Relationship between spectral resolution and speech perception in noise in children with CAPD and children with normal auditory processing

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This Dissertation is submitted as a part of fulfilment

For the Degree of Master of Science in Audiology

University of Mysore, Mysore

All India Institute of Speech and Hearing

Manasagangothri Mysore – 570006

July 2020

<u>CERTIFICATE</u>

This is to certify that this dissertation entitled '**Relationship between spectral resolution and speech perception in noise in children with CAPD and children with normal auditory processing'**is bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student registration No. 18AUD022. This has been carried out under supervision and guidance of the faculty of this institute and has not been submitted earlier to any other University for the award or any other Diploma or Degree.

Mysuru
July, 2020

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DECLARATION

This is to certify that this dissertation entitled '**Relationship between spectral resolution and speech perception in noise in children with CAPD and children with normal auditory processing'**is result of my own study under the guidance of Dr. Chandni Jain, Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru and has not been submitted earlier to any other University for the award or any other Diploma or Degree.

Mysuru **Registration No. 18AUD022**

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Abstract

Spectral resolution involves complex coding of signal across frequency channels and difficulty may affect speech perception in noise ability. Difficulty perceiving speech in noise is one of the common deficit associated with children with central auditory processing disorder (CAPD). The aim of the present study was to investigate the relationship between spectral resolution and speech in noise perception in children with CAPD and children with normal auditory processing. A total of 20 children in age range of 7-14 years participated in the study. They were divided into two groups, control group included 15 children with normal auditory processing and clinical group included five children diagnosed as CAPD with auditory closure deficit. Spectral resolution was assessed through ripple noise discrimination (RND) and frequency difference limen (FDL) and speech perception in noise ability through speech perception in noise test in Kannada (SPIN-K). Results showed that mean RND threshold, mean FDL and mean SPIN-K scores were better in control group as compared to clinical group for both the ears. Further, there was no significant correlation seen between spectral resolution and speech perception in noise in children with normal auditory processing. To conclude, spectral resolution and speech perception in noise is poorer in children with CAPD, however, correlation between spectral abilities and speech perception in noise could done be done in CAPD due to less number of participants.

Key words; central auditory processing disorder, ripple noise discrimination, frequency difference limen, speech perception in noise

Chapter 1

Introduction

“Central auditory processing disorder (CAPD) refers to difficulties in the perceptual processing of auditory information at the level of the central auditory nervous system” (ASHA, 2005). “These include poor performance in one or more of the skills such as sound localization and lateralization, auditory discrimination, auditory pattern recognition, and temporal aspects of audition that include temporal integration, temporal discrimination, temporal ordering, and temporal masking, as well as auditory performance with degraded acoustic signals” (ASHA, 2005).

CAPD can be caused due to neuro-maturational delay, hereditary developmental abnormalities, neuroanatomical anomalies, auditory deprivation and neurologic insult of the CANS. Also, alterations in central auditory nervous system as a consequence of aging leads to auditory processing difficulties in elderly. The prevalence of CAPD in United States was estimated to be 2%-5% (Chermak & Musiek, 1997) and the prevalence for at risk of CAPD school-age children as estimated by Muthuselvi and Yathiraj, (2009) was 3.2% in India. Diagnosis of CAPD involves test battery approach constituting of various behavioral, electroacoustic and electrophysiological tests with documented specificity and sensitivity to assess several central auditory processes affected in children with CAPD.

Individuals with CAPD shows various behavioural symptoms such as difficulty comprehending speech in environment with noisy background, in reverberant environments, in competing messages or when presented with fast rate or in rapid manner. They also have trouble in localizing sound, take long time to reciprocate in oral communication situations, ask for frequent repetitions, use words such as "what" and "huh" frequently. These children respond inconsistently or inappropriately, find trouble in following and comprehending rapid speech as well as in following complicated auditory directions or instructions, have problems in acquiring nursery rhymes or songs, misinterpretation of messages, such as in identifying variations in prosody that helps in interpretation of humour (jokes), exhibit poor musical and singing abilities and have trouble giving attention and prone for distractions easily. Also, they may have associated spelling, reading, and learning difficulties, trouble acquiring a novel language and may demonstrate poor or below average performance on psychoeducational or speech and language tasks and tests in auditory-related abilities (ASHA, 2005).

Auditory processing disorder persistent constraints in the execution of auditory tasks and hindrance in participation, perception of speech in challenging listening circumstances is the most often encountered problem in individuals with CAPD. (Musiek & Geurkink, 1980; Chermak et al., 1999; Keith, 1999; Bamiou, Musiek, & Luxon, 2001; Bellis, 2003; Chermak, 2002; Vanniasegaram et al., 2004).

1.1 Speech Perception in Noise

A speech signal is a broadband signal, complex and comprised of multiple frequencies. Apoux, Yoho, Youngdahl and Healy (2013) stated that precise extraction of temporal signal cues along with fine structure cues is required to observe speech in the presence of noise. Additionally, speech recognition ability is also aided through spectral features of sounds such as gross spectral shape (Allen & Wightman, 1992; Assmann & Summerfield, 2004; Henry, Turner & Behrens, 2005). For perceiving spectral shape, extraction of intensity and frequency information across every auditory filter is essential. The obscurity in the extraction of information across the output of auditory filters such as frequency and weighing intensity information may lead to trouble in distinguishing speech sounds varying subtly in their spectral profile. The listener's ability to separate between differences in sounds that have alike spectra can be used to assess the ability to perceive spectral shape (Allen & Wightman 1992) as well as acoustically controlled non-speech stimuli such as broadband and complex acoustic signal, like a rippled spectrum (Goldsworthy, 2015) can be utilized to assess perception of spectral shape.

