Research Article

Segmental Speech Characteristics in Individuals with Auditory Neuropathy Spectrum Disorder

JAIISH(2018)
Vol 37 pp. 33-40

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Key Words
Auditory Neuropathy Spectrum Disorder (ANSD)
Segmental
Vowels
Stops
Fricatives

Abstract

Speech primarily is learnt through auditory mode. Disruption in the auditory feedback, as in instances of cochlear hearing loss, is reported to have deleterious influence on speech production. Individuals with ANSD are reported to have severe speech perception deficits especially in spectral and temporal processing. In light of these findings, the present study hypothesized that long standing ANSD could affect speech production characteristics similar to that of cochlear hearing loss and thus aimed to investigate the segmental speech characteristics in individuals with ANSD. Twenty individuals each with ANSD and normal auditory abilities were recruited as participants. Word lists consisting of target vowels and consonants in initial and medial positions were prepared and speech samples of all participants were recorded. The samples were acoustically analyzed in terms of spectral and temporal parameters of speech. Results revealed significant differences between the two groups of participants for several acoustic measures, especially in case of plosives. The temporal measures such as voice onset time, burst duration and transition duration were among the variables which differed significantly between the two groups. The findings are discussed in light of the existing literature on speech perception and support the closed loop models of speech production. The study was a preliminary investigation on speech production in ANSD and highlights the importance of auditory feedback in speech production.

Introduction

The auditory neuropathy spectrum disorder (ANSD) is characterized by absence of auditory brainstem responses in the presence of normal otoacoustic emissions and/or cochlear microphonics (Starr, Picton, Sininger, Hood, & Berlin, 1996; Sininger & Oba, 2001). Speech identification abilities of individuals with ANSD are reported to be disproportionate to the degree of their hearing loss (Zeng & Liu, 2006; Starr et al., 1996) and are the cardinal characteristics of persons with ANSD. Speech perception abilities in this population appears to depend on the extent of distortion of temporal cues at suprathreshold levels rather than access to speech spectrum (related to audibility), unlike in patients with cochlear hearing loss (Zeng, Oba, Garde, Sininger, & Starr, 1999; Zeng, Kong, Michalewski, & Starr, 2005).

Davis and Hirsh (1979) reported that 1 out of 200 children with hearing impairment exhibit an audiological profile that is consistent with the contemporary diagnosis of ANSD. In an Indian study, Ajith and Jayaram (2006) estimated a prevalence of 1 in 183 (0.54%) among individuals with sensorineural hearing loss. The psychoacoustical, neurophysiological and perceptual aspects of individuals with ANSD have been well established in the literature (Sininger & Oba, 2001; Sininger, Hood, Starr, Berlin, & Picton, 1995; Kumar & Jayaram, 2006).

Disruptions in the perception of temporal cues are reported both in children and adults with ANSD (Kraus et al., 2000; Michalewski, Starr, Nguyen, Kong, & Zeng, 2005; Rance, McKay, & Grayden, 2004; Starr, Picton, Sininger, Hood, & Berlin, 1996; Zeng et al., 2005). In addition to the distortion of the spectral information seen in individuals with cochlear hearing loss (Moore, 1995; Rance, McKay, & Grayden, 2004), individuals with ANSD have relatively greater distortion in temporal information (Rance et al., 2004; Zeng, Kong, Michalewski, & Starr, 2005; Kraus et al., 2000). Hence, the input signal in the auditory system is expected to be a lot more distorted in individuals with ANSD compared to those with cochlear hearing loss. This is supported by the findings of earlier studies on speech perception in individuals with ANSD (Kumar & Jayaram, 2006; Rance et al., 2004; Starr et al., 1996; Starr, Sininger, & Pratt, 2000; Zeng, Oba & Starr, 2001; Zeng & Liu, 2006).

Speech production characteristics of adults with ANSD have not been systematically explored in any of the earlier western studies. A preliminary attempt was made by Pooja and Sandeep (2009), where they carried out a perceptual and acoustic analysis of the speech of Kannada speaking individuals with ANSD. Reading of a standard passage and description of a standardized picture were recorded as speech samples. Thirteen judges performed the perceptual rating as 'normal/abnormal' for the following parameters: voice, articulation, prosody, rate of speech, and overall intelligibility. Acoustic analysis carried out by the investigators included measures of temporal parameters of speech: word duration, voice onset time, burst duration, transition duration and speed of transition, preceding vowel duration, and following vowel duration. Their findings revealed that the speech of ANSD is perceptually abnormal, more so in its prosody. In addition, the results of acoustic analysis revealed longer duration of all the temporal parameters in ANSD. They also reported a significant high correlation between deficits in speech production and speech perception scores. However, it was only a preliminary attempt and did not include detailed evaluation of segmental or supra-segmental speech characteristics.

The segmental and suprasegmental aspects of speech production are speculated to be influenced by long standing ANSD, due to prolonged disruption in the temporal characteristics of the input auditory signal. Investigating these aspects of speech production in individuals with ANSD would help in verifying the direction into velocities of articulators (DIVA) model of speech production and further validate the findings of Pooja and Sandeep (2009). If found deviant, the specific characteristics would guide in understanding the relationship between the auditory cues and speech production. In addition, it would stress the need for early identification and rehabilitation of ANSD. Thus, the present study was set forth to characterize the segmental speech production of individuals with ANSD. Specifically, the acoustic characteristics of vowel and consonant production were compared between individuals with ANSD and normal hearing.

