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Effect of Modality and Acoustic Enhancements on Feature Transmission Index in Individuals with Auditory Neuropathy Spectrum Disorder

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ABSTRACT

***Rationale*:** Effective management of individuals with auditory neuropathy spectrum disorder (ANSD) is always a challenge for audiologists due to the heterogeneity of the disorder in terms of perception deficits and pathophysiology. The present study was undertaken to apprehend the feature transmission index in terms of different signal enhancement strategies and modality of presentation to develop specific management strategies for the target group.

***Design*:** Repeated measure standard group comparison design was utilized for the present study. Clinical group had 40 participants with confirmed diagnosis of ANSD and the control group included 40 individuals with normal auditory abilities. Stimuli tested were plosives, /k/, /ṭ/ /p/, /b/, /ḍ/ and /g/. These stimuli were acoustically enhanced, which includes both companding and envelope enhancement. The perception of both the unprocessed and acoustically enhanced stimuli was studied in the auditory alone (A), visual alone (V) and, the auditory-visual (AV) modalities. In the A and AV, modalities perception was studied both in quiet and 0 dB SNR conditions, whereas in the visual modality perception was studied only in quiet for the unprocessed stimuli. Sequential information analysis was carried for each stimulus, modality and condition using the FIX software.

Results: SINFA result showed that the place and voicing feature transmission and the total information transmitted is lesser in ANSD for the stimulus, modality and condition compared to control. The results were comparable for the acoustically enhanced stimuli in both the groups. AV modality transmitted higher place and total information compared to an auditory or visual modality in both groups. Additional visual cues have an added advantage in ANSD compared to control, and this was more pronounced in the 0 dB SNR condition.

Conclusion: Signal enhancements in the current form revealed negligible improvement in feature transmission in ANSD and control. The result that AV modality improved feature transmission in ANSD brings out the need to facilitate both the auditory modality and visual modality for the successful management of ANSD.

Key Words: SINFA, Signal enhancements, ANSD Management

INTRODUCTION

Individuals with ANSD have major trouble in understanding speech due to the deficits in temporal processing. Successful audiological management is an unachievable task for audiologists due to the heterogeneity of the disorder in terms of their perceptual deficits and underlying pathophysiology. Management of the condition with traditional amplification devices was unsuccessful as it may not address their core temporal deficits. In the late-onset ANSD, cochlear implant seems to be successful, if the lesion is presynaptic[1,2].The benefit is questionable in the postsynaptic condition. FM devices are useful only in limited listening conditions[3].

Signal enhancement strategies for the speech signal have been studied to manage the speech perception deficits in ANSD [4–7]. Companding is a spectral enhancement procedure wherein the peak to valley difference in the spectrum is increased, and it was found to improve speech perception in cochlear Implant users [8]. Narne et *al* [7] found improvement in speech perception using companding in individuals with ANSD. Improvement was significant in quiet compared to 0 dB SNR condition. Narne and Vanaja [9] enhanced the envelope of the speech signal by a magnitude of 15 dB and reported an improvement in speech perception in individuals with ANSD.

Ramirez and Mann [10] studied speech perception in ANSD in different modalities and found that persons with ANSD primarily rely on visual cues to understand speech in quiet and noisy environments. They reported that individuals with ANSD rely exclusively on visual cues. On contrary, Maruthy and Geetha [11] have shown evidence for persons with ANSD utilizing cues from both auditory and visual modalities and they reported that speech perception in ANSD in the AV modality is driven by cues of both auditory and visual modalities. In a similar way Balan and Maruthy [12] reported that during instances of compromised auditory input, audio-visual modalities help in compensating the speech perception difficulties in individuals with ANSD.

Sequential information analysis (SINFA) is a tool to identify the feature transmission index. Gnanatheja and Barman [13] studied the perception of place, manner, and voicing in cochlear hearing loss and ANSD. They reported that all the three cues are poorly perceived in ANSD compared to the cochlear hearing loss. Kumar and Jayaram [4] examined the effect of lengthened transition duration on speech perception and Just Noticeable Difference (JND) in transition duration of stop consonants in individuals with ANSD. Sequential information analysis (SINFA) revealed that lengthening the transition duration ensured better transmission of the place information compared to voicing information.