In individuals with CAPD, speech perception in noise (SPIN) is a greatest challenge. Ankmnal, Veeranna, Allan, Macpherson and Allen, (2019) reported that spectral ripple discrimination (SRD) maturation lags behind in CAPD as relative to normally developing children. The authors concluded that some of the listening problems encountered by children with CAPD may be explained by poor spectral ripple discrimination.

1.2 Need for the Study

Difficulty in spectral resolution coding may result in poor speech perception in noise abilities as discussed above (Ankmnal, Veeranna, Allan, Macpherson & Allen, 2019). Spectral resolution is based on the complex processes and requires coding of signal across frequency channel. Evidences show that children with CAPD have trouble in coding the basic structure of acoustic signal that give rise to many behavioral deficits including hearing in background noise (Allan, 2011; Raben, 2018). Thus, it is necessary to evaluate spectral resolution and speech perception in noise in children with CAPD and children with normal auditory processing skills. In the present study, spectral resolution was assessed through ripple noise discrimination (RND) and frequency difference limen (FDL). RND test is a broadband evaluation of spectral resolution and FDL is a narrowband evaluation analysing spectral resolution differently (Goldsworthy, 2015).

1.3. Aim of the Study

The present study aimed to investigate the relationship between spectral resolution and speech perception in noise in children with CAPD and children with normal auditory processing.

1.4 Objectives of the Study

1. To compare spectral resolution using RND in children with CAPD and children with normal auditory processing.

2. To compare spectral resolution using FDL in children with CAPD and children with normal auditory processing.

3. To compare SPIN in children with CAPD and children with normal auditory processing.

4. To correlate between spectral resolution abilities and SPIN in children with normal auditory processing.

1.5 Hypotheses

A null hypothesis was assumed for the present study showing

1. There would be no significant difference in spectral resolution assessed through ripple noise discrimination between children with CAPD and children with normal auditory processing.

2. There would be no significant difference in spectral resolution assessed through frequency discrimination between children with CAPD and children with normal auditory processing.

3. There would be no significant difference in speech perception in noise abilities between children with CAPD and children with normal auditory processing.

4. There would be no significant correlation between spectral resolution abilities and speech perception in noise in children with normal auditory processing.

Chapter 2

Review of Literature

Auditory processing is a complex phenomenon which involves central to auditory periphery that requires the release of nerve impulses to the auditory stations such as cochlear nuclei, thalamus and auditory cortex which contributes in auditory discrimination, temporal processing, auditory recognition, auditory performance with competing acoustic signals and/or in unfavorable acoustic situations and, sound localization and lateralization. "Central Auditory Processing Disorder (CAPD) refers to deficits in the neural processing of auditory information in the CANS not due to higher order language or cognition, as demonstrated by poor performance in one or more of the skills listed above" (ASHA, 2005).

CAPD individuals have delayed listening skills which are essential for successful listening. The clinical presentation of CAPD involve many behavioral symptoms such as difficulty following instructions, difficulty localizing sounds, difficulty listening in degraded condition, requires repetition, difficulty following rapid speech. It results in limitation in auditory activities.

CAPD assessment involve test battery to identify lesion and to define the functional auditory deficits in central auditory nervous system. Routine audiological evaluation should be done prior to the assessment of central auditory processes (Chermak & Musiek, 1997). Behavioral central tests that are used to assess central auditory processing abilities include:

1. Dichotic tests
2. Temporal processing tests
3. Binaural interaction tests
4. Monoaural low redundancy speech tests

2.1 Dichotic tests

Dichotic speech tests evaluate binaural integration and binaural separation using different tasks. Binaural integration is the capability to join in and interpret different auditory stimulus presented to each ear and binaural separation is directing attention to target stimuli presented in dichotic paradigm. The tests commonly used are dichotic digit, dichotic consonant-vowels, dichotic sentence identification (DSI), and staggered spondaic word (SSW) test which assesses binaural integration (Bellis, 1996; Museik & Pinheiro, 1985) and the competing sentences test and synthetic sentence identification with contralateral competing message (Museik & Pinheiro, 1985), are used to assess binaural separation.

2.2 Temporal processing tests

Temporal processing tests are used to evaluate the capability to analyze acoustic events over time. Gap detection test (GDT) and gap in noise test (GIN) are the common tests used to assess temporal resolution. Pitch pattern test (PPT) and duration pattern test (DPT) are used for assessing temporal patterning and forward and backward masking is used for assessing temporal masking.

2.3 Binaural interaction tests

Binaural interaction tests helps to assess the ability to process complementary information or disparate information presented to both ears. Tests used to assess binaural interaction are masking level difference (MLD), inter-aural timing task (Levine et al., 1993) rapid alternating speech perception (RASP) (Willeford, 1977) and binaural fusion test (BFT) (Matzker, 1959).

