SPEECH CHARACTERISTICS IN INDIVIDUALS WITH AUDITORY DYS-SYNCHRONY

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Abstract

The present study was aimed to examine the effects of longstanding Auditory dys-synchrony (AD) on speech production. Speech production of 12 individuals with acquired long-term AD was characterized and compared against that of 20 age matched individuals with normal hearing sensitivity. It was hypothesized that any difference between the two groups in their speech production will because of long standing perceptual deficits due to AD. Long-term AD was operationally defined as AD for more than 5 years. The study was carried out in 2 phases; Phase 1 included the perceptual analysis of speech of adults with long-term AD, and the phase 2 included acoustic analysis of the same speech samples. Results showed that speech of individual with AD was abnormal on perceptual as well as acoustical analysis. The extent of deficit in speech production correlated well with the speech identification scores. These results highlight the importance of auditory feedback in maintaining the speech production skills. The results show a close relationship between speech perception and production skills in turn supporting the closed loop models of speech production. There was also evidence of compensatory strategies in production that could be associated with the perceptual deficit.

Introduction

Auditory dys-synchrony (AD) is a clinical syndrome in which outer hair cell function is spared, but afferent neural transmission is disordered (Starr, Picton, Sininger, Hood, & Berlin, 1996). A typical person with AN will have elevated pure tone thresholds, very poor speech discrimination for degree of hearing loss, absent acoustic reflex in any configuration for any stimuli, no auditory brainstem response, but presence of robust Otoacoustic emissions. The prevalence of AD is around 1 in 183 (0.54%) among individuals with sensorineural hearing loss (Ajith, 2006).

AD may affect the functioning of inner hair cells, synaptic junctions between the inner hair cells and auditory nerve, or the auditory nerve itself (Starr et al., 1996). These individuals typically have speech recognition deficits that are not in consonance with their pure tone hearing thresholds (Sininger, & Starr, 1999). They usually do not benefit from conventional amplification (Zeng Oba, Garde, Kong, Sininger, & Starr, 1999; Starr, 2004). Poor speech perception abilities in these patients are attributed to abnormal temporal coding and asynchrony (Rance, McKay, & Grayden, 2004).

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Results of psychophysical studies have shown that individuals with AD are proved to have more serious deficits in frequency resolution, temporal resolution and poor gap detection (Zeng, Kong, Michalewski, & Starr, 2005). These deficits further deteriorate in adverse listening conditions (Kraus, Bradlow, Cheatham, Cunningham, King, & Koch, 2000).

Studies have shown that there is a close relationship between speech perception and the development of speech production skills. The relationship between hearing ability and speech intelligibility supports the acoustic theory of speech production (Kuhl, 1981; Stevens, 2002), which claims that the acoustic patterns of a speech signal are processed and organized into an internal map that can be distorted if the acoustic patterns have not been adequately received during the input process. With a compromised input process, such as that associated with a hearing loss, the incorrect mapping will result in distorted or deleted speech sounds in speech production (Stevens, 2002). Dunn and Newton (1986) reported suprasegmental errors in the speech of people with severe to profound hearing impairments.

Ramsden (1981) reported that speech of the adventitiously deaf degenerated systematically over time, indicating that auditory information plays an important role in the maintenance of normal speech. Zimmermann and Rettaliata (1981) investigated the systemic longitudinal degeneration of speech in hearing impaired individuals and found that the adventitiously deaf speaker's speech degenerated slowly due to overlearned motor patterns, and errors made without knowledge. They also reported that it takes many instances of exceeding the normal range of variability to change production. Articulatory movement patterns were less efficiently maintained over time when only non-auditory sensory systems were available. Consequently, auditory information is not used for moment-to-moment monitoring, but periodically to update and calibrate the system. Houde and Jordan (1998) reported that compensatory changes in individual sound production can be induced over time by systematically altering auditory feedback to indicate inaccurate articulation.

Rance, Barker, Sarant, and Ching (2007) reported that school aged children with AD are developing spoken language more slowly than would be expected for children with normal hearing. This is expected as the perceptual deficits occur before the development of the speech and language. However, it was interesting to study perceptual deficits secondary to AD would change the speech production in postlingually acquired AD. There was no such study in AD in the literature. Therefore, the present study was taken up.

The objectives of the present study were:

1. To characterize the speech production of adults with long-term AD through perceptual analysis.
2. To characterize the speech production of adults with long-term AD through acoustic analysis.

