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Original Research Article

Effect of Consonant-Vowel Ratio Enhancement and Duration Enhancement on Speech Perception among Individuals with Auditory Neuropathy Spectrum Disorders

Priyanka Jaisinghani[a], P. Manjula[b]

[a] DST INSPIRE Fellow, All India Institute of Speech and Hearing, Mysuru, (Karnataka), India
[b] Professor of Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru, (Karnataka), India

Corresponding Author: Priyanka Jaisinghani

ABSTRACT

Purpose: Management of individuals with Auditory Neuropathy Spectrum Disorders has always been an enigma. The present study evaluated the effect of speech enhancement strategies i.e., Consonant-Vowel Ratio Enhancement (CVRE) and Duration enhancement (DE), on speech identification in quiet, in individuals with ANSD.
Methods: Repeated measures design was used for the study on thirteen individuals with ANSD. Speech identification scores were obtained for sentences in Original, with CVRE by 9 dB & 12 dB, and DE conditions. The stimuli were presented to the test ear of participants through audiometric headphones at 40 dB SL (ref: SRT). Verbal responses were audio recorded and the raw speech identification scores across four conditions were tabulated.
Results: Out of 13 participants, DE improved the raw SIS in four individuals, CVRE-9 in three and CVRE-12 in seven individuals. The mean and median of raw SIS was higher with DE in comparison to CVRE and original conditions. No significant difference was noted in the raw scores with and without speech enhancement strategies in individuals with ANSD. This could be because first, CVRE efficiently enhanced the alveolar stops and affricates however, only a portion of the Kannada sentence was enhanced by CVRE and it remained largely unaltered. Second, syllable vowel context is found to influence the medial consonant identification in DE. Since, a sentence structure has diverse CV combinations which could have possibly contributed to no difference in speech identification with DE. Third, longer vowel durations with DE may also have led to excessive backward masking of the preceding consonant.
Conclusion: Both CVRE and DE did not enhance the speech identification.

Keywords- duration enhancement, consonant-vowel ratio enhancement, speech identification

INTRODUCTION

Auditory neuropathy spectrum disorder (ANSD) is a clinical condition wherein the otoacoustic emissions are (or previously were) present but, auditory brainstem response (ABR) is either absent or abnormal [1, 2]. The prevalence rate of ANSD in India is 1 in 183 of the population with sensorineural hearing loss, including children, adults, and geriatrics [3]. The pure-tone hearing thresholds, in nearly 97% of individuals with ANSD, ranged from minimal hearing loss to profound hearing loss [4]. However, their speech recognition ability, in quiet as well as in noise, is generally low. On a similar note, a few researchers failed to acquire any measurable speech identification scores in 60% of the individuals with ANSD, owing to their severely impaired temporal processing ability [3].

The amplification devices render minimal or no significant benefits in individuals with late-onset ANSD [1, 5, 6, 7]. Contrary to this, Penido and Issac [8] outlined that 11% of individuals with ANSD had functional gain present when fitted with an amplification device. Vanaja and Manjula [9] also reported improved speech perception with hearing aids in three out of five young adults with ANSD. Since quite a long time, appropriate management option for the ANSD has been a much-discussed enigma. Several researchers have investigated the potential of speech cue enhancement or signal enhancement strategies to alleviate speech perception problems of these individuals in recent years [10-12]. These strategies aim to identify the speech sound using any acoustic feature and further exaggerating it for easier recognition. The successful strategy can be incorporated as digital algorithms in hearing aids.

One of the strategies illustrated in literature is increasing the duration of the speech sound [13]. In the same light, manually extending the burst, transition, and the voice onset time of various stop consonants in CV syllables was tried with the just noticeable differences as the basis and this improved the perception [3,11, 14]. However, the extent of lengthening varies across individuals, cues, and speech sounds. Therefore, such temporal enhancements though beneficial are impractical with hearing aids when real-time or online processing is essential.

Mathai and Yathiraj [12] estimated consonant perception of individuals with ANSD using VCV syllables in the unprocessed and three stretched condition (25%, 35%, and 50%). The 25% stretched condition yielded maximum scores in speech identification. This type of duration enhancement technique has more utility since the whole stimulus is stretched unanimously and specific identification and manipulation of a segment is not required. However, there is a need to examine this duration enhancement technique on sentence identification of individuals ANSD.