Method

Participants

Two groups of participants were included in the study; a clinical group (n= 20, Males = 7, Females = 13; Mean age = 25;6 years) comprising of individuals with a confirmed diagnosis of ANSD and a control group (n = 20, Males = 6, Females = 14; Mean age = 24;4 years) consisting of individuals with normal hearing sensitivity. All the participants were native speakers of Kannada and could read as well as write Kannada. The duration of ANSD ranged from 5 years to 20 years in the clinical group.

Stimuli

Three short vowels /a/, /I/ and /U/ were considered and a list of nine meaningful words with these vowels was prepared. Among consonants, eight plosives (four voiced & four unvoiced)- /k/, /g/, /ṭ/, /ḍ/, /t̪/, /d̪/, /p/, and /b/; and three fricatives- /s/, /ʃ/, and /f/ were considered. A total of 16 words having plosives and six words having fricatives, with each of the consonants in word initial and word medial position were prepared. The wordlists included in the study are given in Table 1.

Table 1: Wordlists for target sounds included in the study

Vowels	Plosives		Fricatives	
	Initial	Medial	Initial	Medial
/k**ə**bbu/	/**k**a:ru/	/a:**k**e/	/**s**əra/	/a:**s**e/
/d̪**ə**ppa/	/**g**a:re/	/a:**g**a/	/**ʃ**ənkʰa/	/a:**ʃ**a/
/s**ə**ra/	/**ṭ**a:ru/	/a:**ṭ**a/	/**f**æ:nu/	/ka:**f**i/
/k**I**vi/	/**ḍ**əbbi/	/a:**ḍ**i/		
/d̪**I**mbu/	/**t̪**a:ru/	/a:**t̪**a/		
/s**I**hi/	/**d̪**a:ri/	/a:**d̪**i/		
/k**U**ri/	/**p**a:ru/	/a**p**a/		
/d̪**U**mbI	/**b**a:ri/	/a**b**a/		

Note: Phonemes in bold indicate targets

Procedure

Participants were instructed to read each of the target words embedded in a common carrier phrase (*i:ga na:nU (target word) heḷUt̪t̪ene*). The speech samples were recorded using a Sony digital voice recorder (Model: IC recorder ICD-UX81) with an omnidirectional microphone, which was transferred to a personal laptop and saved as .wav files. These were sampled at 44,100 Hz, 32 bits and analyzed using wide band spectrograms in Praat software (version 5.4.04) (Boersma & Weenink, 2011). All the recordings were done in a sound treated room.

Analyses

The acoustic characteristics analyzed included F_0, F_1, F_2, bandwidth of two formants (F_1BW & F_2BW) and vowel duration (VD) for vowels; burst duration (BD), closure duration (CD), voice onset time (VoT), transition duration (TD), extent of transition (EoT) and speed of transition (SoT) for stop consonants; and frication duration (FD), transition duration (TD), extent of transition (EoT) and speed of transition (SoT) for fricatives. Figure 1 shows the representation of temporal measures considered in the study. The group data were statistically analyzed using Statistical Package for the Social Sciences (Version 21) (SPSS Inc, Chicago).

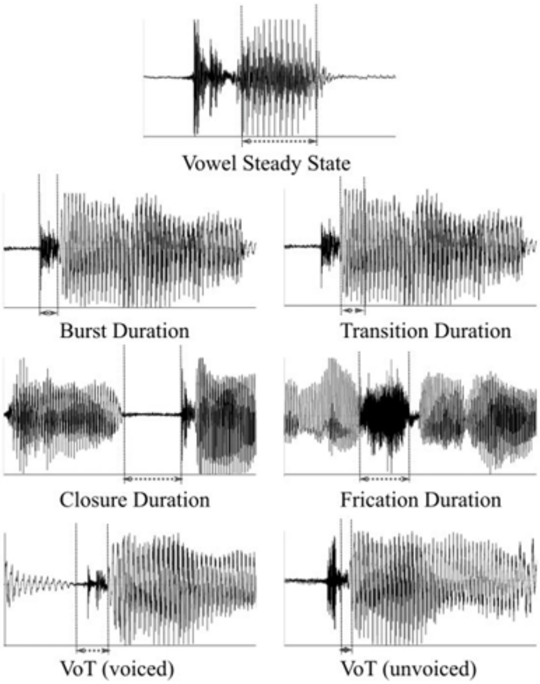

Figure 1: Representation of temporal measures considered in the study

Results

The present study aimed to investigate the segmental characteristics of speech of individuals with ANSD, in particular the acoustic characteristics of vowels and consonants. The means, medians, and standard deviations for acoustic parameters considered for each of the vowels and consonants is summarized in Tables 2, 3 and 4.

Comparison of vowel production between genders and between groups

Mann Whitney-U test was done to investigate the effect of gender on acoustic parameters in both clinical and control groups. Results revealed significant difference between males and females for F_0 of /a/ ($|z| = 3.36$, $p< 0.05$), /I/ ($|z| = 3.52$, $p< 0.05$) and /U/ ($|z| = 3.52$, $p< 0.05$), F_1 of /a/ ($|z| = 2.17$, $p< 0.05$), and F_2 of /a/ ($|z| = 2.49$, $p < 0.05$) and /I/ ($|z| = 3.20$, $p < 0.05$) in clinical group. Similarly, males and females in control group were found to be significantly different for F_0 of /a/ ($|z| = 3.13$, $p < 0.05$), /I/ ($|z| = 3.13$, $p < 0.05$) and /U/ ($|z| = 2.63$, $p < 0.05$), F_1 of /I/ ($|z| = 2.30$, $p < 0.05$) and /U/ ($|z|= 2.47$, $p < 0.05$), F_1 bandwidth of /a/ ($|z| = 3.29$, $p < 0.05$), F_2 of /U/ ($|z| = 2.55$, $p < 0.5$) and F_2 bandwidth of /a/ ($|z| = 2.63$, $p < 0.05$).