Method

Subjects

The study was conducted in 12 individuals (8 females & 4 males) with acquired long-term AD and 20 age matched individuals (10 males & 10 females) with normal hearing sensitivity. Individual with AD were grouped under experimental group while normal hearing individual were grouped under control group. Long-term AD was operationally defined as AD for more than 5 years. The individuals in the AD group had the same diagnosis five years back and they were contacted through mail and recruited. This way, longstanding (at least for 5 years) nature of the disorder was confirmed. Age of the subjects in this group ranged between 17 and 30 years. Subjects in both the groups were native speakers of Kannada and belonged to same geographical location (Mysore city or places within Mysore district). As reported by the parents and also as observed in the informal testing, all the subjects in the present study had normal speech and language development.

Test materials

Two speech samples were collected from all the subjects. The first of these was during reading of a Standardized passage in Kannada on Bengalooru (had total of 39 words containing only voiced sounds) and second was during a description of a standardized picture depicting a picnic situation. The recording of the speech samples was done in sound treated room in ideal recording conditions.

Analysis

Two types of analysis were used in the study: perceptual analysis and acoustic analysis.

Perceptual Analysis

Thirteen sophisticated listeners perceptually rated the parameters (voice, articulation, prosody, rate of speech & overall intelligibility) of speech. They rated the sample as either normal or abnormal. Listeners were blindfolded to the purpose of the study. Also overall intelligibility was rated on speech intelligibility rating scale given by Markides (1986). A score between 1 and 7 was determined for each sample to the following description:

1. Normal
2. Very easy to follow
3. Fairly easy to follow
4. Rather difficult to follow
5. Very difficult to follow
6. Unintelligible
7. Non-existive

Acoustic Analysis

Each sample was acoustically analyzed. Temporal parameters of speech were noted. The parameters analyzed and recorded were word duration, voice onset time, burst duration,

transition duration and speed of transition, preceding vowel duration, & following vowel duration.

Statistical Analysis

The perceptual and acoustical data thus obtained were tabulated. Descriptive statistics like mean and standard deviation of the data were obtained for all the parameters analyzed. Independent t test, Mann-Whitney test and Equality of proportion were applied to check whether there were any significant differences between normal and AD group in their speech production.

Results

Perceptual Analysis

Mean percentage of judgment was calculated for both 'Normal' and 'Abnormal' judgments using the following formula.

$$\text{Mean percentage (\%)} = \frac{\text{No. of 'Normal/ Abnormal' judgments in each parameter}}{\text{Total no. of judgments}} \times 100$$

The mean percentages of 'Normal/ Abnormal' judgments of the samples were compared among control and experimental groups. Figure 1 showed Mean percentage of 'Normal' judgments in each parameter of speech in normal and AD group & Figure 2 showed Mean percentage of 'Abnormal' judgment in each parameter of speech in normal and AD group.

Results of the perceptual experiment showed that, majority of speech samples of auditory dys-synchrony (AD) were perceptually abnormal. All the parameters of speech (voice, articulation, prosody, rate of speech & overall naturalness) were rated as abnormal, although prosody was found to be maximally affected.

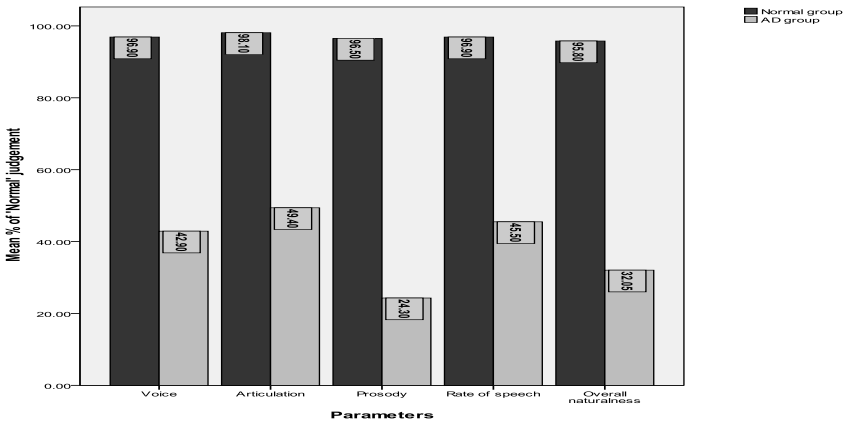

Figure 1: Mean percentage of 'Normal' judgments in each parameter of speech in normal and AD group.

