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Original Article

Speech Perception in Quiet and in Noise Condition in Individuals with Auditory Neuropathy Spectrum Disorder

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OBJECTIVE: The study investigated the effect of noise on syllable perception in individuals with Auditory Neuropathy Spectrum Disorder (ANSD) and compared that with the normal hearing individuals.

MATERIALS and METHODS: A total of 54 participants were considered, out of which 26 individuals were diagnosed with ANSD and 28 with normal hearing sensitivity. Syllable identification and discrimination were assessed in both the groups in quiet as well as +10 dB SNR.

RESULTS: All the individuals with ANSD performed poorer on syllable identification and syllable discrimination tasks compared to individuals with normal hearing. Information transfer and d-prime analyses revealed that noise affects the perception of voicing information in individuals with ANSD compared to place and manner information. Among the consonants tested, /pa/ was more resistant to noise.

CONCLUSION: Noise had deleterious effects on speech perception in individuals with ANSD. Low-frequency information appears to be more susceptible to the effects of noise in individuals with ANSD.

KEYWORDS: Auditory neuropathy spectrum disorder, noise, speech perception, signal-to-noise ratio

INTRODUCTION

Speech perception in the presence of noise is a ubiquitous problem in individuals with hearing impairment. Two important factors that contribute to poor speech understanding in noise in individuals with hearing impairment are audibility and suprathreshold auditory skills. It has been reported that some individuals with hearing impairment show poor speech understanding in presence of noise even after being compensated for audibility owing to suprathreshold auditory deficits. Individuals with Auditory neuropathy spectrum disorder (ANSD) form one such group of individuals with suprathreshold auditory deficits. Individuals with ANSD typically have normal otoacoustic emission and/or cochlear microphonics (indicating the normal functioning of cochlear outer hair cells) along with the absent or severely abnormal auditory brainstem responses (indicating the disrupted auditory nerve activity). Individuals with ANSD have disproportionate speech understanding problems in relation to their pure-tone hearing loss. They also have poor suprathreshold auditory abilities, particularly those related to auditory temporal processing [1, 2]. Behavioral data shows that speech recognition abilities in individuals with ANSD can range from poor recognition ability to fairly good recognition ability [3, 4]. In individuals with ANSD, the degree of speech perception deficits appear to be dependent on suprathreshold auditory deficits rather than on audibility [1, 2]. Although it has now been well established that individuals with ANSD have severely affected speech perception in noise skills, differential effects of noise on different consonants have not been studied. In individuals with cochlear hearing loss, it has been shown that certain consonants are more resistant to noise compared to others [5]. To the best of our knowledge, there is no published literature regarding consonantal confusions in the presence of noise in individuals with ANSD. This information is essential as it can aid in planning rehabilitation strategies and may also give input to hearing aid designs.

MATERIALS and METHODS

Participants

A total of 54 individuals participated in the study. They included 26 individuals (14 males and 12 females) with ANSD and 28 age-matched individuals with normal hearing. Individuals with ANSD were diagnosed by a certified audiologist following the recommendations of Starr, Sininger, and Pratt [6]. Accordingly, all participants had preserved OAEs, abnormal auditory brainstem responses, and normal tympanometry results with absent acoustic reflexes. The age range of the participants was 20–50 years with a mean age of 27.5 years. All participants in the ANSD group had symptoms of difficulty in understanding speech. Table 1 shows the basic demographic details and audiological findings of all individuals in the ANSD group.

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Participants in both the groups did not have any history of external or middle ear problems, ototoxic drug usage, and exposure to loud noise. Informed consent was obtained from all the individuals using the informed consent form [7]. This study was approved by the ethical committee of the institute.

Stimuli

Four naturally produced speech stimuli /da/, /ma/, /pa/, and /ba/ were used as stimuli. The stimuli were recorded using Pratt software with MOTU sound card interface at a sampling frequency of 44100 Hz. All stimuli were edited to have 240-ms duration. The duration was kept same in order to avoid identification of the syllables based on durational cues. These four syllables were selected so that they represent the place, manner, and voicing distinctions: /ba/-/da/ for place contrast, /ba/-/ma/ for manner, and /ba/-/pa/ for voicing. All the four syllables were mixed with speech noise to generate +10-dB signal-to-noise ratio (SNR) using MATLAB 2010 (Mathworks Inc., Natick, MA, USA).