Owing to gender differences in both clinical and control groups, further analysis to compare between the two groups was carried out separately for each gender. Results of Mann Whitney-U test are summarized for both males and females in Table 5. As shown in Table 5, significant differences were observed between male participants of clinical and control groups for F_1 and F_2 of /U/ and F_1 bandwidth of /I/ and /U/. Further, participants in control group were found to have higher values for these parameters compared to clinical group. Similarly, significant differences were seen in female participants of clinical and control groups for F_0 of /a/ and /I/, F_1 bandwidth of /a/ and F_2 bandwidth of /U/. Unlike males, female participants in clinical group had higher values than those in control group except for F_2 bandwidth of /U/ which was lower.

Comparison of consonant production between genders and between groups

Plosives

Mann Whitney-U test was performed to investigate the effect of gender on production of plosives. Results revealed significant differences ($p < 0.05$) for only a few variables and thus, the data was combined for gender in both clinical and control groups for further analysis. A normality check was done on the combined data using Shapiro-Wilk test which revealed normal distribution. Thus, an independent t-test was carried out to compare between clinical and control groups. Results of t-test revealed significant differences between two groups for VoT of /b/ [$t(38) = 2.64$, $p < 0.05$], /t̪/ [$t(38) = 2.23$, $p < 0.05$], /d̪/ [$t(38) = 2.16$, $p < 0.05$], /ṭ/ [$t(38) = 3.05$, $p<0.05$], /ḍ/ [$t(38) = 2.83$, $p<0.05$], and /g/ [$t(38) = 2.18$, $p<0.05$] in initial position, and /ṭ/ [$t(38) = 3.81$, $p < 0.05$] in medial position as well. Further, two groups also differed on BD for /p/ [$t(38) = 2.33$, $p < 0.05$] in initial position and for /b/ [$t(38) = 2.62$, $p < 0.05$] in medial position. The EoT was found to be significantly different between groups for /b/ [$t(38) = 2.76$, $p < 0.05$] and /t̪/ [$t(38) = 2.14$, $p < 0.05$] in medial position. Significant difference in SoT was observed only for the plosive /b/ [$t(38) = 2.19$, $p < 0.05$] in medial position.

In summary, a similar trend was observed for most of the parameters in both males and females. The participants in clinical group were found to have higher values than control group for VoT (unvoiced plosives), BD, CD, and EoT. In contrast, VoT of voiced plosives was higher in control group when compared to clinical group. Mixed findings were observed for TD and SoT with no particular trend.

Fricatives

Similar to plosives, Mann Whitney-U test was performed to investigate the effect of gender on production of fricatives. Results revealed significant differences for only a few variables and thus for further analysis, the data were combined for gender in both clinical and control groups. Shapiro-Wilk test of normality was done for the combined data which revealed normal distribution and thus parametric test was used. Results of independent t-test

Table 2: Means, Medians and standard deviations (SD) for acoustic parameters of vowels

		Clinical group(n=20)						Control group(n=20)					
		Male (n=7)			Female (n=13)			Male (n=6)			Female (n=14)		
		Mean	**Med**	**SD**	**Mean**	**Med**	**SD**	**Mean**	**Med**	**SD**	**Mean**	**Med**	**SD**
/a/	F_0 (Hz)	143.14	142.96	26.04	225.38	235.10	34.88	123.85	124.18	15.33	194.72	198.94	26.89
	F_1 (Hz)	590.25	598.26	140.47	707.99	744.68	94.51	705.97	717.52	54.29	680.65	681.25	53.38
	F_1BW (Hz)	202.74	200.50	125.55	217.53	177.60	100.19	373.99	344.62	182.66	129.56	128.96	33.69
	F_2 (Hz)	1377.99	1313.03	247.29	1567.48	1570.52	109.04	1466.09	1485.89	150.62	1594.44	1631.73	100.13
	F_2BW (Hz)	271.10	279.31	126.02	265.99	150.16	291.85	459.40	439.77	219.36	211.80	147.00	213.77
	VD(ms)	65.47	61.66	10.87	74.46	75.67	18.36	67.94	63.50	13.28	68.66	67.50	11.03
/I/	F_0 (Hz)	150.16	147.73	25.49	239.22	246.23	30.77	130.13	128.36	16.52	209.55	212.32	31.36
	F_1 (Hz)	485.04	340.13	421.72	442.11	419.42	108.02	1272.70	1356.23	603.48	415.48	403.38	57.37
	F_1BW (Hz)	143.14	79.88	159.28	197.06	206.62	114.18	284.46	217.24	172.66	179.73	139.89	185.87
	F_2 (Hz)	2082.40	2080.26	155.92	2420.54	2384.31	153.53	2433.55	2406.66	208.13	2469.77	2478.71	135.80
	F_2BW (Hz)	289.52	242.42	220.10	657.89	375.97	942.32	275.09	294.61	127.10	310.57	277.14	162.46
	VD(ms)	61.90	54.33	20.77	71.07	92.00	29.67	69.44	63.00	19.83	60.42	60.16	15.24
/U/	F_0 (Hz)	151.21	152.17	29.17	233.14	226.85	22.98	134.13	134.56	16.29	201.38	220.28	42.09
	F_1 (Hz)	462.87	401.33	167.63	518.51	520.60	113.80	755.16	834.28	217.32	468.54	457.65	72.51
	F_1BW (Hz)	189.97	181.81	58.75	254.46	119.46	219.33	339.18	296.39	145.85	229.17	158.72	179.24
	F_2 (Hz)	1488.93	1332.50	323.53	1405.02	1419.54	177.44	2024.85	2138.55	378.68	1452.76	1430.15	139.37
	F_2BW (Hz)	493.81	295.01	365.73	262.62	214.51	150.34	539.26	462.22	289.49	448.01	322.54	257.80
	VD(ms)	58.23	51.00	34.12	53.02	53.67	14.89	56.38	52.50	14.49	56.38	53.16	10.29