Apoux et al. [15] suggested that enhancing the envelope of the signal improves speech perception in noise among those with cochlear hearing loss and normal hearing. On a similar note, Narne and Vanaja [16] found significant improvement in the word perception in quiet and noise in individuals with ANSD with envelope enhancement. They reported that the good performers (SIS ≥ 50%) showed a significant improvement in quiet and at all the three SNRs (+10, +5, and 0 dB). On the other hand, the poor performers (SIS < 50%) showed significant improvement only in quiet and at +10 dB SNR. Similar results were reported by Narne and Vanaja [17] of up to 36% improvement in word recognition in quiet, with envelope enhanced stimuli. Significant improvement was noted in individuals having relatively good speech identification in quiet and no improvement for the individuals having poor speech identification in quiet. Contrary to this, no improvement or even deterioration in speech perception with the advent of envelope enhancement is also reported [18, 19].

Many researchers have investigated the utility of companding technique that highlights the spectral and temporal contrasts to improve the speech perception of individuals with ANSD [18, 20, 21, 22]. There is a strong evidence of improved speech perception in quiet and in noise at different SNRs with companded stimuli in individuals with ANSD and those with normal hearing [21, 22]. However, contradictory findings are also reported of no improvement with the companding technique in listeners with ANSD [18].

There is an evidence of improved sentence recognition of individuals with ANSD when clear speech is practiced instead of conversational speech [23]. This could be attributed to the beneficial acoustic and phonetic changes brought about by clear speech, such as reduced speaking rate, enhancement of energy in 1kHz-3kHz range, enhanced temporal modulations, expanded voice pitch range, and expanded vowel space [23]. Increased consonant-vowel ratio (CVR) is also one of the attribute of clear speech yielding improved speech perception [24]. This increment in the CVR to improve speech perception can be used as an enhancement technique [13]. Jayan and Pandey [25] studied the potential rate of spectral centroid change in detecting spectral transitions for enhancing real-time CVR. They reported significant improvement in syllables and word recognition with CVR enhancement in normal-hearing individuals even at low SNRs. In similar lines, further research to examine the potential of CVR enhancement (CVRE) to improve speech perception of individuals with ANSD is much warranted. This technique can be implemented in real-time and hence has scope in the hearing aids.

There have been equivocal findings of effect of speech enhancement technique on speech perception of individuals with ANSD with the type of stimuli [19]. Envelope enhanced words were found to be easiest, followed by sentences and monosyllables in them. However, the task of sentence identification is more practical as it reflects real-world communication situation. Therefore, it is essential to examine the benefit of these speech enhancement strategies using more often used stimuli in everyday life. The present study focused on sentence recognition in quiet with two enhancement techniques, CVRE and DE. The improvements in CV syllable identification and word intelligibility at degraded SNRs with the CVRE strategy are well recognized in individuals with normal hearing [25-27]. Therefore, it was necessary to study whether these cues benefit individuals with ANSD who have severely altered speech perception in quiet. In addition to this, since the magnitude of CVRE resulting in benefit is unknown, it is necessary to evaluate enhancement at different levels (e.g., 9 dB and 12 dB) to infer on its efficacy. Apart from CVRE, the DE by 25% stretch factor (compared to 35% and 50% stretching) was the optimum duration enhancement factor by Pottackal Mathai and Yathiraj [12], yielding the highest speech identification scores for VCV syllables. However, there is a need to evaluate this strategy using stimulus akin to natural speech (sentence identification) in individuals with ANSD. It was speculated that if favorable results are obtained, their implementation in real-time hearing aid will be a promising management option.

Aim and Objectives

To evaluate the effect of speech enhancement strategies, the Consonant-Vowel Ratio Enhancement (CVRE) strategy at two enhancement levels 9 dB (CVRE-9), 12 dB (CVRE-12), and the Duration Enhancement (DE) strategy on speech perception abilities of individuals with auditory neuropathy spectrum disorders (ANSD).