2.4 Monoaural low redundancy speech tests

The ability to recognize the degraded speech stimuli presented to one ear can be assessed through various measures. The speech stimuli can be degraded through variety of strategies such as time compressing the speech signals, filtering selected frequencies and entrenching speech background noise and in verbal competition. Tests that are commonly used are speech-in-noise test, the synthetic sentence identification with ipsilateral competing message (SSI-ICM) (Jerger & Jerger 1974), low pass filtered speech test (Rintelmann, 1985), and paediatric speech intelligibility test (Jerger, Jerger & Abrams, 1983), and the compressed speech with reverberation test (Borstein &Museik, 1992).

In individuals with CAPD, speech perception in noise (SPIN) is greatest challenge. Lagace (2010) illustrated psychometric functions of SPIN test based on the hypothetical APD group, intending to found the underlying source of speech perception in noise problems in same group. They concluded that in CAPD population, SPIN-like tests conceivably be utilized to assess difficulties with perceiving speech in noise and nature of deficit underlying it.

Keith (1999) reported that basic difficulty in individuals with CAPD is that any speech signal presented in the conditions that are less than optimal is difficult to understand. Similarly, Chermak (2002) characterized individuals with CAPD as having trouble perceiving spoken language in the presence of competing signal or in noisy backgrounds and in reverberating conditions. Bamiou et al., (2001) in their review article regarding causes and clinical features of auditory processing disorders, reported that difficulty understanding speech was one of the frequently encountered symptoms in children having CAPD.

Vanniasegaram (2004) compared the performance of normal-hearing school-going children suspected with CAPD to that of normal-hearing control children. The auditory test battery consisted of a Tallal discrimination task, a dichotic test of competing sentences, simultaneous and backward masking and a consonant clusters minimal pairs (CCMP) in noise test, in which subjects had to identify the minimal pairs as same or different presented in three different manner. One minimal pair with the initial consonant differing between pairs in term of place, manner or voicing, two minimal pair in which one word was obtained from the other by omitting a particular consonant from and consonant cluster at initial position and four minimal sets or pairs that included words differing in a particular consonant of a s-cluster at initial position. These test items were presented binaurally at 60 dBSPL with speech spectrum noise presented simultaneously in background taking -2.3 dB as signal-to-noise ratio. From these four tests CCMP had highest ecological validity for suspected group, reflecting the common symptom of the children in APD suspected group of difficulty understanding speech in noisy background.

Thus, the above studies suggest that perception of speech in difficult listening situation is one of the majorly found problem in these individual.

2.4.1 Speech perception in noise

A speech signal is a complex broadband signal comprised of multiple frequencies. Apoux, Yoho, Youngdahl & Healy (2013) studied the importance of temporal fine structure and envelope cues in recognizing sentences presented in noise. They used stimuli in which target (350 sentences) was combined at five distinct SNRs with masker (speech spectrum noise and randomly selected speech sentences) and filtered within 30 conterminous frequency bands. Hilbert decomposition was used in each band to obtain envelope and temporal fine structure data. Final stimuli included envelope and temporal fine structure of the target/masker sound mixture at different signal-to-noise ratios as x dB SNR and y dB SNR, respectively. They reasoned that envelope is primary to get speech information while detecting impressions of target is aided by temporal fine structure cues.

2.4.2 Speech perception in noise and spectral resolution

Allen and Wightman (1992) investigated discrimination of spectral pattern in children aged 4-9 years in forced choice paradigm with adults taken as controls. They did three experiments using a stimuli that differed in their amplitude spectra. In experiment 1, they used a flat-spectrum noise and a patterned spectrum and then determined the efficacy of listeners to distinguish within them. In experiment 2, they estimated the spectral ripple discrimination threshold of two sinusoidal rippled amplitude spectra in terms of minimum spectral contrast in dB needed to discriminate and its association with frequency resolving power. Discriminability between spectrally similar isolated speech sounds was assessed in experiment 3. The discriminability of the sounds was estimated in two conditions as in quiet and in background of wide-band noise. They found that there was a substantial age effect. They also revealed that the adult control outperformed younger children group significantly on both classes of speech sounds. The ability to perceive shape of spectra could be exhibited by a listener's ability to distinguish between variations in sounds that are spectrally alike as in speech. The authors concluded that spectral shape also aids in speech recognition.

Henry, Turner and Behrens (2005) conducted a study on three groups of participants including normal hearing, hard of hearing, and cochlear implant listeners with the aim to assess spectral peak resolution and also the correlation with vowel and consonant recognition in quite condition across the groups. Consonant recognition was assessed in /aCa/ context in 16 alternative identification paradigm and a 12-alternative identification procedure in /hVd/ context was utilized for vowel recognition in closed-set manner. Stimuli used were 100–5000 Hz bandwidth rippled noise with 30 dB peak-to-trough ratio. Spectral envelope frequency of ripple stimuli varied in range of 0.125 to 11.314 RPO (ripples per octave) in 14 steps. Stimuli was filter shaped with a long-term speech spectrum with the duration of stimuli as 500 ms with 150 ms rise/fall. For the standard (reference) envelope phase was zero and reverse phase for test stimuli. Subjects had to discriminate between two ripple noise having peaks and valleys interchanged in frequency positions. Spectral peak resolution threshold was evaluated based on minimum ripple spacing that facilitates detection of reversals in peaks and trough positions. Results showed that spectral peak resolution threshold was least in normal hearing individuals, intermediate in hard of hearing individuals and most in cochlear implant listener. They concluded that speech recognition ability was positively significantly correlated with spectral peak resolution ability.