Table 3: Means, Medians and standard deviations (SD) for acoustic parameters of plosives

	Para-meter	Clinical group(n=20)						Control group(n=20)					
		Male (n=7)			Female (n=13)			Male (n=6)			Female (n=14)		
		Mean	**Med**	**SD**	**Mean**	**Med**	**SD**	**Mean**	**Med**	**SD**	**Mean**	**Med**	**SD**
/p/-I	BD (ms)	14.57	13.00	5.12	9.76	9.00	3.34	10.33	8.50	5.16	7.35	6.50	3.36
	VoT (ms)	22.57	17.00	22.05	14.46	12.00	8.64	12.83	12.00	3.81	16.64	8.50	24.79
	TD (ms)	7.14	18.00	5.01	15.69	14.00	4.73	19.00	18.50	4.69	20.28	17.50	9.97
	EoT (Hz)	218.78	173.30	165.55	141.54	121.30	74.88	130.01	121.35	47.45	112.21	101.50	62.49
	SoT(Hz/ms)	13.69	8.25	12.32	9.89	8.65	6.42	7.67	5.99	4.99	6.59	5.44	4.48
/p/-M	BD (ms)	11.28	9.00	5.02	9.38	8.00	3.92	8.83	8.00	4.40	7.85	8.00	2.53
	CD (ms)	104.28	121.00	25.42	93.92	84.00	30.51	104.16	101.50	40.11	101.35	107.00	26.94
	VoT (ms)	18.71	19.00	13.70	12.00	11.00	6.05	9.66	8.50	3.77	9.64	8.00	4.30
	TD (ms)	19.85	18.00	10.73	19.07	16.00	10.91	14.50	14.00	2.25	19.00	17.50	6.31
	EoT (Hz)	208.30	253.80	113.22	240.49	200.00	166.05	205.10	173.30	117.24	144.34	154.5	92.52
	SoT(Hz/ms)	11.21	11.00	4.82	16.72	11.56	15.22	14.25	12.53	7.35	8.62	6.06	6.84
/b/-I	BD (ms)	12.00	11.00	2.58	7.61	8.00	2.29	11.16	12.00	3.71	9.42	8.50	4.55
	VoT (ms)	65.71	68.00	20.32	62.46	58.00	22.36	93.33	101.50	27.00	79.64	76.00	26.34
	TD (ms)	20.14	23.00	7.33	20.30	19.00	6.06	20.33	20.00	6.37	18.14	16.50	7.04
	EoT (Hz)	183.08	145.00	123.34	173.85	156.00	98.87	173.33	156.00	107.39	110.49	86.63	78.62
	SoT(Hz/ms)	10.87	7.87	7.67	8.52	7.96	3.86	8.44	8.52	4.39	6.79	5.91	5.55
/b/-M	BD (ms)	13.00	11.00	4.86	8.76	8.00	3.05	7.50	8.50	2.88	7.21	6.00	2.80
	CD (ms)	57.14	61.00	20.10	63.23	66.00	30.02	63.33	61.50	18.21	73.57	78.00	13.26
	VoT (ms)	67.00	64.00	17.04	66.00	70.00	21.76	81.50	78.00	18.92	76.50	80.00	17.57
	TD (ms)	17.85	19.00	7.33	19.46	18.00	6.97	16.33	15.50	4.92	17.64	18.00	8.54
	EoT (Hz)	201.68	164.00	97.88	251.73	254.00	136.05	150.21	147.35	35.76	145.10	126.50	80.54
	SoT(Hz/ms)	12.22	12.39	5.44	13.08	12.70	6.70	9.06	9.41	3.36	9.00	9.10	5.06
/t̪/-I	BD (ms)	11.28	11.00	4.34	9.15	8.00	4.05	10.00	9.50	2.75	7.14	6.50	2.87
	VoT (ms)	16.57	13.00	8.54	12.76	10.00	5.76	12.00	11.50	3.46	9.21	8.00	4.49
	TD (ms)	20.71	19.00	8.53	20.15	19.00	9.54	19.16	19.00	7.08	23.85	22.00	14.06
	EoT (Hz)	320.28	381.00	132.94	211.09	190.60	145.53	138.65	121.35	65.74	220.65	186.95	136.19
	SoT (Hz/ms)	16.30	14.31	7.46	11.98	9.26	8.09	7.79	6.12	3.91	10.34	11.11	4.27