METHODS

Within-subject or repeated measures design [28] was framed to evaluate the speech perception abilities of individuals with ANSD across the unprocessed and processed conditions in quiet. The participants were recruited based on the purposive convenient sampling.

Participants

Thirteen adult participants with a confirmed diagnosis of ANSD were recruited for the study. These individuals with ANSD had transient evoked otoacoustic emissions present, absent auditory brainstem responses, and A-type tympanogram with absent acoustic reflexes [2]. Only individuals having late-onset of ANSD or acquired ANSD were included in the study. The ANSD diagnosis was confirmed by a certified audiologist and neurologist.

The age range of the participants was from 17 to 43 years, mean age being

25.69 years. Their mean four frequency (0.5 kHz, 1 kHz, 2 kHz, and 4 kHz) pure-tone average (PTA) was 23.88 dB HL, and the mean speech identification score (SIS) was 67.7%. Individuals having a maximum upto moderate degree of sensorineural hearing loss in the better ear, which was the test ear, were selected. The participants were considered as relatively good performers since they had an SIS of >50% [17]. It was also ascertained that the participants had no experience with any amplification device, nor were they exposed to any formal training in listening before participating in the study. The participants were native speakers of the Kannada language, an official Dravidian language spoken in the Karnataka state [29]. It was also ensured that they had a minimum education of 10th standard or equivalent.

Exclusion Criteria: Individuals having complaints of external or middle ear infections were excluded from the study. Individuals with cognitive or psychological complaints were also excluded.
The demographic and audiological details of the participants are given in Table 1.

Table 1: Demographic and audiological details of the participants

Participant No.	Age/Gender	Test Ear	Pure-Tone Average (in dB HL)	Speech Recognition Threshold (in dB HL)	Speech Identification Score (in %)
1	30 yr /Male	Right	22.5	30	88
2	20 yr /Female	Right	16	25	60
3	18 yr / Male	Left	13.75	30	52
4	26 yr / Male	Left	30	25	60
5	17yr / Male	Right	13.75	40	52
6	20 yr / Male	Right	26	45	56
7	35 yr / Male	Left	55	60	52
8	43 yr / Male	Left	32	40	60
9	23 yr/Female	Right	27.50	50	60
10	30 yr / Male	Right	35	50	52
11	23 yr / Male	Left	7.5	10	100
12	25 yr /Female	Right	20	40	92
13	24 yr / Male	Left	11.25	15	96

Test set-up

All the audiological tests were carried out in an air-conditioned, sound-treated double room test suite. The noise levels were within the permissible limits [30]. The study required the active involvement of the participant for the assessment of speech perception in quiet. The test stimuli were loaded on to a personal Laptop routed via an audiometer and presented to the test ear of the participant through headphones. A digital audio recorder was placed in front of the participant to record the uttered responses for later analysis. The schematic representation of the test set-up is illustrated in Figure 1.

