey. *Journal of Neurophysiology, 34,* 685-699.

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

Russo, N., Nicol, T. G., Zecker, S. G., Hayes, E. A., & Kraus, N. (2005). Auditory training improves neural timing in the human brainstem. *Behavioural and Brain Research, 156,* 95–103.

Scheffers MT (1983). *Sifting vowels.* Unpublished doctoral dissertation, University of Groningen, The Netherlands.

Schwartz, J., & Tallal, P.(1980) Rate of acoustic change may underlie hemispheric specialization for speech perception. *Science, 207,* 1380–1381.

Sidtis, J. J. (1982). Predicting brain organization from dichotic listening performance: cortical and subcortical functional asymmetries contribute to perceptual asymmetries. *Brain and Language, 17,* 287–300.

Sininger, Y.S., Abdala, C., Luckoski, C.A., (1996). Ear asymmetry and gender effects on audition of human infants. *Abstracts of Midwinter Meeting, Association for Research in Otolaryngology,* St. Petersburg Beach, FL.

Sininger, Y.S., Cone-Wesson, B., (2004). Asymmetric cochlear processing mimics hemispheric specialization. *Science, 305,* 1581-1584.

Smith, J. C., Marsh, J. T., & Brown, W.S (1975). Far-field recorded frequency following responses: evidence for the locus of brainstem sources. *Electroencephalography and Clinical Neurophysiology, 39,* 465–472.

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

Wible, B., Nicol, T., & Kraus, N. (2004). Atypical brainstem representation of onset and formant structure of speech sounds in children with language-based learning problems. *Biological Psychology, 67,* 299-317.

Zatorre, R. J. (2001). Neural specializations for tonal processing. *Annals of the New York Academy of Sciences, 930,* 193–210.