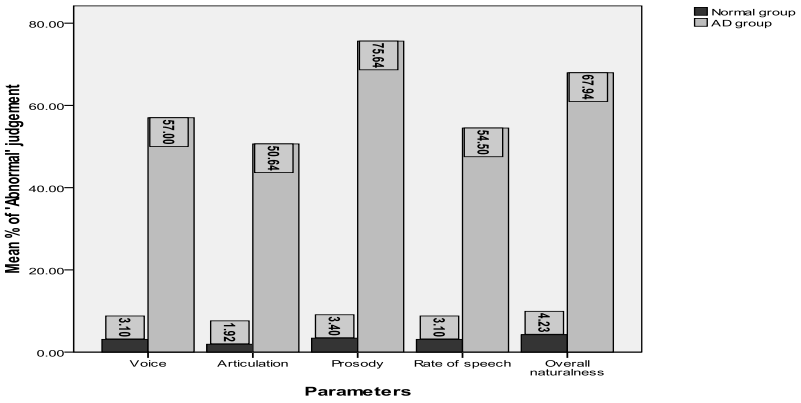

Figure 2: Mean percentage of 'Abnormal' judgment in each parameter of speech in normal and AD group.

To verify whether the mean percentage of normal/abnormal judgment was significantly different between control and experimental groups, Equality of proportion was tested and Z scores were calculated. Results of Z scores are given in Table 1. Results showed a significant difference between the 2 groups in all the parameters at 0.05 level of significance.

Table 1: Z scores showing the significance of difference between the mean percentage of 'Normal/ Abnormal' judgments in normal and AD group.

Parameter	Z (Normal judgment)	Z (Abnormal judgment)
Voice	10.59*	13.18*
Articulation	11.90*	11.91*
Prosody	19.93*	19.93*
Rate of speech	12.44*	12.83*
Overall naturalness	16.18*	16.71*

Note: * - $p < 0.05$

Mean percentage of overall intelligibility was calculated using the following formula.

$$\text{Mean \% percentage of judgments} = \frac{\text{No. of subjects rated under a particular scale}}{\text{Total no. of judgments}} \times 100$$

Figure 3 showed Mean percentage of overall intelligibility rating in normal and AD groups. Results showed that AD group had higher rating on the intelligibility scale compared to normal. This means intelligibility of speech of AD was poorer compared to normal. The overall intelligibility ranged from 2 -5 in AD group and 1-3 in normal group.

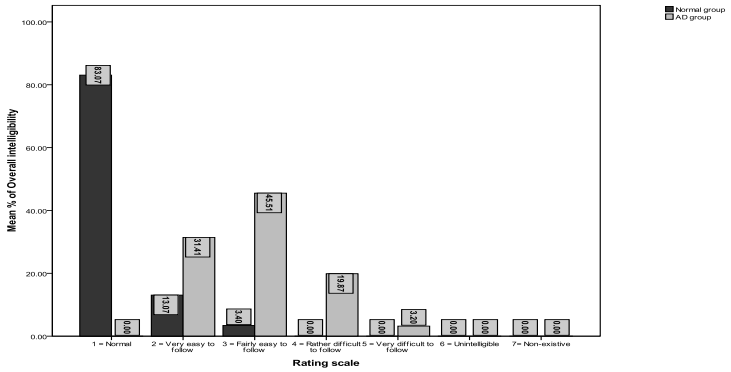

Figure 3: Mean percentage of overall intelligibility rating in normal and AD groups.

Correlation between Speech Identification Scores and Overall Intelligibility

Speech identification scores and ratings of overall intelligibility were correlated using the data obtained from AD group. Correlation was not carried out for the data from normal group. Correlation was done for the identification scores of the better ear as well as poorer ear. Spearman's rho test was used for the task and the results are as given in Table 2. The correlation coefficient for the better and poorer ear scores are given separately.

Table 2: Results of correlation between overall intelligibility and speech identification scores of better and poorer ear.

Ear	N	r
Results of better ear	12	-0.624*
Results of poorer ear	12	-0.673*

Note: * - $p < 0.05$

In individuals with AD, there was a significant high correlation between speech identification scores and, the severity of abnormality in speech intelligibility ($p<0.05$). Results showed that, as the speech identification scores decreased, overall speech intelligibility reduced.