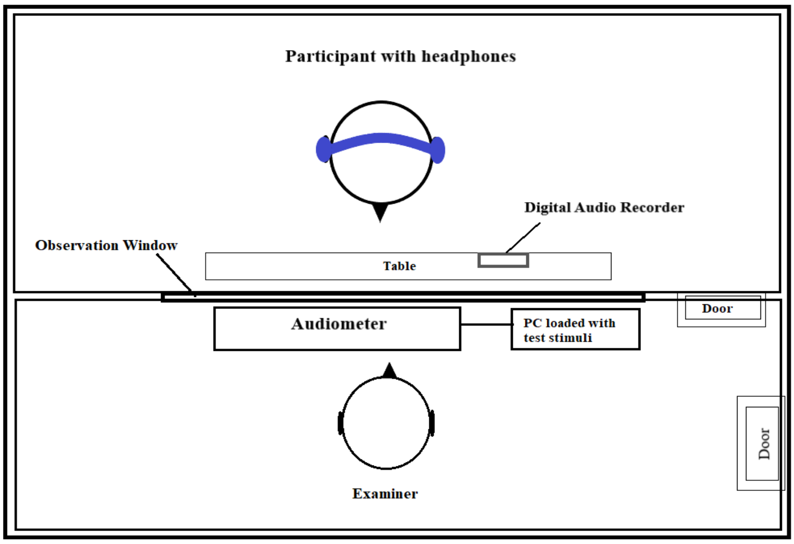

Fig. 1 Depiction of an experimental test setup

Stimuli

For the generation of the test stimuli, sentences in the Kannada language from the Sentence Test in the Kannada Language for Adults developed by Geetha et al. [31] were utilized. The sentence test contained 25 lists of sentences equivalent in difficulty in quiet and homogenous even at -5 dB SNR level. Each list of the test comprised of 10 different sentences, each with four key words. In the present study, four different lists were utilized. For each condition, a different list of sentences was used to minimize the effect of familiarity with the test stimuli. A single list of ten sentences was retained as it is for evaluation of speech identification in the original or unprocessed condition. Two lists were used to evaluate speech perception in quiet with CVRE strategy, one each for 9 dB level (CVRE-9) and 12 dB level (CVRE-12) conditions. The fourth list was used to evaluate speech perception with DE strategy.

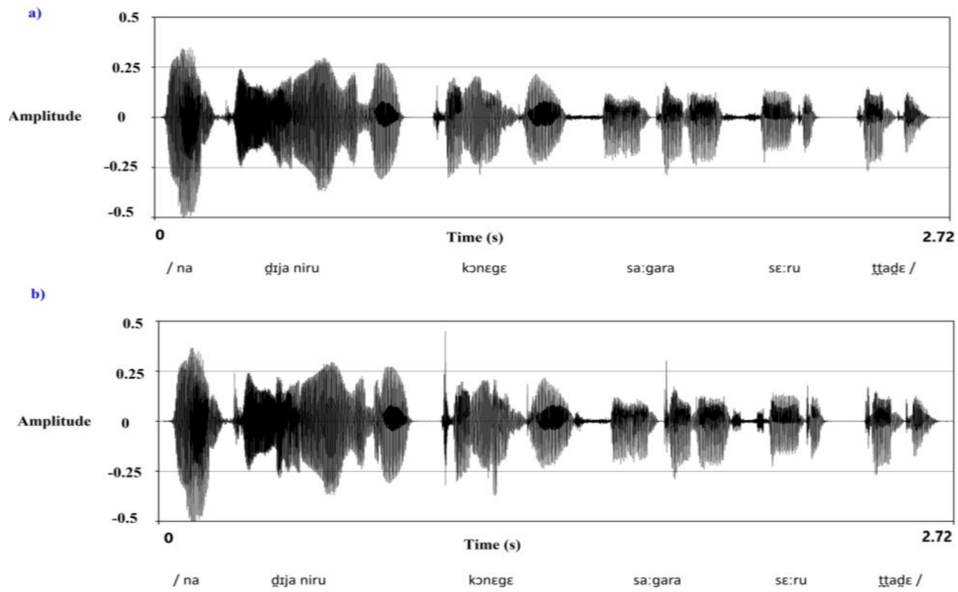

Fig. 2 a) Waveform of the unprocessed sentence /naḏɪja niru kɔnɛgɛ saːgara sɛːruṯṯaḏɛ/; b) Waveform of the same sentence enhanced using CVR of 9 dB, CVRE-9