Goldsworthy, (2015) studied the correlation between phoneme perception and pitch perception in cochlear implant users and normal hearing individuals. Consonant and vowel stimuli was used to assess phoneme identification in four different conditions in quiet, in stationary speech-shaped noise (SSN), in spectrally notched SSN, and in temporally gated SSN. A three-interval, 3AFC paradigm was used to measure pitch discrimination threshold for pure tones of standard frequencies of 500, 1000, and 2000 Hz and complex tones of standard F0s of 110, 220, and 440 Hz, under four different conditions amplitude and frequency roving. Results showed that phoneme identification correlated higher with pitch perception measures having amplitude and frequency roving. Phoneme identification correlation was higher with complex tone discrimination than for pure tone discrimination ability. In background of temporally gated SSN measures of complex tone discrimination strongly correlated with phoneme identification. In the background of spectrally notched noise, pure tone pitch discrimination was significantly correlated with phoneme identification and same is non-significantly correlated in background of stationary and temporally gated speech shaped noise. So, along with speech sounds, a rippled stimuli which is acoustically controlled non-speech stimuli, complex broadband acoustic signal, could be accustomed for assessing the listener's perception of spectral shape. The authors also stated that RND test can be used as a broadband estimate of spectral resolution and FDL as a narrowband evaluation examining spectral resolution differently.

2.5 Spectral resolution in children with CAPD

Allan (2011) studied the signal encoding capabilities of school-going children suspected of CAPD applying an adaptive procedure with a three alternative force- choice paradigm with feedback combined. Frequency resolution, frequency discrimination, intensity discrimination, temporal resolution and temporal integration was assessed in CAPD and non-CAPD group. It was found that few participants in the CAPD group experienced difficulty encoding acoustic features of signal accurately and efficiently. Variation in performance was observed across signal coding tasks on group and individual basis, but most of the participants exhibited difficulties in temporal and spectral encoding.

Ankmnal, Veeranna, Allan, Macpherson and Allen, (2019) studied the maturational effect of spectral ripple discrimination and also compared the discrimination ability of children with CAPD with the control normal group. The subjects' included,14 adults, 15 children with CAPD and, 17 typically developing children. Around 200 sinusoids with frequencies separated mid to 100 and 6400Hz (six octaves) logarithmically were combined to form a ripple spectra with peak –to- trough depth at 30 dB. The standard stimuli had a modulation phase of 0 radians whereas the target stimuli was inverted with phase kept at π/2 radian. Ripple density was varied between 0.125 to 10 ripples per octave, with duration of stimuli as 500 ms, presented at 60 dBSPL. Subjects had to distinguish between target and standard stimuli with increment in ripple density, varied using 1-up-2 down procedure using 1.41 as ratio for increase and decrease for each reversal in two-alternative three interval forced-choice paradigm. Spectral ripple discrimination (SRD) threshold was obtained at the uppermost ripple density at which distinction is made between inverted and standard ripple stimuli with fixed modulation depth. Results revealed that adults have better SRD compared to typically developing children. A maturational trend was seen in typically developing children as well as in children with CAPD. They also stated that SRD maturation lags behind in CAPD as relative to typically developing children. The authors concluded some of the listening challenges encountered in children with CAPD might be explained by poor spectral ripple discrimination

Thus, it is necessary to evaluate spectral resolution and speech perception in noise in children with CAPD and children with normal auditory processing.

Chapter 3

Methods

The aim of the present study was to investigate the relationship between spectral resolution and speech perception in noise in children with CAPD and children with normal auditory processing.

3.1 Research Design

A between-subject design to compare Ripple noise discrimination (RND), frequency difference limen (FDL) and speech identification in noise in Kannada (SPIN-K) between clinical group and control group was used. Further a within-subject design to determine relationship between spectral resolution and speech perception in noise in control group was used in this study.

3.2 Participants

A total of 20 participants within the age range of 7 to 14 years participated in the present study. Participants were divided into two groups with clinical group having five children with the mean age of 11.8 years who were clinically diagnosed as CAPD with auditory closure deficit. The control group included 15 children with normal auditory processing skills with the mean age of 10.4 years. Control group participants passed 'Screening Checklist for Auditory Processing' (SCAP) developed by Yathiraj and Mascarenhas (2002, 2004). The participants in the study fulfilled the below-mentioned criteria:

3.2.1 Participant inclusion criteria

Participants of both the groups fulfilled the following criteria:

- Hearing thresholds within normal limits that is air conduction thresholds in the frequency range of 250 to 8000 Hz, and bone conduction thresholds in the frequency range of 250 to 4000Hz were within or equal to 15 dBHL and the air-bone gap was lesser than 10dBHL at all the frequencies bilaterally.

- Normal functioning of middle ear as indicated by'A' type tympanogram and ipsilateral and contralateral acoustic reflexes present for both ears.
- All the participants were native Kannada speakers.
- Speech identification scores in quiet greater than 80% assessed using Phonetically Balanced word list in Kannada.

3.2.2 Participant exclusion criteria

A detailed case history was obtained from all participants. Participants having any history of otological, speech and language problem, developmental delay and associated deficits were excluded from the study.