Procedure

All participants underwent two experiments: identification and discrimination of stimuli. For both the experiments, participants were seated in a quiet well-illuminated room. Stimuli were presented at 75-dB SPL through a loudspeaker connected to a laptop. The intensity of the stimuli was calibrated at the beginning of the experiment and regularly thereafter using SLM (B & K, 2270) and microphone (type 4189).

Syllable Identification

Participants identified four syllables, /da/, /ma/, /pa/, and /ba/, in quiet condition as well as in the presence of noise in a closed set

Table 1. Demographic details and audiological findings of individuals with ANSD

Participant	Age (year)/ Gender	PTA (dB HL)		Speech Identification Scores (%)		Configuration of hearing loss (Lloyd & Kaplan, 1978)	
		Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear
ANSD1	25/M	35	30	84	86	Raising	Raising
ANSD2	20/M	31.25	32.5	68	84	Flat	Flat
ANSD3	26/M	28.75	22	48	80	Raising	Raising
ANSD4	55/M	46.25	47.5	84	80	Flat	Flat
ANSD5	40/F	45	43.75	28	32	Raising	Raising
ANSD6	35/M	30	22.5	40	44	Flat	Flat
ANSD7	19/F	36.25	23.75	76	84	Peaked	Raising
ANSD8	20/F	17.5	15	95	95	Flat	Flat
ANSD9	20/F	32.5	36.2	60	40	Peaked	Peaked
ANSD10	21/M	31.25	35	68	44	Raising	Raising
ANSD11	21/F	10	12.5	68	76	Flat	Flat
ANSD12	36/F	47.25	37.25	64	80	Raising	Raising
ANSD13	18/M	28.75	25	92	96	Flat	Flat
ANSD14	41/F	8.75	7.4	72	44	Flat	Flat
ANSD15	16/F	37.5	28.75	70	80	Flat	Flat
ANSD16	19/M	15	22.5	76	76	Flat	Flat
ANSD17	29/M	43.75	51.25	84	80	Raising	Raising
ANSD18	28/F	28.5	32.5	56	48	Peaked	Peaked
ANSD19	26/F	46.25	40	90	90	Raising	Raising
ANSD20	39/F	50	12.5	86	92	Flat	Flat
ANSD21	17/F	33.75	47.5	32	36	Raising	Raising
ANSD22	37/M	37.5	22.5	36	36	Raising	Raising
ANSD23	34/M	28.5	35	76	72	Flat	Flat
ANSD24	28/M	52.5	52.5	60	76	Raising	Raising
ANSD25	28/M	53.7	57.5	92	92	Raising	Raising
ANSD26	19/M	15	22.5	44	68	Flat	Flat

PTA is the pure-tone average of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz.
ANSD: auditory neuropathy spectrum disorder; PTA: pure tone average

Table 2. Confusion matrix generated for individuals with normal hearing and for those with ANSD

A	**/ba/**	**/da/**	**/ma/**	**/pa/**	**B**	**/ba/**	**/da/**	**/ma/**	**/pa/**
/ba/	279	0	0	3	/ba/	235	0	0	6
/da/	0	279	0	0	/da/	1	280	0	0
/ma/	0	1	279	0	/ma/	0	0	279	0
/pa/	1	0	1	277	/pa/	44	0	1	274
C	**/ba/**	**/da/**	**/ma/**	**/pa/**	**D**	**/ba/**	**/da/**	**/ma/**	**/pa/**
/ba/	204	33	0	58	/ba/	107	55	23	51
/da/	10	187	3	9	/da/	38	94	17	24
/ma/	14	19	257	22	/ma/	45	31	158	6
/pa/	32	21	0	171	/pa/	70	80	62	179