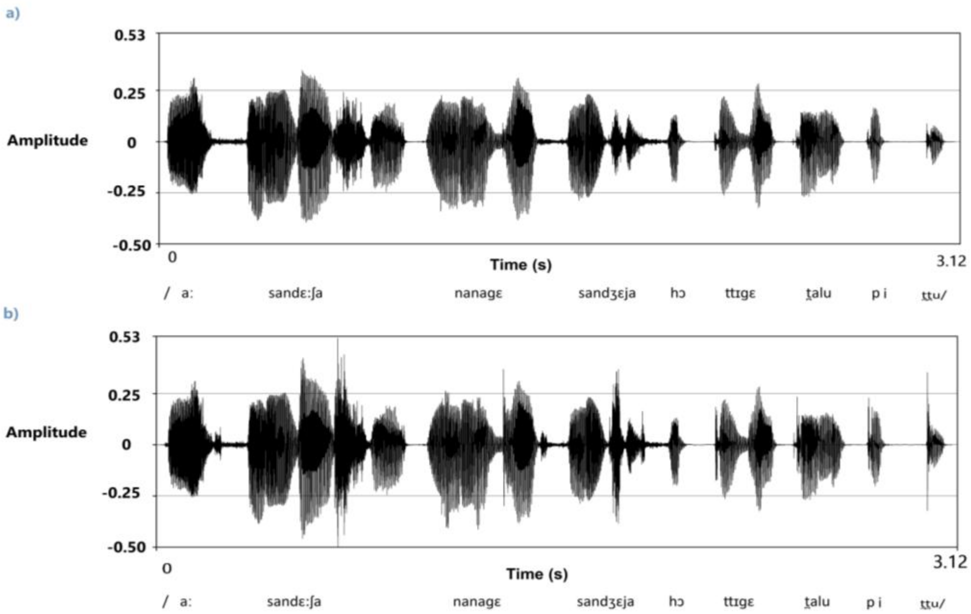

Fig. 3 a) Waveform of unprocessed sentence /aː sandɛːʃa nanagɛ sandʒɛja hɔttɪgɛ ṯalupiṯṯu/; b) Waveform of the same sentence enhanced using a CVR of 12 dB, CVRE-12

The stimuli preparation for CVRE was carried out as per the procedure illustrated by Jayan and Pandey [25]. In this procedure, CVRE of stops was carried out using the rate of spectral centroid change for spectral transition detection. To illustrate, the waveforms of an unprocessed sentence and the same sentence processed using CVRE-9, are depicted in Figure 2. Likewise, the waveforms of an unprocessed sentence and the same sentence processed using CVRE-12 are displayed below in Figure 3.

For DE, a list of ten sentences was stretched with a factor of 25% using a Pitch Synchronous and Overlap and Add technique (PSOLA algorithm) [32], available in PRAAT [33] software. This particular technique was undertaken as it causes minimal digital artifacts and retains the formant structure of stop consonants compared to other time scaling algorithms [34]. It works by decomposing the original signal based on pitch synchronous marks into short time signals, and then these are duplicated to generate the stretched signal based on predefined stretch factor. The waveform of an unprocessed sentence and sentence processed using DE strategy are displayed in Figure 4.

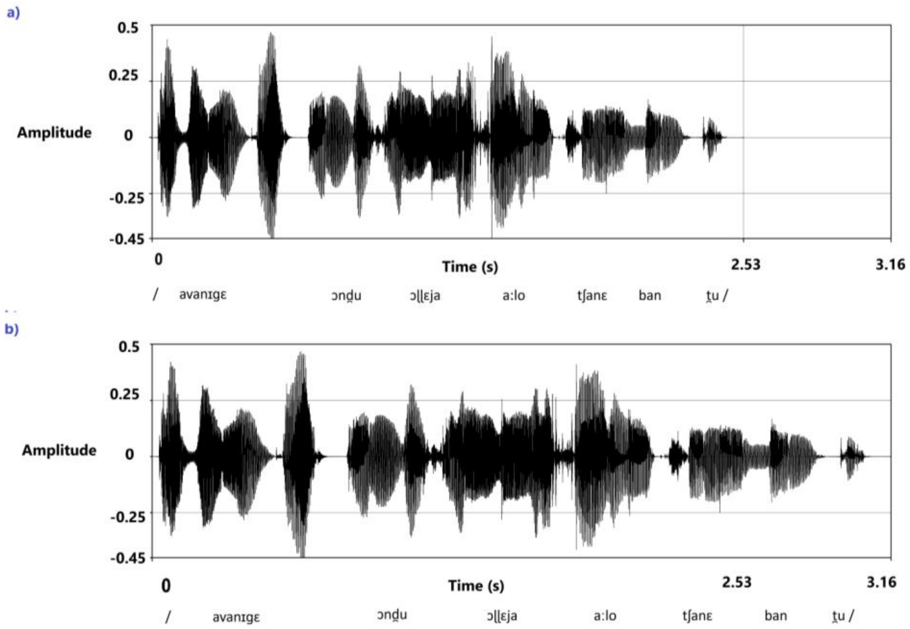

Fig. 4 a) Waveform of unprocessed sentence /avanɪgɛ ɔnd̪u ɔɭɭɛja aːlotʃanɛ bant̪u /; b) Waveform of the same sentence enhanced using DE