3.3 Test environment

All the testing was administered in a sound shielded room with noise levels within permissible noise limits (ANSI S3.1: 1999)

3.4 Instrumentation

The following instrument were used in the study:

- A calibrated diagnostic audiometer, two channel Inventis piano with Sennheiser HDA 200 circumaural headphones with MX 141 adapter and B-71 bone vibrator was utilized for routine audiological evaluation
- A calibrated Immittance meter, GSI Tympstar (version 2) was used to do tympanometry. The same equipment was used to assess middle ear reflexes.

- Screening Checklist for Auditory Processing (SCAP) was administered for inclusion of the participants in the control group.
- A personal laptop (HP notebook) of windows 7 configuration installed with MATLAB version 7.10 was used for the study. Maximum Likelihood Procedure (MLP) toolbox uploaded in the laptop was used to assess ripple noise discrimination (RND) and frequency difference limen (FDL). The stimulus was routed through the audiometer connected via auxiliary input.
- The same laptop was used to present speech identification in noise in Kannada (SPIN-K) (Vaidyanath & Yathiraj, 2012) which includes 4 list of bisyllabic word taken from 'phonetically balanced word identification test in Kannada' and 8-speaker speech babble served as noise stimuli was played through CD routed through audiometer connected via auxiliary input.

3.5 Procedure

Written informed consent was taken from parents/guardians of participants in the study before test administration.

3.5.1 Routine audiological evaluation

Routine audiological evaluation included puretone audiometry and immittance evaluation. Air conduction thresholds and bone conduction thresholds were evaluated using modified Hughson and Westlake procedure (Carhart & Jerger, 1959) at each octave from 250 Hz to 8000 Hz and 250 Hz to 4000Hz, respectively. Pure tone average of air conduction thresholds at 500Hz, 1000Hz, 2000Hz and 4000Hz was obtained. Speech identification in quite was assessed at 40dBSL with reference to SRT. Immittance evaluation was done to check middle ear functioning on all the participants having threshold within 15dBHL.

3.5.2 CAPD Screening

SCAP (Yathiraj & Mascarenhas, 2002, 2004) was carried out for inclusion of control group participants. SCAP is a screening questionnaire, consisting of 12 questions. Each question is scored on a 2 point rating scale as 'Yes' or 'No'. For every answer scored as yes a score of 'one' was given and each answer scored as no a score of 'zero' was given. Based on this questionnaire children who scored below 50% were taken as participants for control group. For clinical group, participants were already diagnosed as CAPD were included. The diagnosis was made based on the detailed diagnostic audiological tests as dichotic digit test (DDT), duration pattern test (DPT), speech in noise test (SPIN), and binaural masking level difference (BMLD). Children diagnosed with CAPD with auditory closure deficit were included in the clinical group.

3.5.3 Assessment of Spectral Resolution abilities

Spectral resolution abilities were assessed using ripple noise discrimination and frequency difference limen. The Maximum Likelihood Procedure (MLP) was used for administering tests. The MLP makes use of the large number of participant's psychometric function which gives the highest likelihood of the stimulus to be presented in the next trial. In each trial, it estimates the likelihood of arriving at the participant's response for all the presented stimuli. The 44,100 Hz sampling rate was used to generate the stimulus in MLP. A total of 30 blocks were completed for each ear at 40dB SL. Both RND and FDL was measured using three interval forced choice method.

Ripple Noise Discrimination: The RND was assessed using ripple as stimuli, a complex signal with its spectral domain consisting of regular peaks and troughs. Rippled stimuli was made using a 500 ms duration Gaussian noise, low pass filtered at 3000 Hz and then added to itself at a delay of 5 ms that generated sinusoidal ripples. The standard noise was a 500 ms broadband noise with uniform power spectrum, having band pass filtering as that of the rippled noise. A variable amount attenuated the delayed noise in units of dB. The attenuation of delayed noise had starting level of 30 dB with first midpoint and last midpoint at-30dB and 0 dB, respectively. The standard and delayed stimuli were equalized to RMS power. All the participants were instructed that "you will be hearing three noises among which one will be slightly different than the other two. Your task is to identify which is the odd noise among three". At the end of test ripple noise discrimination threshold was recorded manually.

Frequency Difference Limen: The FDL was evaluated using a pure tone of 1000 Hz, with 250ms duration and to prevent spectral splatter gated offset and onset 10ms raised cosine ramps was applied. The starting level of presentation was set at 1100.1 Hz (Δf = 100.1 Hz) with the first midpoint at 1000.1 Hz and last midpoint at 1100.1 Hz. The instructions given were "you will be hearing three tones, among which one will have a slightly higher pitch than the other two. Your task is to identify which among the three tones is having the highest pitch". The absolute difference limen for frequency was recorded manually.

3.5.4 Assessment of Speech Perception in Noise

The SPIN test was administered using the CD version of speech identification in noise in Kannada (SPIN-K) (Vaidyanath &Yathiraj, 2012) loaded into the personal laptop at 0 dB SNR. The output from the laptop was routed through the audiometer followed by headphone at 40dB SL. 25 words list was presented to participants in both ears and verbal response was obtained. Scoring for every correct response was marked as one and for every incorrect response as zero.

3.6 Statistical Analyses

Data from both the groups were compiled, tabulated and then statistically analyzed using Statistical Package for social Sciences (SPSS V.20). Descriptive statistics was used to obtain the mean and standard deviation for each of the tests for both the groups. Shapiro Wilks tests of normality was used for assessing normality of data and Spearman’s Rank correlation was done for within group comparison for assessing correlation.