Acoustic Analysis

The words for this purpose were chosen from speech samples of passage reading as well as picture description task. The words were categorized based on the number syllables. For passage reading, these words were categorized as bisyllabic, trisyllabic, foursyllabic, fivesyllabic and sixsyllabic words. For picture description, these words were categorized as bisyllabic, trisyllabic, and foursyllabic.

Mean and standard deviation of word duration were obtained in different word categories in the two groups (Table 3). In general, the mean word duration was longer in AD group compared to normal group in all the word categories. The AD group had greater

variations in the word duration than that of normal group. To verify whether these differences in word duration were significantly different, the two groups were compared using independent *t* test.

Table 3: Mean and Standard Deviation (SD) of word duration in different word categories.

Word Category	Subject	Passage Reading			Picture Description		
		N	Mean (in ms)	SD	N	Mean (in ms)	SD
Bisyllabic	Normal	20	290.59	29.62	19	3.44	38.34
	AD	12	348.77	44.83	11	4.30	70.24
Trisyllabic	Normal	20	440.67	46.62	14	4.11	85.18
	AD	12	509.71	79.48	8	4.80	106.49
Foursyllabic	Normal	20	547.85	64.89	16	5.84	77.30
	AD	12	607.27	102.58	5	5.94	52.43
Fivesyllabic	Normal	20	622.92	74.11	-	-	-
	AD	12	684.54	102.18	-	-	-
Sixsyllabic	Normal	19	774.55	84.73	-	-	-
	AD	12	862.33	153.15	-	-	-

Table 4 gives results of independent *t* test. Results showed a significant difference in the word duration between the two groups. The mean word duration in AD group was significantly longer compared to normal group. However, this statistical difference ($p<0.05$) was seen only in bisyllabic and trisyllabic words. There was no difference ($p>0.05$) in the mean word duration between the two groups in four syllabic, five syllabic and six syllabic words.

Table 4: Results of independent t test in different word categories

Word	Passage Reading		Picture Description	
	T	df	t	df
Bisyllabic	4.431*	30	4.353*	28
Trisyllabic	3.111*	30	1.671*	20
Foursyllabic	2.014	30	0.279	19
Fivesyllabic	1.974	30	-	-
Sixsyllabic	1.982	29	-	-

Note: * - $p < 0.05$

In the picture description task, result showed a significant difference ($p<0.05$) in the word duration between the two groups in bisyllabic words and trisyllabic words. However,

between the groups, there was no significant difference ($p>0.05$) in the mean word duration of foursyllabic words. Since the data available for foursyllabic words in the clinical group was less, Mann Whitney test was done to cross check the results of Independent *t* test. Results of Mann-Whitney test is [Z= -0.165, p= 0.869]. Results showed no significant difference between the two groups.

Other Temporal Parameter

The other temporal parameters that analyzed were voice onset time (VOT), burst duration (BD), transition duration (TD) and speed of transition (STD), preceding vowel duration (PVD), following vowel duration (FVD). Mean and standard deviation of data of each temporal parameter are given in Table 5 for the two tasks.

Table 5: Mean and Standard deviation (SD) of data of different temporal parameter in two groups

Parameter	Group	N	Passage Reading		Picture Description	
			Mean (in ms)	SD	Mean (in ms)	SD
VOT	Normal	20	48.15	7.94	65.57	11.64
	AD	12	60.29	7.82	81.78	21.78
BD	Normal	20	9.24	1.31	9.14	1.94
	AD	12	12.64	1.68	13.20	1.78
TD	Normal	20	38.10	6.02	45.01	5.25
	AD	12	26.47	7.48	50.91	5.46
STD	Normal	20	8.90	2.91	6.87	3.32
	AD	12	14.01	6.11	4.11	2.65
PVD	Normal	20	87.11	18.88	-	-
	AD	12	109.28	16.49	-	-
PVD	Normal	20	76.88	14.43	-	-
	AD	12	114.37	27.74	-	-

For passage reading, in general, the mean VOT, BD, PVD and FVD were longer in AD group compared to normal group. STD was faster in AD groups compared to normal groups. However, the mean TD was shorter in AD group compared to normal group. The AD group had greater variation in all parameters than that of normal group.