All the four lists of sentences prepared for the four conditions (Original, CVR-9, CVR-12, and DE) were normalized to -6 dB level. This was done to ensure that the loudness is maintained across the conditions and sentences. Further, to ensure the absence of distortion in the test stimuli, ten adult listeners with normal hearing and native speakers of Kannada language were listened to all the test stimuli. The listeners with normal hearing were presented with test stimuli at 40 dB SL (ref: SRT), through audiometer headphones, and were instructed to repeat what they heard. The test stimuli were finalized as there was no deterioration in performance of individuals with normal hearing in any of the processed condition in comparison to the original condition.

Procedure

A formal structured interview of the participants was conducted to rule out other otological, neurological, and psychological problems. The participants recruited for the study underwent pure-tone audiometry, speech audiometry, tympanometry with acoustic reflex testing, otoacoustic emissions, and auditory brainstem responses (ABR). Only the participants fulfilling the inclusion criteria were considered for further evaluation. The study was conducted at the All India Institute of Speech and Hearing (AIISH), Mysore. Written informed consent for the participation was obtained at the commencement of the testing from all the recruited participants. The study adhered to the Ethical Guidelines for Bio-Behavioral Research involving human subjects by AIISH, Mysore, and was approved by the AIISH Ethics Committee (reference number: ECC-Res.art/02/2020).

The participants were subjected to sentence identification task in quiet in four test conditions. The conditions were original (O), CVR enhancement with 9 dB level (CVRE-9), CVR enhancement with 12 dB level (CVR-12), and duration enhancement (DE) with 25% stretch. In the present study, the sentence identification task was targeted in quiet. The sentence identification in quiet was targeted since there is prior evidence of improvement in speech perception in quiet with enhancement techniques for those individuals with ANSD obtaining good speech identification scores [16, 17].

To obtain sentence identification score in each condition, one list (with 10 sentences) per condition was used. Hence to evaluate four conditions, 40 sentences were utilized for the overall speech identification task in quiet. The order of the conditions was randomly selected for the participants. Furthermore, for each condition, the selection of sentences for the presentation was made in random order using a random number generation between one and ten.

All the stimuli were loaded in a personal laptop computer which was connected to the audiometer for stimulus presentation. The original and processed stimuli were presented to the participants' test ear, through the audiometer's headphones at 40 dB SL (re: speech recognition threshold). The participants were instructed to repeat what they heard. Their verbal responses were audio-recorded for scoring later.

Response Analysis

Each sentence in the test comprised of four keywords. Hence, for each condition a total of 40 keywords were scored. The total number of correct keywords identified for each condition or the raw speech identification scores (SIS) were noted. The SIS for all the participants across four test conditions was tabulated and was subjected to descriptive and inferential statistical analyses using SPSS Statistics (version 23 for Windows).

RESULTS

Table 2: Mean, Median, standard deviation (SD) and Range of raw speech identification scores (Max. = 40)

Conditions	Mean	Median	SD	Range
Original (O)	32.85	35	7.65	17-40
CVRE-9	31.23	31	6.16	22-40
CVRE-12	33	34	7.08	20-40
DE	34.23	36	5.34	23-40