I-initial, M-medial

	Parameter	Clinical group(n=20)						Control group(n=20)					
		Male (n=7)			Female (n=13)			Male (n=6)			Female (n=14)		
		Mean	**Med**	**SD**	**Mean**	**Med**	**SD**	**Mean**	**Med**	**SD**	**Mean**	**Med**	**SD**
	BD (ms)	13.42	13.00	5.38	10.38	8.00	5.02	11.50	12.00	3.67	8.78	8.50	4.19
	CD (ms)	76.42	74.00	24.90	87.00	88.00	20.52	81.66	80.50	18.07	87.85	94.50	18.28
	VoT (ms)	17.71	16.00	9.67	14.69	12.00	10.47	12.66	11.52	3.55	11.35	8.00	11.35
/t̪/-M	TD (ms)	15.71	13.00	5.21	17.30	13.00	7.22	12.83	11.50	4.75	17.90	16.00	7.51
	EoT (Hz)	272.38	236.00	132.64	159.79	109.00	129.45	95.28	86.65	53.46	137.67	143.85	71.69
	SoT (Hz/ms)	19.61	12.24	14.20	10.48	8.38	8.61	8.45	7.86	4.86	8.27	6.48	4.67
	BD (ms)	12.42	10.00	6.18	9.38	9.00	4.55	12.33	12.50	4.27	6.57	6.50	2.10
	VoT (ms)	81.14	74.00	24.01	69.23	66.00	18.67	82.83	76.00	30.13	91.35	88.50	21.54
/d̪/-I	TD (ms)	17.71	18.00	3.40	19.23	14.00	8.68	14.66	13.50	5.78	21.64	16.00	14.06
	EoT (Hz)	277.35	308.00	97.10	169.15	145.00	65.22	98.21	95.35	23.64	202.55	168.15	139.56
	SoT (Hz/ms)	16.46	18.11	7.29	10.43	10.19	5.67	7.82	6.89	4.11	11.78	8.95	8.23
	BD (ms)	12.42	9.00	6.99	8.30	7.00	3.11	10.00	9.00	2.44	7.92	7.00	4.39
	CD (ms)	56.14	58.00	12.60	57.30	49.00	34.09	55.66	51.00	24.58	57.64	55.50	14.12
	VoT (ms)	64.42	65.00	18.68	56.00	48.00	19.31	67.16	71.00	17.80	61.28	58.00	10.63
/d̪-M/	TD (ms)	16.85	18.00	2.79	18.53	19.00	6.33	16.16	17.50	2.92	16.28	13.50	9.16
	EoT (Hz)	147.81	138.00	104.12	188.33	145.00	137.51	121.40	147.35	62.89	148.96	115.50	95.37
	SoT (Hz/ms)	8.75	6.90	5.75	11.73	7.03	11.87	7.60	8.44	3.86	10.04	7.12	6.97
	BD (ms)	7.85	8.00	1.46	6.30	7.00	1.18	7.16	7.00	1.72	5.92	5.50	1.49
	VoT (ms)	11.85	11.00	2.54	9.15	8.00	3.95	9.16	8.50	2.78	6.21	6.50	1.57
/ṭ/-I	TD (ms)	21.42	18.00	10.98	17.23	14.00	6.91	20.16	15.00	14.35	21.14	22.50	8.89
	EoT (Hz)	260.38	146.00	183.78	178.46	173.30	112.04	176.20	173.30	89.32	212.33	169.50	133.95
	SoT (Hz/ms)	14.57	10.97	12.26	10.72	9.06	8.10	10.36	7.98	6.49	10.66	9.11	4.62
	BD (ms)	8.85	9.00	2.91	7.23	7.00	2.00	7.33	7.00	0.81	6.14	5.50	2.24
	CD (ms)	53.57	54.00	10.79	76.69	75.00	19.74	72.33	67.00	11.96	84.00	85.50	19.57
	VoT (ms)	15.57	14.00	6.37	9.46	8.00	3.25	7.50	7.50	1.65	6.28	5.50	2.49
/ṭ/-M	TD (ms)	19.14	14.00	14.04	15.46	13.00	4.61	15.16	14.00	4.83	16.21	13.00	6.19
	EoT (Hz)	284.41	308.00	115.77	164.12	138.70	107.45	127.11	138.65	76.47	150.73	121.35	91.51
	SoT (Hz/ms)	18.76	18.15	10.08	10.95	9.25	7.47	8.98	6.97	6.62	9.68	7.94	6.15
	BD (ms)	10.14	9.00	3.48	7.38	7.00	2.63	9.50	9.50	3.14	5.50	5.00	1.87
	VoT (ms)	65.57	64.00	21.54	62.84	67.00	26.98	80.50	85.50	19.20	89.50	84.00	29.46
/ḍ/-I	TD (ms)	12.00	13.00	3.74	13.23	12.00	4.91	15.83	15.00	3.60	14.28	13.50	5.78
	EoT (Hz)	158.77	109.00	141.48	114.45	73.00	94.56	150.25	156.05	44.76	148.02	115.15	119.86
	SoT (Hz/ms)	17.87	7.78	20.67	8.71	8.52	4.94	9.66	9.00	2.96	10.10	10.57	6.12
	BD (ms)	9.71	7.00	6.07	7.15	6.00	2.64	7.50	7.00	1.37	5.28	5.00	1.97
	CD (ms)	30.57	31.00	13.74	38.30	25.00	35.15	38.66	30.00	29.98	34.85	32.50	14.98
	VoT (ms)	36.42	37.00	12.42	35.46	34.00	19.78	42.83	37.00	20.00	37.28	37.50	12.25
/ḍ/-M	TD (ms)	16.28	15.00	5.96	17.23	16.00	10.17	16.00	12.00	6.60	15.85	13.00	7.00
	EoT (Hz)	180.28	109.00	146.17	157.51	173.40	91.41	132.88	112.65	102.07	142.30	109.00	76.77
	SoT (Hz/ms)	11.03	9.08	7.80	10.61	9.63	7.14	8.90	9.78	5.94	10.07	8.70	6.53
	BD (ms)	21.14	19.00	9.20	17.69	15.00	8.29	16.50	18.00	3.61	19.64	19.00	6.28
	CD (ms)	85.42	68.00	31.78	95.76	90.00	29.22	98.83	87.50	39.60	90.28	90.50	17.56
	VoT (ms)	19.71	18.00	8.65	15.15	14.00	7.40	17.83	17.50	7.62	17.28	15.50	9.48
/k/-I	TD (ms)	20.00	19.00	5.22	13.61	14.00	2.93	18.00	17.50	6.06	17.85	16.50	7.57
	EoT (Hz)	127.80	127.00	46.05	151.07	121.30	95.86	127.00	112.70	81.78	152.59	106.15	145.01
	SoT (Hz/ms)	6.72	5.82	2.71	11.20	8.66	5.72	6.67	6.58	2.63	9.75	7.25	10.98
	BD (ms)	16.42	13.00	8.82	14.46	14.00	5.07	18.50	18.00	4.41	16.50	17.00	5.45
	VoT (ms)	69.42	72.00	21.15	64.23	61.00	28.48	66.33	68.50	32.01	91.42	95.50	19.71
/k/-M	TD (ms)	19.85	17.00	6.36	17.23	17.00	3.56	15.66	16.50	3.14	19.71	19.00	7.59
	EoT (Hz)	189.85	156.00	96.75	119.25	90.00	88.87	124.15	112.45	65.25	112.05	112.65	57.86
	SoT (Hz/ms)	10.55	10.58	6.41	7.11	5.84	5.41	8.46	6.53	5.47	5.99	5.42	3.38