Narne and Vanaja [9] studied the feature transmission for the envelope enhanced speech in individuals with ANSD and reported that the cues for manner and place of articulation were transmitted better than voicing cues in the envelope enhanced condition compared to the unprocessed stimulus. On the contrary, Balan and Maruthy [14] reported no significant effect of signal enhancements such as Companding and Envelope enhancements in individuals with ANSD for the perception of stops. There are unequivocal results regarding the benefit with signal enhancements and modality of presentation for successful management of ANSD. Hence the present study was designed to uncover the effect of signal enhancements and modality of stimulus presentation on feature transmission index, taking a large number of samples.

MATERIALS AND METHODS

Aim

The aim of the study was to quantify the effect of modality of presentation and acoustic enhancements on feature transmission index in individuals with ANSD and normal hearing individuals.

A repeated measure standard group comparison design was utilised for the present study. The clinical group had forty participants with a confirmed diagnosis of ANSD in the age range of 16-35 years (mean age: 23.17 years, SD: 6.46), while the control group had 40 age and gender-matched individuals with normal auditory abilities. The age of onset of hearing loss in these participants was closer to 13 years of age, and all of them had acquired ANSD postlingually. The participants had sensorineural hearing loss up to moderate degree, but a few of the participants had normal hearing sensitivity. The diagnosis of ANSD was made by an experienced audiologist based on the audiological findings and the report of the neurologist. The participants included in the present study were native speakers of Kannada, language spoken in the southern state of Karnataka (India). Individuals with any other neurological abnormalities and with active middle ear infections were excluded in the study. It was also made sure that all participants in both groups were literate and had passed secondary school examinations. All the participants had normal or corrected vision (6/6). Informed consent was taken from the participants before carrying out the study. The test procedure used adhered to the 'AIISH ethical guidelines for bio-behavioural research project involving human subjects'. [15]

Procedure

It involved the (i) generation of test stimuli and acoustic enhancement such as Companding and Envelope enhancement (ii) assessing speech perception in different modality and stimulus presentation and generation of confusion matrices and analysing using FIX.

Generation of unprocessed stimuli

Stimuli tested were plosives, velar /k/, retroflex /ṭ/ and bilabial /p/, and their voiced counterparts, /b/, /ḍ/ and /g/.The syllables were uttered by a male speaker who has clinically normal speech. These six syllables were audio-recorded using Adobe audition (version 3) connected to a PC (Sony Vaio-64-bit with windows-7 OS). A high definition camera (Sony HXR-MC2500) was used and recorded the video of the male speaker articulating the syllables in order to make the audio-visual stimuli. The audio recorded stimuli were time-aligned to the video using Videopad video editor (V4.22). In order to make visual alone conditions, the AV recording was used with audio muted. All the recordings were carried out in a sound-treated audiometric room in which the ambient noise maintained as per the standards of ANSI S3.1-1991.

Generation of acoustically enhanced stimuli

The unprocessed stimuli were spectrally enhanced through companding, using the procedure given by Turicchia and Sarpeshkar[16]. MATLAB-7 (The Math Works, Natick, USA) was used for the purpose. During companding (based on instantaneous amplitude) signals were enhanced by a factor ranging between 0.3 and 1. The resultant syllables are called "Companded syllables." On the other hand, the unprocessed syllables were temporally enhanced (envelope enhancement) using the procedure recommended by Apoux et al., [17]. The syllables were enhanced by a factor of compression value of 0.3 and an expansion value of 4. The resultant syllables are called "Envelope enhanced syllables." Figure 1 shows the spectra of the representative vowel/a/and the spectra of the same vowel after companding. Figure 2 shows the waveform of the representative unprocessed, and the envelope enhanced syllable/da/.