A and B represent the confusion matrix for individuals with normal hearing in quiet and noise and C and D represent for individuals with ANSD in quiet and noise, respectively.
ANSD: auditory neuropathy spectrum disorder

paradigm. Each stimulus was presented 10 times, making a total of 80 stimulus presentations. Participants were instructed to carefully listen to the stimuli presented and select the appropriate option depicting the orthographic script on a computer screen. Presentation sequence was randomized and was not blocked by the conditions. Presentation of the stimulus and collection of the responses were controlled via Paradigm Stimulus presentation software [8]. Responses of the participants were analyzed using confusion matrices and sequential information transfer analyses (SINFA) [9]. Furthermore, responses were also analyzed for differential effects of noise on consonants.

Syllable Discrimination

Syllable discrimination was assessed using the "AX" paradigm. Syllables were paired with another syllable that had one different feature. Thus, in total, there were six pairs of stimuli: /ba-da/, /ba-ma/, /ba-pa/, /da-ma/, /da-pa/, and /ma-pa/ that were presented in quiet and in the presence of +10-dB SNR. Each pair was presented 10 times. In addition, 40 catch trials were randomly presented in between. In catch trials, both the stimuli belonged to the same category (/ba-ba/, /ma-ma/, / pa-pa/, and/da-da/). The total number of presentations for each participant, including the catch trial, was 160. Presentation sequence was randomized and was not blocked by the conditions. The participants performed same/different judgment tasks. They were provided with a laptop placed in front of them with two blocks shown on the screen. The blocks had an orthographic script as "same" and "different". They had to listen to the stimuli presented through the loudspeaker and select the appropriate response on the laptop screen.

Data Analyses

The data obtained from the syllable identification task were analyzed using SINFA, and the data obtained from the syllable discrimination task was analyzed by estimating d-prime (d′). SINFA analysis was performed using FIX software (developed by University College of London), and the procedure followed was according to that followed by Wang and Bilger [9].

d′ is an estimate of the strength of the signal. It is the statistic that incorporates both hit rate and false alarm rate. Hit rate is defined as the percentage of correct identification of the target stimuli, and false alarm rate was defined as the percentage of incorrect identification of the target in the control condition. Both SINFA and d′ measure were used to analyze the data obtained from this study.

RESULTS

The data from all the participants were added up together to create a confusion matrix, separately for each participant group and listening conditions. Table 2A–D shows confusion matrices for individuals with normal hearing in quiet and in noise and for those with ANSD in quiet and in noise, respectively. In these confusion matrices, rows represent the stimuli presented and the column represents the response of the participants. The total number of correct responses can be obtained by summing the numbers occurring along the main diagonal line. It can be seen from the confusion matrices that addition of noise increased consonant confusions in individuals with normal hearing and in those with ANSD. However, the noise more drastically increased confusions in individuals with ANSD compared to those with normal hearing. SINFA analysis was separately carried out on each of the confusion matrices. The result of SINFA analyses is shown in Figure 1. From Figure 1, it can be seen that total information transited was maximum for individuals with normal hearing in quiet, followed by individuals with normal hearing in noise, those with ANSD in quiet, and those with ANSD in noise. The addition of noise resulted in a reduction in place, manner, and voicing features by a small amount in individuals with normal hearing. In contrast, in the ANSD group, addition of noise resulted in drastic reduction of total information transmitted, as well as of individual features. Information transfer was reduced by more than 50% in +10-dB SNR condition in the ANSD group compared with that in the quiet condition. In individuals with ANSD, manner information transferred was 0.588 in quite, but it reduced to 0.174 when the noise was added. Similarly, place information transferred was 0.456 in quiet and reduced to 0.094 when noise was added; voicing information transfer reduced from 0.1990 to 0.062 with the addition of noise. The total transmitted information was 1.051 in quiet, which got reduced to 0.299 in the presence of noise. Furthermore, it can also be observed that noise uniformly reduced the transmission of all features by small amounts in individuals with normal hearing. A similar pattern was observed in individuals with ANSD, but the reduction in information transfer was substantial.