I-Initial, M-Medial

	Parameter	Clinical group(n=20)						Control group(n=20)					
		Male (n=7)			Female (n=13)			Male (n=6)			Female (n=14)		
		Mean	Med	SD	Mean	Med	SD	Mean	Med	SD	Mean	Med	SD
/g/-I	BD (ms)	14.71	14.00	6.31	13.30	11.00	6.92	14.50	14.50	2.07	14.07	13.00	5.99
	CD (ms)	47.71	41.00	18.88	46.46	43.00	11.95	52.50	48.00	14.76	52.00	53.00	9.65
	VoT (ms)	55.28	46.00	24.68	56.61	53.00	17.61	66.16	66.00	14.68	66.00	68.50	10.65
	TD (ms)	24.14	24.00	7.94	13.92	13.00	4.48	16.00	16.50	2.60	17.14	14.00	6.56
	EoT (Hz)	155.28	127.00	86.67	90.33	91.00	54.13	156.00	138.65	81.31	83.36	73.00	49.62
	SoT (Hz/ms)	6.57	6.00	3.03	6.48	6.63	2.97	7.39	6.88	4.32	5.01	4.64	2.31

I-Initial, M-Medial

Table 4: Means, Medians and standard deviations (SD) for acoustic parameters of fricatives

	Parameter	Clinical group(n=20)						Control group(n=20)					
		Male (n=7)			Female (n=13)			Male (n=6)			Female (n=14)		
		Mean	Med	SD	Mean	Med	SD	Mean	Med	SD	Mean	Med	SD
/s/-I	FD (ms)	101.85	102.00	24.47	118.30	107.00	31.56	112.67	96.50	38.81	114.92	112.50	15.90
	TD (ms)	24.57	23.00	7.48	21.23	19.00	8.21	17.67	18.00	3.93	19.07	17.50	5.25
	EoT (Hz)	282.57	236.00	229.76	183.62	163.00	149.72	152.31	69.15	164.70	159.00	100.50	139.61
	SoT (Hz/ms)	10.59	7.61	7.15	8.41	7.58	4.33	9.19	3.78	9.90	9.36	5.33	9.53
/s/-M	FD (ms)	97.42	96.00	19.16	119.38	122.00	22.64	107.33	104.50	15.21	114.35	117.00	5.91
	TD (ms)	26.14	26.00	8.07	21.84	21.00	11.35	21.83	21.50	4.91	19.57	18.00	6.14
	EoT (Hz)	156.84	90.00	176.00	199.20	207.90	93.21	185.15	203.50	61.95	156.87	145.50	78.32
	SoT (Hz/ms)	6.20	4.00	7.32	10.04	10.19	5.19	8.56	8.13	3.19	8.21	8.26	3.03
/ʃ/-I	FD (ms)	119.14	102.00	48.42	136.38	131	23.08	109.00	98.00	39.53	119.07	117.00	13.69
	TD (ms)	20.00	22.00	7.04	20.69	23.00	5.67	16.83	18.00	4.02	18.14	18.50	5.80
	EoT (Hz)	202.75	218.00	93.36	241.63	200.00	126.45	164.95	147.35	100.16	239.93	177.15	211.78
	SoT (Hz/ms)	11.86	14.21	6.70	11.99	11.37	5.40	11.21	8.44	9.40	13.17	9.29	9.32
/ʃ/-M	FD (ms)	109.42	107.00	12.24	119.00	116.00	17.62	107.50	102.50	19.31	116.57	118.50	17.62
	TD (ms)	22.00	22.00	5.29	20.38	17.00	9.89	18.16	15.50	6.24	22.92	19.00	10.04
	EoT (Hz)	258.04	127.00	219.49	172.71	145.00	95.59	145.83	147.30	38.05	207.25	211.50	87.08
	SoT (Hz/ms)	11.77	5.45	9.77	8.48	7.25	3.30	8.35	8.67	4.24	9.58	8.35	3.83
/f/-I	FD (ms)	74.33	74.50	28.85	115.92	114.00	34.31	101.16	96.00	32.92	121.71	124.50	30.20
	TD (ms)	21.66	16.50	11.37	25.69	25.00	9.70	20.83	20.50	6.94	23.78	26.00	8.15
	EoT (Hz)	198.55	227.00	102.38	232.24	235.00	127.40	135.16	93.50	84.05	207.21	138.70	166.38
	SoT (Hz/ms)	9.81	8.08	5.66	9.83	7.89	6.63	7.68	5.25	6.64	8.92	8.37	5.73
/f/-M	FD (ms)	66.00	49.00	37.67	99.46	103.00	34.12	107.33	108.00	18.72	107.50	113.00	22.77
	TD (ms)	22.42	22.00	2.99	22.84	19.00	11.63	19.66	19.50	5.95	30.57	24.00	19.61
	EoT (Hz)	184.48	190.70	97.46	303.63	218.00	207.11	157.45	173.30	47.80	370.48	311.15	220.68
	SoT (Hz/ms)	8.25	8.38	4.35	13.09	12.42	4.77	8.92	8.37	4.59	12.44	12.23	4.65

I-initial, M-medial

Table 5: Results of Mann Whitney-U test comparing clinical and control groups for vowels

Parameter	|z| value					
	/a/		/I/		/U/	
	Male	Female	Male	Female	Male	Female
F_0	1.57	2.47*	1.71	2.52*	1.14	1.84
F_1	1.85	1.89	2.00	0.97	2.28*	0.97
F_1BW	1.71	2.76*	2.57*	1.16	2.42*	0.24
F_2	1.14	0.92	0.28	0.82	2.28*	0.67