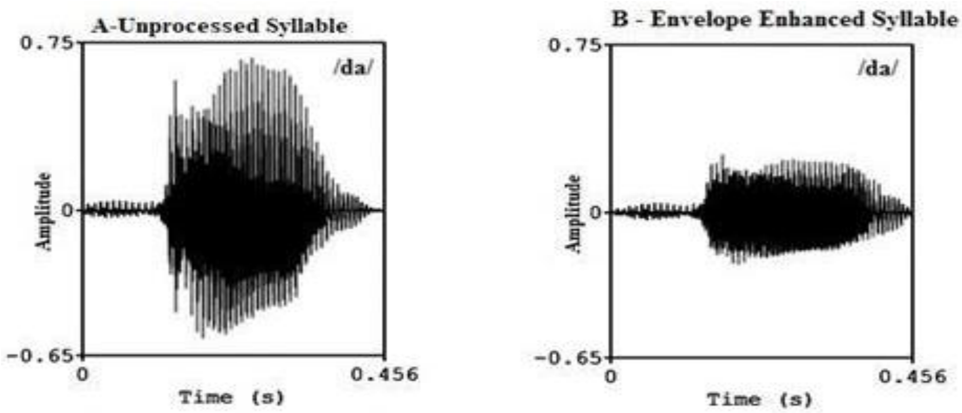

Figure1. Waveform of the unprocessed /da/ syllable (A) and the envelope enhanced syllable (B)

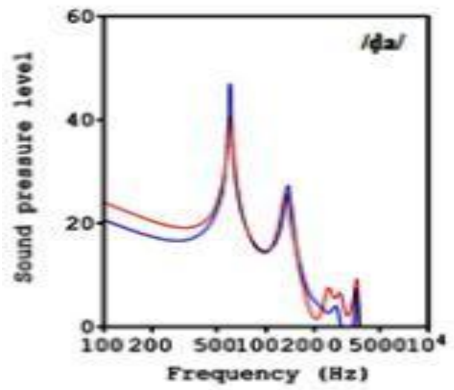

Figure 2. Spectra of syllable /da/ in the unprocessed (red) and envelope enhanced (blue) condition

Test procedure

The participants were asked to sit in a relaxed posture in the audiometric room. They were asked to repeat back the syllable heard or click the corresponding syllable, which was displayed on the LCD screen. The procedure involved the identification of syllables in auditory (A), visual (V), and (audio-visual) AV modalities. In the A and AV modalities, perception of the unprocessed, spectrally enhanced and temporally enhanced syllables was assessed in quiet as well as 0 dB SNR conditions. In the V modality perception of syllables was tested for unprocessed stimuli in quiet condition only. Paradigm software (version 2.5.0.68) was used for the presentation of the stimulus and for response recording. The audio stimuli were presented through GSI Audiostarpro Audiometer via loudspeaker kept at 45° azimuth. The stimuli were presented at most comfortable levels. The visual stimuli were presented through a 21 inch LCD screen. Each syllable was presented ten times in a random sequence. The selection of stimulus and modality of the presentation was randomised. Six syllables, presented in 13 different stimulus conditions, hence there were total 780 (6 × 10 × 13) stimulus presentations. The participants were instructed to identify the syllable presented. Correct responses were assigned a score of one, and incorrect responses a score of zero. Each participant's responses in each stimulus presentation were noted down as the raw score.

SINFA ANALYSIS

Sequential Information Analysis (SINFA) was done to find out the percentage of information transmitted for each phonetic feature in each condition, using the software, Feature Information Xfer (FIX) (developed by University College of London, Department of Linguistics). SINFA follows the procedure given by Wang and Bilger [18]. To analyse using SINFA, identification scores of each participant in each condition was added using FIX, and a summed single confusion matrix was created. This was done across all conditions and then analysed. SINFA was done to derive the transmission index of each of the phonetic features in the different stimulus presentations of the study. The 'manner of articulation' was common among the syllables tested; hence it was excluded from the SINFA. The six CVs being tested were classified based on the place, manner and voicing features as listed in Table 1.

Table1. Classification of consonants studied based on their phonetic features

Feature	/p/	/ṭ/	/k/	/b/	/ḍ/	/g/
Manner	plosive	plosive	plosive	plosive	plosive	plosive
Place	bilabial	retroflex	velar	bilabial	retroflex	velar
Voicing	unvoiced	unvoiced	unvoiced	voiced	voiced	voiced

RESULTS

Comparison of feature information transmitted between the two groups for the primary stimulus

Figure 3 shows the total information transmitted in the two groups in the three modalities, in the two conditions analysed by SINFA. This was only for the primary syllable. Total information transmitted is much lesser in ANSD group compared to that in control group. This was true in all the three modalities and in both quiet and 0 dB SNR. The difference in the total information transmitted between the two groups was more in A-modality compared to AV modality in both quiet and 0 dB SNR. The difference was least in V modality. The total information transmitted in the control group at -5 dB SNR was more than that of ANSD group at better SNRs (quiet & 0 dB SNR) in any of the modality.