To verify whether these differences in all parameters were significantly different, the two groups were compared using independent *t* test. Table 6 gives results of Independent t-test. Results showed a significant difference ($p<0.05$) in all the parameters; VOT, BD, TD, STD, PVD and FVD between two groups.

Table 6: Results of Independent t test in different temporal parameter of speech

Parameter	Passage Reading		Picture Description	
	t	df	t	df
VOT	0.744*	30	2.469*	24
BD	6.381*	30	4.194*	22
TD	4.827*	30	2.634*	25
STD	3.201*	30	2.080*	25
PVD	3.365*	30	-	-
FVD	5.045*	30	-	-

Note: * - $p < 0.05$

In picture description, in general, the mean VOT, BD and TD were longer in AD group compared to normal group. However, the mean STD was faster in AD group compared to normal group. The AD group had greater variation in all parameters than that of normal group. Since the data available in the picture description task in the clinical group was less, Mann Whitney test was done to cross check the results of Independent *t* test. Table 7 gives results of Mann-Whitney test. Results showed a significant difference ($p<0.05$) between the two groups in VOT, BD, TD, and STD.

Table 7: Results of Mann-Whitney test for the data from picture description task.

Parameter	Z	p
VOT	1.706	0.008*
BD	2.898	0.004*
TD	2.154	0.031*
STD	2.177	0.029*

Note: * - $p < 0.05$

Discussion

Results of Perceptual Analysis

Speech production was abnormal in individuals with longstanding AD. Perceptually, all the parameters of speech were found to be abnormal. The result of abnormal production is in agreement with earlier studies in individuals with cochlear hearing loss. Houde and Jordan, (1998) reported that compensatory changes in individual sound production can be induced over time by systematically altering auditory feedback to indicate inaccurate articulation. Similar findings have been reported by other investigators (Binnie, Daniloff, & Buckingham, 1982; Cowie, Douglas-Cowie, & Kerr, 1982; Elman, 1981; Kirchner & Suzuki, 1968; Penn, 1955; Ramsden, 1981, Zimmermann & Rettaliata, 1981). Auditory feedback helps in

moment-to-moment monitoring, periodic update and calibration of the system. These results seem to support closed loop models of speech production.

These results further validate the need of auditory feedback in maintaining the speech production skills. In instances of disordered auditory feedback, there is deterioration of speech over time. Also, more speech perception difficulties were found to be associated with more abnormalities in speech production. The results show a close relationship between speech perception and speech production skills in turn supporting the closed loop models of speech production.

Results of the present study showed that the speech produced by individuals with AD was less intelligible compared to normal. Also, there was a significant correlation between speech identification scores and the over intelligibility of speech of AD. That means, ones who had relatively better speech identification, produced more intelligible speech compared to ones who had poorer speech identification. This result again supports the importance of auditory feedback to speech production skills. More the disruption in auditory feedback, more likely of errors in speech production. In contrast, Binnie et al. (1982) and others (Cowie et al., 1982; Plant, 1984) had reported that the changes in speech production observed in deafened adults appear to have little effect on speech intelligibility in cases where onset of deafness occurred in adulthood. The earlier the onset of deafness, the greater the effect of hearing loss on intelligibility.

Results of Acoustic Analysis

Earlier studies on speech perception in AD (Ajith, 2006) had shown increased just noticeable differences in the VOT, burst duration and transition duration. Considering these results, it was hypothesized that there shall be changes in the temporal parameters of speech of longstanding AD. Also, results of perceptual analysis in the present seemed to support the closed loop models of speech production. In such a case, the type of errors seen in the speech production in some way related to type of perceptual deficit. That is, if individuals with AD require more temporal and spectral difference to discriminate between phonemes, in their own production they may be using compensatory changes and producing the phonemes accordingly different. This was probed through acoustic analysis of speech of AD. The parameters analyzed were word duration, voice onset time, transition duration, burst duration, speed of duration, preceding vowel duration, and following vowel duration.

Results also showed deviations in speech production in the acoustical analysis. In general, there were lengthened temporal cues of speech. Earlier studies had shown increased JNDs in AD. Hence, lengthened temporal cues could be probably a compensatory strategy used by individuals with AD to facilitate the perception of their own speech.