F_2BW	1.00	0.67	1.21	1.11	1.00	2.32*
VD	0.28	0.75	1.14	1.04	0.57	0.92

*Note: *$p < 0.05$*

revealed no significant difference ($p > 0.05$) between the two groups for any of the parameters, both in initial and medial positions. Further, no common trends were observed among males and females for any of the acoustic parameters for fricatives. However, in general, participants in clinical group had higher values for most of the parameters in comparison with control group.

Discussion

The major objective of the study was to investigate the segmental speech characteristics in individuals with ANSD. The study hypothesized that long-standing speech perception deficits could result in speech production deficits as in case of cochlear hearing loss (Culbertson & Kricos, 2001; Dunn & Newton, 1986; Hudgins & Numbers, 1942; Smith, 1982).The results of the study revealed that speech production characteristics of ANSD are deviant compared to controls, both for vowels and consonants. However, the extent of deviation observed was more for consonants.

Analyses of vowel production revealed significant differences for spectral measures between males and females in both clinical and control groups. Gender differences observed are attributed to the differences in the vocal tract characteristics of males and females (Simpson, 2009; Pépiot, 2015). Further, males in the clinical group had significantly lower F_1 and F_2 for vowel /U/ and lower F_1 bandwidth for /I/ and /U/. Among the female participants, clinical group was observed to have higher values for F_0 of /a/ and /I/ and F_1 bandwidth of /a/, but lower F_1 bandwidth of /U/. As stated previously, studies on speech production characteristics in ANSD are sparse. However, literature on individuals with cochlear hearing loss provides evidence of deviant spectral characteristics when compared to normal hearing individuals (Culbertson & Kricos, 2002; Dunn & Newton, 1986; Hung, Lee, & Tsai, 2017). The researchers have attributed deviant production to the deficits in perception and auditory feedback. The present study also reports similar trend in ANSD group which could be attributed to the disrupted auditory feedback in these individuals.

In case of plosives, individuals with ANSD significantly differed from normal hearing individuals on temporal measures like VoT and BD. Though there are limited studies reporting deviant acoustic characteristics in the speech of individuals with ANSD, there exists a vast body of literature reporting significant deficits in their perception. To reiterate, individuals with ANSD are reported to have relatively greater deficits in temporal processing when compared to spectral processing. A study by Kumar and Jayaram (2006) revealed increased just noticeable differences in VoT, BD and TD. Based on these findings, it is speculated that long standing temporal processing deficits could be reflected as a distortion or disruption of the temporal measures like VoT and BD. Further, greater mean values or longer duration was observed for both VoT and BD in individuals with ANSD. These findings are in consensus with the findings of Pooja and Sandeep (2009) reporting lengthened temporal cues in the speech of individuals with ANSD and suggested this to be a compensatory strategy used for better perception.