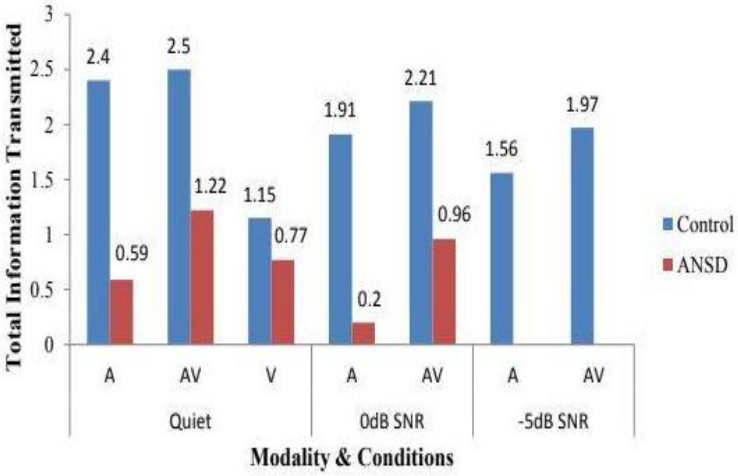

Figure 3 Comparison of total information transmitted in the two groups of participants in the three modalities in different conditions. The data were derived by SINFA on the scores of primary syllables.
Note. A: auditory modality, AV: auditory-visual modality, V: visual modality, SNR: signal to noise ratio, ANSD: auditory neuropathy spectrum disorder

The feature-wise information transmission for the primary syllable derived for place feature (Figure 4) and voicing feature (Figure 5) showed lower information transmission in the ANSD group compared to control group for both the feature.

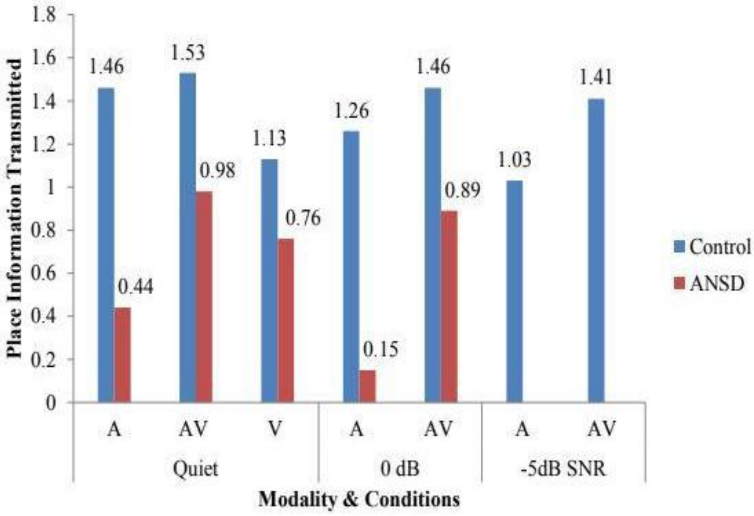

***Figure 4*: Comparison of place feature transmitted in the two groups of participants in the three modalities in different conditions for the primary stimuli.**
Note. *A: auditory modality, AV: auditory-visual modality, V: visual modality, SNR: signal to noise ratio, ANSD: auditory neuropathy spectrum disorder*

Similar to the total information transmitted, the difference in the place feature transmission between the two groups was highest in A-modality followed by AV modality and least in V modality. The pattern was similar in quiet and 0 dB SNR conditions. The place feature transmission in the control group at -5 dB SNR was more than that of the ANSD group at better SNRs in any of the modalities.