Summary and Conclusions

Results of the perceptual analysis showed that the speech of auditory dys-synchrony (AD) was perceptually abnormal. All the parameters of speech (voice, articulation, prosody, rate of speech & overall naturalness) showed abnormality, although the prosody was found to be maximally affected. Overall intelligibility of speech of AD was found to be poorer. In individuals with AD, there was a significant high correlation between speech identification scores and, the severity of abnormality in speech intelligibility. Results also showed deviations in speech production on acoustical analysis. In general, there were lengthened temporal parameters of speech in AD.

Overall, there was agreement between the perceptual deficits and the speech production characteristics. This supports the closed loop models of speech production and active theories of speech perception. There was also a good agreement between perceptual deficits in individuals with AD (as reported in studies in the literature) and the characteristics of speech of AD. In general, there were lengthened temporal cues of speech and this could be probably a compensatory strategy used by individuals with AD to facilitate the perception.

References

Ajith, K. U. & Jayaram, M. (2006). Prevalence and audiological characteristics in individuals with auditory neuropathy/auditory dys-synchrony. *International Journal of Audiology, 45:(6),* 360-366.

Binnie, C.A., Daniloff, R.G., & Buckingham, H. W. (1982). Phonetic disintegration in a five-year-old following sudden hearing loss. *Journal of Speech Hearing Research, 47;* 181-189.

Cowie, R., Douglas-Cowie, E., & Kerr, A.G. (1982). A study of speech deterioration in post-lingually deafened adults. *Journal of Speech Hearing Disorders, 96;* 101-112.

Dunn, C. & Newton, L. (1986). A comprehensive model for speech development in hearing impaired children. *Topics in Language Disorders, 6(3);* 25-46.

Elman, J. (1981). Effect of frequency shifted feedback on the pitch of vocal production. *Journal of Acoustical Society America, 70;* 45-50.

Houde, J. F., & Jordan, M. I. (1998). Sensorimotor adaptation in speech production. *Science 279;* 1213–1216.

Kirchner, S., & Suzuki, Y. (1968). Laryngeal reflexes and voice production. *NY academy Science, 155;* 98-129.

Kraus, N., Bradlow, A. R., Cheatham, J., Cunningham, C. D., King, D.B., Kouch, T. G., Nicol, T.J., McGee, L. K., Stein, L. K., & Wright, B. A. (2000). Consequence of neural asynchrony: A case study of auditory neuropathy. *Journal of the Association for Research in Otolaryngology, 1,* 33-45.

Kuhl, P.K. (1981). Discrimination of speech by nonhuman animals: Basic auditory sensitivities conducive to the perception of speech-sound categories. *Journal of the Acoustical Society of America, 70,* 340-349.

Markides, A. (1986). Age at fitting of hearing aids and speech intelligibility. *British Journal of Audiology, 20;* 165-167.

Penn, G. (1955). Voice and speech patterns in the hard of hearing. *Acta Otolaryngology,* (Suppl 124).

Plant, G. (1984). The effects of an acquired profound hearing loss on speech production. *British Journal of Audiology, 18,* 39-48.

Ramsden, R. T. (1981). Rehabilitation of the suddenly deafened adults. *Ear Nose Throat Journal, 60;* 49-54.

Rance, G., Barker, E. J., Sarant, J. Z., & Ching, Y. C. (2007). Receptive language and speech production in children with Auditory neuropathy/ Dys-synchrony type hearing loss. *Ear and hearing, 28;* 694-702.

Rance, G., McKay, C., & Grayden, D. (2004). Perceptual characterization of children with auditory neuropathy. *Ear and Hearing, 25;* 34-46.

Starr, A., Picton, T. W., Sininger, Y., Hood, L., & Berlin, C. I. (1996). Auditory neuropathy. *Brain, 119;* 741-753.

Stevens, K. N. (2002). Toward a model for lexical access based on acoustic landmarks and distinctive features. *Journal of the Acoustical Society of America, 111,* 1872-1891.

Zeng, F. G., Oba, S., Garde, S., Sininger, Y., & Starr, A. (1999). Temporal and speech processing deficits in auditory neuropathy. *Neuro Report, 10;* 3429-3435.

Zeng, F. G., Kong, Y. Y., Michalewski, H. J. & Starr, A. 2004. Perceptual consequences of disrupted auditory nerve activity. *Journal of Neurophysiology, 93;* 3050-3063.

Zimmermann, G. N., & Rettaliata, P. (1981). Articulatory pattern of an adventitiously deaf speaker: implication for the role of auditory information in speech production. *Journal of Speech Hearing Research, 24;* 169-179.