Another set of sounds considered was fricatives and the findings of the study revealed no significant difference in the production of fricatives between the two groups. In general, participants in the clinical group were found to have higher values for all temporal measures similar to plosives. This further confirms the assumption that individuals with ANSD tend to lengthen the temporal cues as a compensatory strategy to improve their perception. However, this speculation needs further validation with greater sample size in future investigations.

On comparison of the three classes of speech sounds considered in the present study, it was found that plosives were affected more when compared to vowels and fricatives. This could be due to the transient nature of plosives. As discussed earlier, individuals with ANSD are known to have significant temporal processing deficits. In such instances, perception of plosives is more prone to disruption when compared to vowels and fricatives which are longer in duration. Considering that consonants are more dynamic in nature, one can assume that the distorted auditory perception found in ANSD has greater negative influence on the dynamic phonemes than the static phonemes. Perceptually, individuals with ANSD showed more deviance in consonants. Greater deviation in the production of consonants hints at the direct relationship between perception and production. Further, the findings of the present study support the closed loop models of speech production highlighting the importance of auditory feedback and its role in speech production.

Conclusions

The present study shows definite objective evidence for differences in the acoustic characteristics of speech production of individuals with ANSD. The production of consonants is more deviant compared to vowels. The spectral and temporal distortion in auditory processing could be the probable reason for their production deficits. The findings warrant assessment of speech production in individuals with ANSD and if found to be deviant, it needs to be addressed through appropriate management strategy. This shall ensure better quality of life for individuals with ANSD. Further, comparison of speech production characteristics in individuals with ANSD and cochlear hearing loss may provide better insight into the relationship between perception and production in ANSD.

References

Ajith, K. U., Jayaram, M. M. Perception of some temporal parameters of speech in individuals with Auditory Dys-synchrony. Doctoral dissertation submitted to University of Mysore, 2006.

Boersma, P. & Weenink, D. (2011). Praat: doing phonetics by computer [Computer program]. Version 5.4.04. http://www.praat.org/

Culbertson, D. N., Kricos, P. B. (2001). Language and speech of the deaf and hard of hearing. In: R. L. Schow & M. A. Ling (Eds.). *Introduction to Audiologic Rehabilitation (4th Ed.)* (pp. 183-224). Boston: Allyn and Bacon.

Davis, H., & Hirsh, S. K. (1979). A slow brain stem response for low-frequency audiometry. *Audiology, 18*(6): 445-461.

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

Hudgins, C. V., & Numbers, F. C. (1942). An investigation of the intelligibility of the speech of the deaf. *Genetic psychology monographs.*

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

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

Michalewski, H. J., Starr, A., Nguyen, T. T., Kong, Y. Y., & Zeng, F. G. (2005). Auditory temporal processes in normal-hearing individuals and in patients with auditory neuropathy. *Clinical Neurophysiology, 116*(3): 669-80.

Moore, B. C. (1995). *Perceptual consequences of cochlear damage.* Oxford University Press.

Pépiot, E. (2015). Voice, speech and gender: male-female acoustic differences and cross-language variation in english and french speakers. Corela. Cognition, représentation, langage, (HS-16).

Pooja, D., Sandeep M. Speech characteristics in individuals with auditory dys-synchrony. Unpublished student dissertation submitted to University of Mysore, 2009.

Rance, G., McKay, C., & Grayden, D. (2004). Perceptual characterization of children with auditory neuropathy. *Ear and Hearing, 25*(1): 34-46.

Simpson, A. P. (2009). Phonetic differences between male and female speech. *Language and Linguistics Compass, 3*(2), 621-640.

Sininger, Y. S., & Oba, S. (2001). *Patients With Auditory Neuropathy: Who Are They and What Can They Hear?* In: Sininger YS, Starr A,(Eds.). Auditory Neuropathy: A New Perspective on Hearing Disorders. Albany, NY: Singular Thompson Learning pp. 15-35.

Sininger, Y. S., Hood, L. J., Starr, A., Berlin, C. I., Picton, T. W. (1995). Hearing loss due to auditory neuropathy. *Audiology Today, 7*: 10-13.

Smith, B. L. (1982). Some observations concerning premeaningful vocalizations of hearing-impaired infants. *Journal of Speech and Hearing Disorders, 47*(4): 439-441.

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

Starr, A., Sininger, Y. S., & Pratt, H. (2000). The varieties of auditory neuropathy. *Journal of Basic Clinical Physiology and Pharmacology, 11*(3): 215-30.

Zeng, F. G., & Liu, S. (2006). Speech perception in individuals with auditory neuropathy. *Journal of Speech Language and Hearing Research, 49*(2): 367-380.

Zeng, F. G., Kong, Y. Y., Michalewski, H. J., & Starr, A. (2005). Perceptual consequences of disrupted auditory nerve activity. *Journal of Neurophysiology, 93*(6): 3050-3063.

Zeng, F. G., Oba, S., Garde, S., Sininger, Y., & Starr, A. (1999). Temporal and speech processing deficits in auditory neuropathy. *Neuroreport, 10*(16): 3429-3435.

Zeng, F. G., Oba, Y., & Starr, A. (2001). Suprathreshold processing deficits due to desynchronous neural activities in auditory neuropathy. In: D. J. Breebart, A. J. M. Houstma, A. Kohlrausch, V. F. Prijis, & R. Schoonhoven (Eds.), *Physiological and psychophysical basis of auditory function (pp. 365-372).* Maastricht, Netherlands: Shaker.