Chapter 4

Results

The current study aimed to study the relationship between spectral resolution and speech perception in noise in children with CAPD and children with normal auditory processing. A total of 5 children diagnosed with CAPD and 15 children with normal auditory processing skills in the age range of 7 to 14 years participated in the study. The tests used to assess spectral resolution were ripple noise discrimination (RND) and frequency difference limen (FDL) and speech perception abilities was assessed using speech identification in noise in Kannada (SPIN-K) (Vaidyanath &Yathiraj, 2012). Table 4.1 shows the scores of RND, FDL and SPIN-K of 5 children with CAPD. Table 4. 2. shows mean and standard deviation (SD) values for the various tests across both the groups.

Table 4.1

Individual Scores of RND, FDL and SPIN-K in children with CAPD

	Ear	**S1**	**S2**	**S3**	**S4**	**S5**
RND (dB)	Right ear	0.75	0.75	0.75	0.75	0.75
	Left ear	0.75	0.75	0.75	0.75	0.75
FDL (Hz)	Right ear	38.33	79.88	91.88	96.66	50.17
	Left ear	77	83	76.85	91.11	41.11
SPIN-K (number of words)	Right ear	11	14	12	14	17
	Left ear	12	10	11	15	15

Note: RND-Ripple noise discrimination, FDL- Frequency difference limen, SPIN-K- Speech lentification in noise in Kannada (SPIN-K)

Table 4.2

Mean and SD of RND, FDL and SPIN in clinical and control group

	Ear	Clinical group (N=5)		Control group (N=15)	
		Mean	**SD**	**Mean**	**SD**
RND (dB)	Right ear	0.75	0	-0.55	5.034
	Left ear	0.75	0	-1.61	6.265
FDL (Hz)	Right ear	71.38	25.85	68.92	22.47
	Left ear	73.81	19.19	68.15	23.81
SPIN-K (number of words)	Right ear	14	2.30	18.53	1.73
	Left ear	13	2.30	18.33	1.91

Note: RND-Ripple noise discrimination, FDL- Frequency difference limen, SPIN-K- Speech 'entification in noise in Kannada (SPIN-K)

4.1 Ripple noise discrimination in children with CAPD and children with normal auditory processing.

The data for the clinical group shows that all the five subjects obtained RND threshold of 0.75 dB (Table 4.1). This indicates that there was a floor effect seen in this group. For the control group, the RND threshold for right ear ranged from -18.75 dB to 0.75 dB. The mean RND threshold for the right ear is -0.55 dB with a SD of 5.034 dB. For left ear, threshold ranged from -18.75 dB to 0.75 dB, with mean RND threshold of -1.61 dB and SD of 6.265dB.

The statistical analysis was not done to compare the RND between the two groups as the number of participants in the clinical group was less. However, from Table 4.2 it can be noted that the mean RND threshold was better in the control group compared to the clinical group for both ears.