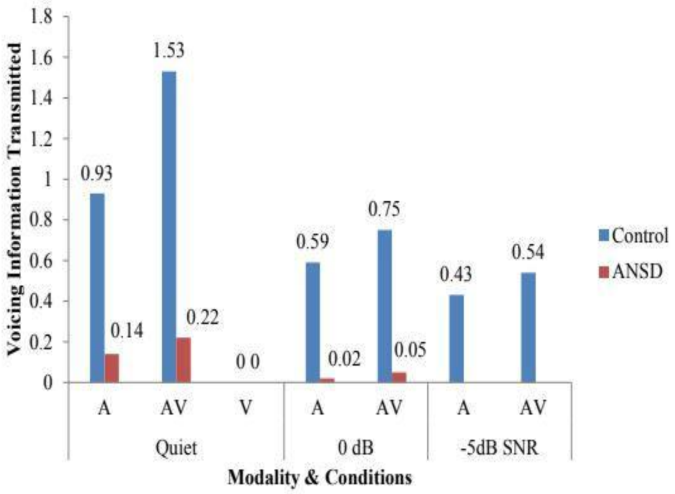

***Figure 5*: Comparison of voicing feature transmitted in the two groups of participants in the three modalities in different conditions for the primary stimuli.**

Note. A: auditory modality, AV: auditory-visual modality, V: visual modality, SNR: signal to noise ratio, ANSD: auditory neuropathy spectrum disorder

On the contrary, the voicing feature was not transmitted in V modality in either of the groups. In A and AV modalities, the voicing feature transmitted in ANSD group was lesser compared to the control group. The voicing feature transmitted in the control group at -5 dB SNR was higher than that of ANSD group at better SNRs in any of the modalities.

Comparison of feature information transmitted between the two groups for the acoustically enhanced stimuli

Total information transmitted is much lesser in ANSD group compared to the control. This was true in A and AV modalities, both quiet and 0 dB SNR conditions and for the two stimuli. The difference in the total information transmitted between the two groups was more in A-modality compared to AV modality in both quiet and 0 dB SNR conditions. The total information transmitted in the control group at -5 dB SNR in each modality was more than that of ANSD group at better SNRs (quiet & 0 dB SNR) in the same modality. Figure 6 shows the total information transmitted for the companded and envelope enhanced stimuli between the two groups in the two modalities and in the two conditions.

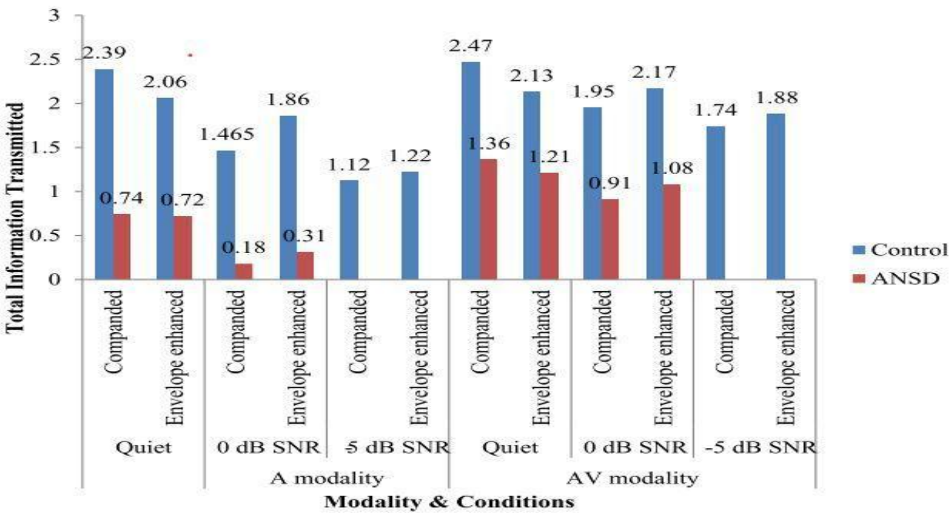

***Figure 6*: Comparison of total information transmitted in the two groups of participants for the companded and envelope enhanced stimuli in the two conditions. The data were derived using SINFA on the scores of acoustically enhanced syllables.**

***Note.** A: auditory modality, AV: auditory-visual modality, SNR: signal to noise ratio, ANSD: auditory neuropathy spectrum disorder*

Similar to the total information transmitted, the difference in the place feature transmission between the two groups was highest in A-modality followed by AV modality as shown in Figure 7. The pattern was similar in quiet and 0 dB SNR conditions. Among the two conditions, the difference was more at 0 dB SNR compared to the quiet condition. The place feature transmission in the control group at -5 dB SNR was more than that of the ANSD group at better SNRs in any of the modalities.