In addition to SINFA, the effect of noise on each of the four syllables was separately analyzed in both the groups. The average syllable identification score was calculated as the ratio of the total number of syllables correctly identified to the total number of syllables presented. This was subtracted from 1 to obtain the syllable identification error. These results are shown in Figure 2. From Figure 2, it can be seen that individuals with normal hearing had close to 0% error in identification of all four syllables. Individuals with ANSD identified all four syllables above chance (75% error or more) levels in both quiet and at +10-dB SNR conditions. Among the syllables, /ma/ was relatively easy to identify, followed by /ba/, /da/, and /pa/ for individuals with ANSD in quiet. Addition of noise substantially reduced the identification scores of /ba/, /da/, and /ma/. Surprisingly, the noise did not have any effect on the identification of the syllable /pa/. From this analysis, it appears that /pa/ is relatively insensitive to noise compared with other consonants in individuals with ANSD. Significance of these differences was separately evaluated in each group using non-parametric statistical tests. Results showed that in individuals with normal hearing, the errors were significantly higher in the +10-dB SNR condition compared to those in the quiet condition only for syllable /ba/ ($z=-2.55$, $p=0.01$), whereas in individuals with ANSD, noise significantly affected the identification scores of all speech sounds, except syllable /pa/ ($z=-0.705$, $p=0.481$). These results confirmed the observations and interpretations of Figure 2.

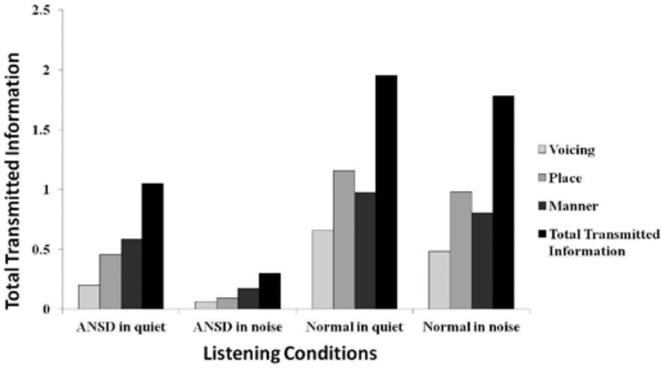

Figure 1. The performance of individuals with ANSD and those with normal hearing in the syllable identification task.
ANSD: auditory neuropathy spectrum disorder

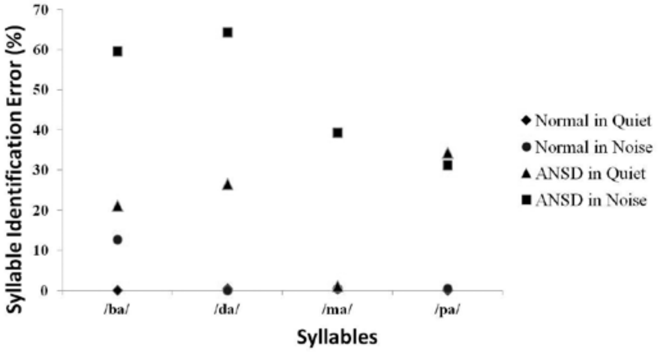

Figure 2. Average syllable identification error for individuals with ANSD and for those with normal hearing.
ANSD: auditory neuropathy spectrum disorder

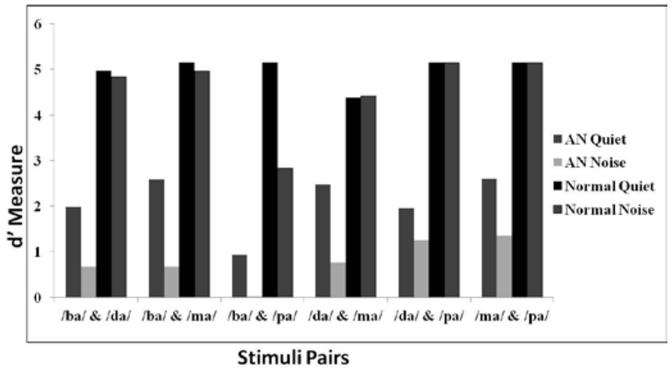

Figure 3. The performance of individuals with ANSD and those with normal hearing in the syllable discrimination task.
ANSD: auditory neuropathy spectrum disorder

d′ scores for syllable discriminations were calculated using the following formula:
$d'=z(\text{Hit})-z(\text{False alarm})$