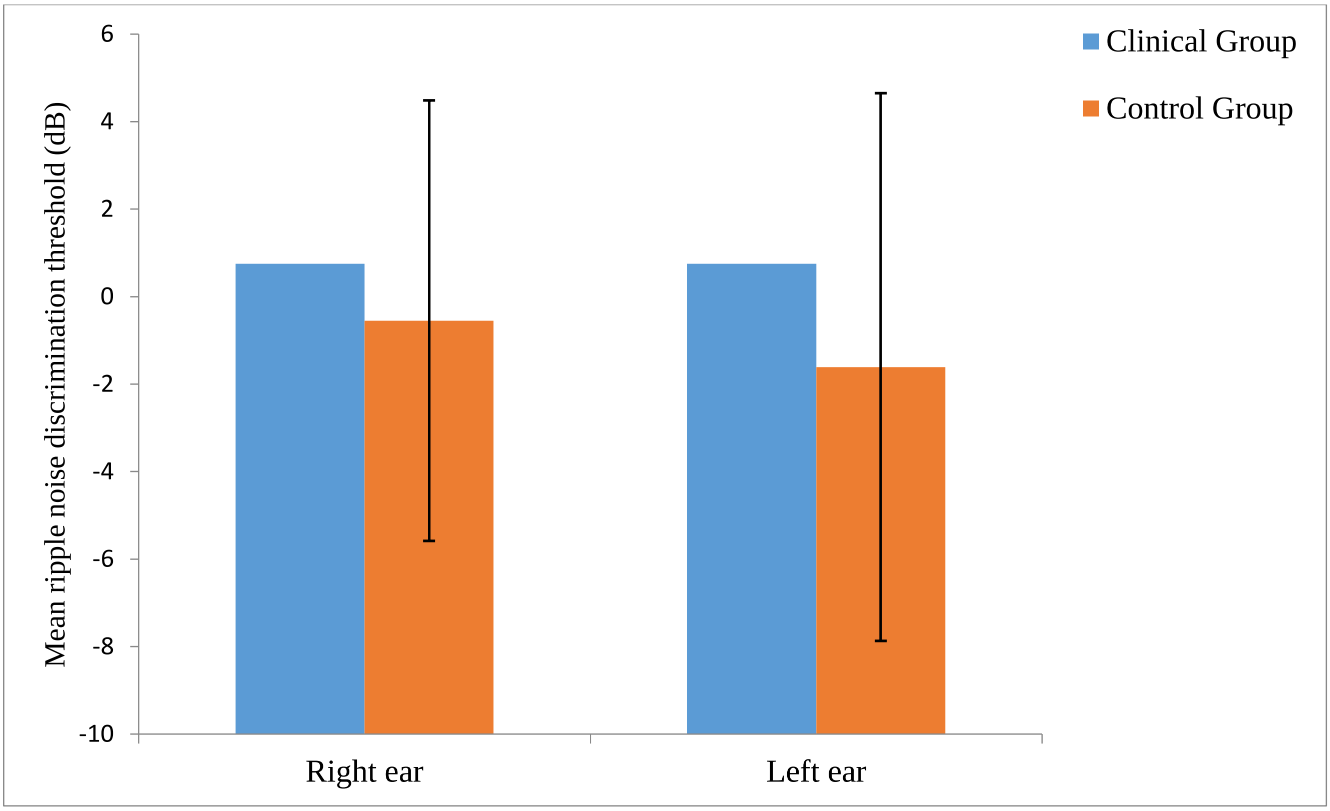

Figure 4.1: Bar diagram representing mean and SD of RND threshold of clinical group and control group in both ears.

4.2 Frequency difference limen in children with CAPD and children with normal auditory processing.

The data for the clinical group shows that for all the five subjects obtained FDL ranging from 38.33 Hz to 96.66 Hz for the right ear. The average FDL for the right ear is 71.38 Hz with a SD of 25.85 Hz. For left ear obtained FDL ranged from 41.11 Hz to 91.11 Hz and the average FDL is 73.81 Hz with a SD of 19.82 Hz. For the control group, the FDL for right ear ranged from 35.12Hz to 101.93 Hz with the average FDL of 68.92 Hz and a SD of 22.47 Hz. For left ear FDL ranged from 16.38 Hz to 100.85 Hz, with average FDL of 68.15 Hz and a SD of 23.81 Hz.

The statistical analysis was not done to compare the FDL between the two groups as the number of participnats in the clinical group was less. However, from Table 4.2, it can be noted that mean FDL was better in the control group compared to the clinical group for both ears.

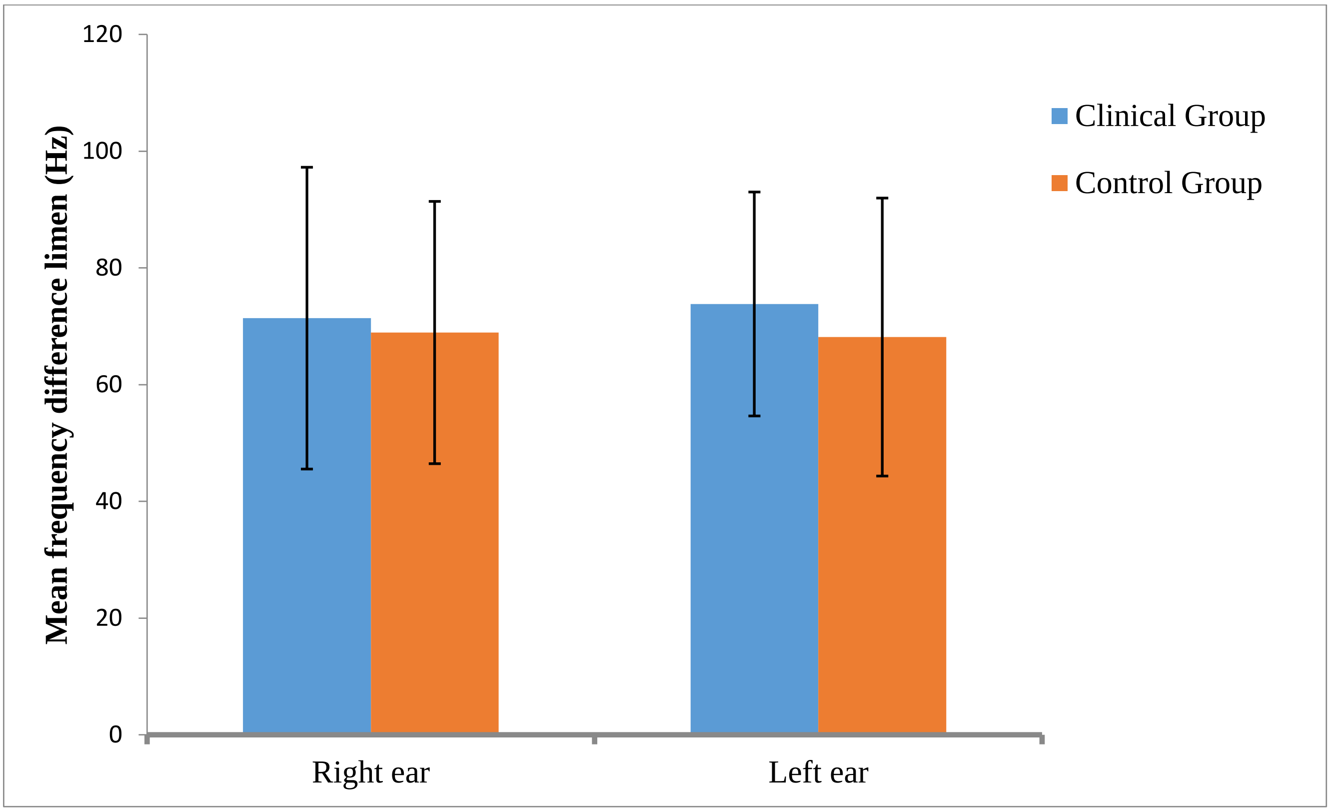

Figure 4.2: Bar diagram representing mean and SD of FDL of clinical group and control group in both ears