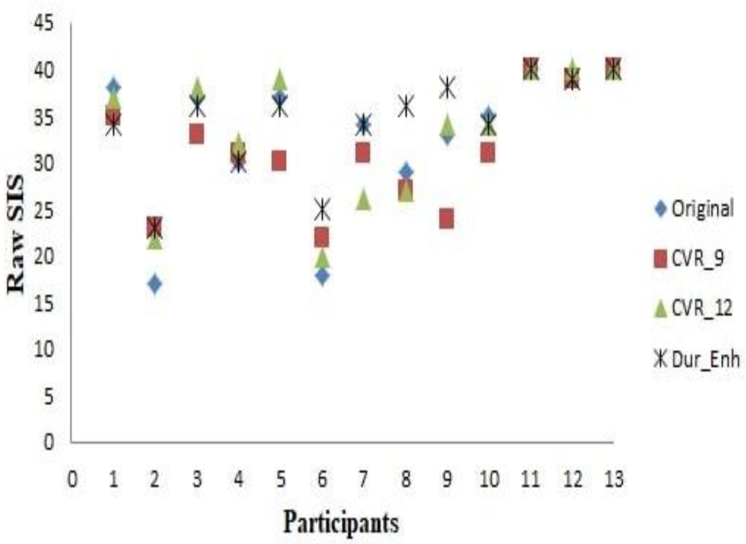

Fig. 5 SIS (Max. SIS=40) of individual participant across conditions

The mean, median, standard deviation (SD), and range of raw SIS were estimated for the original (O), CVRE-9, CVRE-12, and DE conditions (Table 2). As shown in Table 2, the mean SIS was maximum for DE condition, followed by SIS through CVRE-12, SIS for original, and then by SIS for CVRE-9. The highest median score was obtained for DE and followed original stimuli, CVRE-12, and CVRE-9. The individual raw SIS scores distribution across the conditions is also depicted in Figure 5.

Further, the Shapiro Wilk test of normality revealed that the SIS in quiet did not follow normal distribution ($p < 0.05$). Hence, non-parametric Friedman test was deployed to check for a significant difference in the raw scores across the conditions. The results revealed that there was no significant difference with and without speech enhancement strategies in individuals with ANSD [χ^2 (3) =3.62; $p > 0.05$].

On the observation of individual participants' raw SIS across conditions (as shown in Figure 5), it was noted that the last three participants had already achieved maximum scores in the original condition. Among the remaining participants, it was observed that DE improved speech identification in four individuals, CVRE-9 in three individuals and with CVRE-12 in seven individuals. Therefore, to ensure that the lack of significant difference is not due to the ceiling effect, re-analysis was done after excluding the last three participants. Despite the exclusion, no significant difference in the raw SIS was observed across conditions [χ^2 (3) =3.16; $p > 0.05$].

DISCUSSION

The present study found no significant difference in speech identification ability of individuals with ANSD, with and without speech enhancement strategies. The CVR enhancement at both the levels (9 dB and 12 dB) did not significantly provide benefit for speech perception. However, on observation of individuals scores, it was noted that more number of participants showed benefit with CVRE-12 (7/13) in comparison to CVRE-9 (3/13), though non-significant. Hence, it can be inferred from individual raw scores that 12 dB level is more advantageous than the 9 dB level for CVRE for ANSD population. It was also noted that for three participants who were also good performers, there was deterioration in raw SIS with the enhancement techniques in comparison to the original condition. Therefore it can be inferred that though these enhancement techniques were not causing deterioration in speech perception of listeners with normal hearing, it can result in deterioration in speech perception of good performers of ANSD group.

The present study utilized Kannada sentences as stimuli. The Mysore dialect of Kannada language comprises of /n/, /r/, /l/, /t/, /d/ as predominantly occurring consonants in the daily conversation [35]. These consonants with other vowels (/a/, /i/, /a:/, /e/, /u/) constitute 64.5% of the total phonemes in Kannada [35]. Moreover, phonemes (/h/,/s/,/p/,/t-/,/dz/, and /-/) occur in conversation speech of Kannada language for even less than 2%. On the other hand, the CVR enhancement is found to be more effective only on alveolar stops (/t/-/d/) and affricates (t-/-/dz/) in comparison to labial and velar stops (/p/, /b/, /k/, /g/). The CVRE does not adversely affect the fricatives, nasals, and semivowels [25]. Thus, there was an evident enhancement for affricates and transient portion like a burst of stops (as can be visualized in the waveforms, Figures 2 and 3). However, other labial and velar stops, nasals, laterals, and fricative phonemes were not noticeably enhanced by the CVR enhancement strategy. Therefore, some components of the sentences were enhanced with CVR enhancement strategy, and the larger portions were left unaltered. This could have attributed to the absence of any significant improvement with CVR enhancement. Hence, the variation in the frequency of speech sounds occurrence may also be a contributing factor in determining the benefit from enhancement strategy. This effect is evident when longer stimuli is utilized compared to syllable. On these grounds, there might even possibilities of differences in enhancement benefit across languages. Apart from this, CVR modification most effectively occurs in the context of /u/ [25]. In contrast, in Kannada language the occurence of /a/,/i/ and /a:/ is greater than with the occurence of vowel /u/. This factor could have also contributed to the limited improvement in speech identification scores in quiet with CVRE.