Higher d′ scores indicate better discrimination ability. Figure 3 shows d′ scores for six syllable pairs evaluated. From the Figure 3, it can be seen that discrimination abilities of individuals with normal hearing were relatively insensitive to noise, except for the /ba-pa/ pair. However, in individuals with ANSD, discrimination abilities of all syllables pairs were substantially poorer in the +10-dB SNR condition compared with the quiet condition. These observations were confirmed by performing the non-parametric statistical test. Results of the non-parametric tests revealed that d′ scores of individuals with normal hearing were significantly poorer in noise condition compared to those in the quiet condition only for the /ba-pa/ pair ($z=2.26$, $p=0.024$), whereas individuals with ANSD had significantly poor d′ scores in the noise condition for all four syllable pairs.

DISCUSSION

Individuals with ANSD had poor syllable identification as well as poor syllable discrimination abilities compared with those with normal hearing. Poor speech perception, in both quiet and noise, is a hallmark symptom of ANSD and has also been reported by other investigators [10–15]. Poor speech perception in ANSD has been primarily attributed to poor temporal processing skills [12, 14, 16]. Individuals with ANSD are relatively insensitive to gaps and modulations in an ongoing sound stream. Processing and perception of gaps and modulations are crucial for speech understanding, and inability to perceive these cues may result in poor speech identification in individuals with ANSD. It has been shown that the addition of noise to the signal affects the temporal envelope of the speech. This disturbance could be in terms of either addition of extra modulation or removal of the required modulation in the signal, which might lead to confusion in the perception of the speech signal [17, 18].

Sequential information transfer analyses analyses showed that individuals with normal hearing perceived place information better than manner information, followed by voicing information. However, individuals with ANSD perceived manner information better than place information, followed by voicing information. Typically, place information is cued by spectrotemporally dynamic formant transitions [19, 20]. It has been shown that individuals with ANSD have difficulty in perceiving dynamic stimuli [1, 2, 13]. Therefore, individuals with ANSD may find it difficult to perceive place information. Perception of the voicing information was poorest in individuals with ANSD and was close to zero. Even in discrimination task, individuals with ANSD found it difficult to discriminate /pa-ba/ (differs in voicing feature) compared to other pairs. Voicing information in Indian languages is perceived through low-frequency pre-voicing cues. Coding of the low-frequency sounds primarily depends on phase-locked responses from auditory nerve fibers [21]. Individuals with ANSD find it difficult to use phase-locking cues to the same extent as those with normal hearing; hence, the perception of voicing cues may be more adversely affected in ANSD than in other features.

Another interesting observation from the present study was that noise had differential effects on the identification of syllables. Identification of the syllable /pa/ was not influenced by the addition of noise, whereas identification of all other consonants drastically reduced in individuals with ANSD when noise was added. Reasons for these differential effects are not clear to us at present.

CONCLUSION

All the individuals with ANSD performed poorly in the syllable identification and syllable discrimination tasks compared to those with normal hearing. The performance of individuals with ANSD drastically deteriorated in the presence of noise. Individuals with ANSD showed more trouble in identifying/discriminating low-frequency information, especially in the presence of noise. This information might be useful while rehabilitating individuals with ANSD and might throw light on features that are difficult to perceive. This will help in planning a hierarchical training paradigm. Training can also be started with the identification/discrimination of mid- and high-frequency speech sounds and moved to low-frequency sounds as it is difficult to perceive low-frequency signals in the presence of noise.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of All India Institute of Speech and Hearing, Mysore, Karnataka, India.

Informed Consent: Written informed consent was obtained from all the individuals who participated in this study.

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