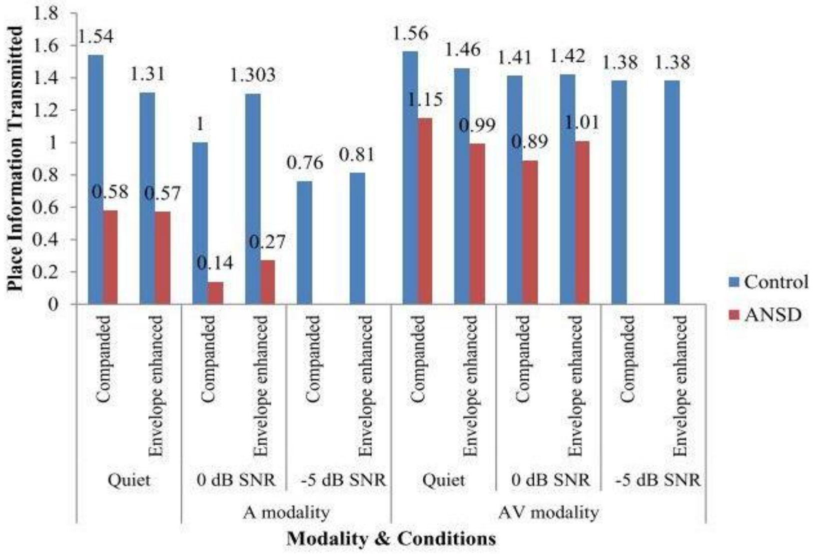

***Figure 7*: Comparison of place information transmitted in the two groups of participants for the companded and envelope enhanced stimuli in the two conditions. The data were derived by SINFA on the scores of acoustically enhanced syllables.**
Note. *A: auditory modality, AV: auditory-visual modality, SNR: signal to noise ratio, ANSD: auditory neuropathy spectrum disorder.*

The voicing feature transmitted in ANSD group was also lesser compared to control in the companded and envelope enhanced stimuli as shown in Figure 8. The difference between the two groups was lesser in AV modality compared to A-modality. Among the two conditions, 0 dB SNR transmitted lesser voicing information compared to a quiet condition. This was more evident in ANSD group compared to the control group. The voicing feature transmission in the control group at -5 dB SNR was more than that of the ANSD group at better SNRs in any of the two modalities.

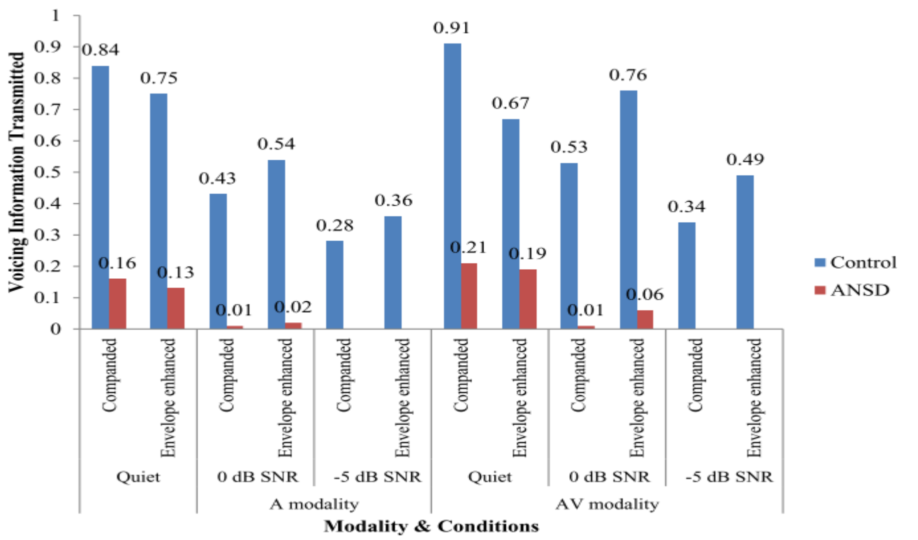

***Figure 8:* Comparison of voicing information transmitted in the two groups of participants for the companded and envelope enhanced stimulus in the two conditions. The data were derived by SINFA on the scores of acoustically enhanced syllables**
Note. A: auditory modality, AV: auditory-visual modality, V: visual modality, SNR: signal to noise ratio, ANSD: auditory neuropathy spectrum disorder