Similarly, though there are proven benefits in consonant identification embedded in VCV syllables by DE of 25% [12], no improvement was found in the present study. This could be attributed to the variation in enhancement perception with neighboring vowel contexts in running speech. Mathai and Yathiraj [12] also have postulated that benefit in consonant identification in VCV syllable with DE varied according to the vowel context. In their study, maximum consonant identification with 25% DE was observed in the context of /a/ followed by /u/ and minimum benefit in the context of /i/ vowel. This factor was advantageous for the current study since, the Kannada language has highest /a/ vowel occurrence in comparison to all other phonemes. The raw scores were higher in comparison to the original in four participants and even mean and median scores of SIS were greater in comparison to the original and CVRE conditions, though non-significant. This can be realized in view of the fact that the present study incorporated sentences, and there were more diverse and unpredictable consonant-vowel combinations, resulting in a lack of improvement.

Past researches have demonstrated the detrimental effect of vowel duration on consonant perception [12]. From the same prespective, greater vowel duration in stimulus with DE could have resulted in the masking of preceding consonant and can be attributed to the lack of improvement in speech identification in quiet. Zeng et al. [36] have proposed that individuals with ANSD encounter greater backward masking than the forward masking. Hence, the detrimental effect of backward masking could also have resulted in lack of improvement with DE.

Besides this, the type of stimuli or sentences deployed for the investigation also could have contributed to the difference in results from the previous studies. There is a dearth of studies incorporating sentences as stimuli for evaluating the benefit with enhancement techniques. Previous studies have employed syllables and words as stimuli. Monosyllables are linguistically least redundant in nature. Hence, the findings with these stimuli are not generalizable to running speech. Unlike the words and syllables, the complex sentences require greater linguistic competence and intelligence as it taps on both peripheral and central hearing processes. In addition, the sentences are more linguistically redundant stimuli, and offer greater linguistic and contextual cues than the words. In spite of this, improvement in sentence identification is difficult to achieve compared to the words and syllables, owing to the fact that the meaningful sentences give recognition scores averaged over vowel contexts, consonant positions, and different consonants.

The population with is a heterogeneous group, and it is difficult to generalize the findings with fewer participants. Therefore, verification of these enhancement strategies with a larger number of participants is also recommended. Additionally, the participants in the present study were naïve listeners to the processed stimuli. Hence, more research is required to investigate if there are any post-training effects with the enhanced stimulus in these individuals.

CONCLUSION

The present study found no significant benefit with CVRE and DE strategies in the sentence perception of individuals with ANSD. The present study also highlights the use of sentences as stimuli for evaluating benefit with any type of speech processing before implementing in hearing aids. Further research in speech perception assessment with these enhancement strategies at different SNR levels is also recommended. Caution must be exercised in generalizing the findings since these findings pertain to individuals with ANSD having SIS greater than 50%. It would be interesting to investigate the effect of these enhancement strategies on the speech perception of individuals with ANSD having poor SIS.

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Ethics Approval: Study adhered to the Ethical Guidelines for Bio-Behavioral Research involving human subjects by AIISH, Mysore, and was approved by the AIISH Ethics Committee (reference number: ECC-Res.art/02/2020).

Authors' Contributions:

Priyanka Jaisinghani: Conceptualization (Lead), Methodology (Supporting), Data curation (Lead), Formal analysis (Lead), Writing – original draft (Lead), Writing – review & editing (Lead)

P. Manjula: Methodology (Lead), Supervision (Lead), Writing – original draft (Supporting), Writing – review & editing (Supporting).

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