DISCUSSION

The results of SINFA indicate a significant difference between the control and ANSD groups in terms of information transmitted. This was true in all the three modalities, in all the stimulus types and in both the conditions. The difference between the two groups was more in the auditory modality compared to AV modality, indicating that persons with ANSD are able to utilize the visual cues in the AV modality to compensate for the deficit input through the auditory modality. This supports the findings of Maruthy and Geetha [11], where they reported the benefit of AV mode on speech perception in ANSD. Feature transmission index indicated that both place and voicing features are poorly transmitted in individuals with ANSD attributable to the impaired temporal processing [19,20].

The results of SINFA in ANSD showed that total transmitted information was lesser compared to typical participants in all the listening conditions. The total information transmitted was lower in the 0 dB SNR condition compared to that in quiet, and in quiet, it was lesser in auditory modality compared to that in the visual modality. The information transmitted was highest in AV modality, indicating that the addition of visual modality supplemented cues for the correct identification, which was true for both place and voicing of the consonant. The benefit derived from the visual cues was more for the correct identification of place of articulation compared to that for voicing. This advantage was seen more in the presence of noise. The information is of high relevance to the audiologists and is crucial while counselling the individuals with ANSD about the benefit derived from the AV modality. The total information, place and voicing information transmitted in typical participants at -5dB SNR was better than individuals with ANSD even in quiet conditions, indicating an inherent SNR loss in ANSD. This inherent SNR loss in individuals with ANSD needs to be studied further.

The total information and place information transmitted in the visual alone condition in ANSD is poorer compared to typical participants indicating an impaired visual processing also in ANSD. The result of SINFA revealed that even an erroneous auditory perception when it is combined to this impaired visual processing did not result an impaired auditory-visual processing, indicating that Mc-Gurk kind of effect is not occurring as the auditory-visual modality results in better feature transmission compared to auditory alone or visual alone condition. This finding also supports the need for auditory-visual based rehabilitation measures for individuals with ANSD. Similar recommendations were made by Balan and Maruthy [12] for managing the speech perception deficits in individuals with ANSD.

The findings that the signal enhancements have not shown improved feature transmission compared to unprocessed stimuli is contradicting previous studies. This difference could be because of the difference in the stimuli used. In the present study, plosives were used, having less redundancy has compared to words which were used in the previous study. It may also be due to the difference in the range of speech perception of individuals with ANSD. They were also not grouped as good and poor performers, similar to the previous study. Moreover the participants were naive listeners for the acoustically enhanced stimuli and the improvement in feature transmission may be further studied by training the individuals with ANSD listening to acoustically enhanced stimuli over a period of time. This can further confirm the effect of training with acoustically enhanced stimuli on speech perception in individuals with ANSD.

The result of the present study as improved feature transmission in AV modality highlights the need to facilitate both the auditory modality for managing the perceptual problems faced by individuals with ANSD. The auditory modality cues can be enhanced in terms of signal enhancement strategies [FM devices [21], Companding [7] and envelope enhancement [22]] and visual modality may be using speech reading using standardized methods[23,24] or though anticipatory compensatory strategies.

CONCLUSION

The inference from feature transmission related to the negligible effect of signal enhancements on speech perception in ANSD may be confined to the perception of the stop consonants only. Future studies can take up after formal training with the acoustically enhanced stimulus to quantify the effect of training on feature transmission in individuals with ANSD. There was a definite improvement in feature transmission in ANSD when the auditory-visual modalities compared to auditory or visual modality alone which highlight the need to facilitate both auditory and visual modality for the successful management of perceptual deficits in individuals with ANSD.

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