4.3 Speech perception in Noise in children with CAPD and children with normal auditory processing.

The data for the clinical group shows that for all the five subjects obtained SPIN-K scores ranging from 11 to 17 for the right ear. The average SPIN-K scores for the right ear is 14 with a SD of 2.30. For left ear SPIN-K scores ranged from 10 to 15 with the average SPIN-K score of 13and SD of 2.30.

For the control group the SPIN-K scores for right ear ranged from 16 to 23. The average SPIN-K scores for the right ear is 1.73with SD of 1.914. For left ear, SPIN-K scores ranged from 16 to 21, with average SPIN-K scores of 18.53 and SD of 1.91.

The statistical analysis was not done to compare the SPIN-K scores between the two groups as the number of participants in the clinical group was less. However, from Table 4.2, it can be noted that the mean SPIN-K score was better in the control group compared to the clinical group for both ears.

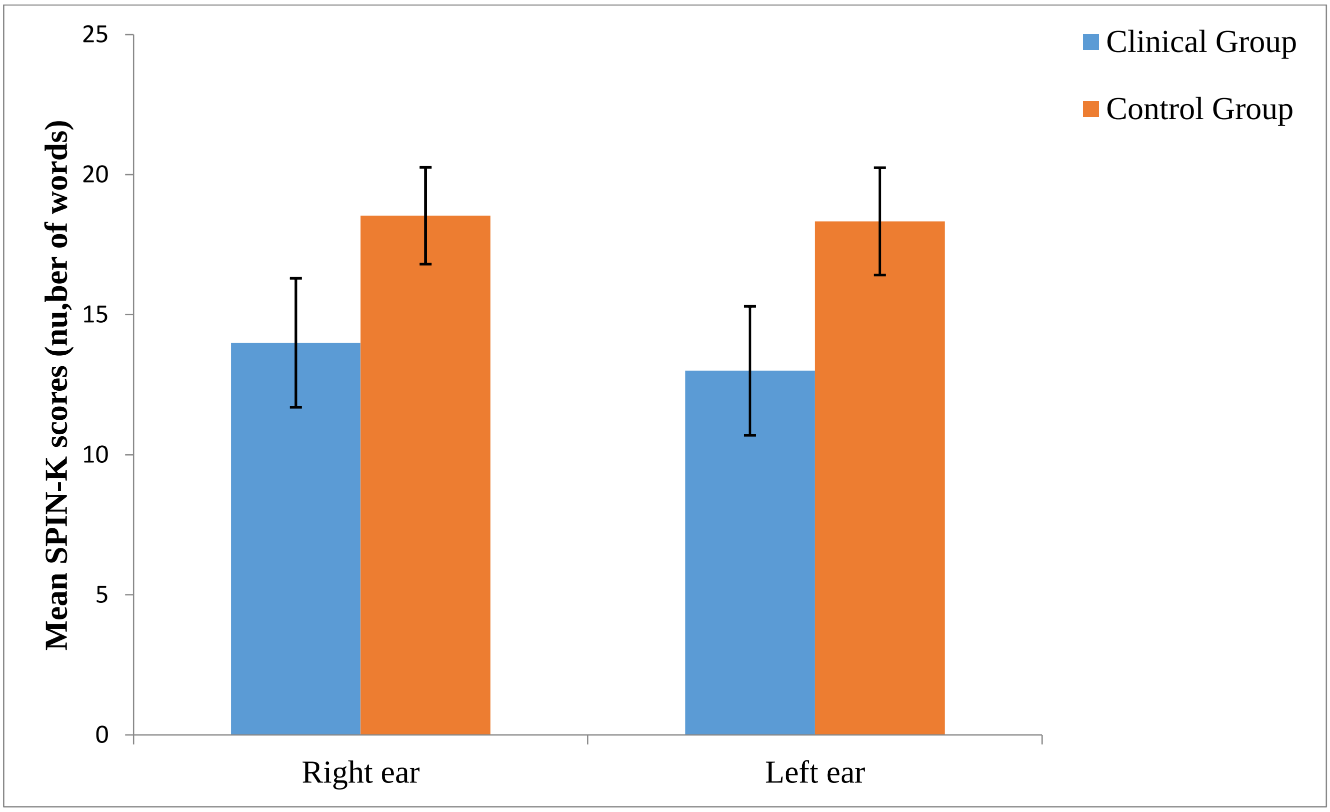

Figure 4.3: Bar diagram representing mean and SD of SPIN-K scores of clinical group and control group in both ears

4.4 Correlation between spectral resolution and speech perception in noise in children with normal auditory processing.

The data in the control group was subjected to normality test using Shapiro- Wilk test to check for correlation between spectra resolution and speech perception in noise in children with normal auditory processing. The analysis revealed that few of the test parameters such as RND threshold for both ears did not fulfil the assumptions of normality ($p<0.05$). Hence the non-parametric test was used for inferential statistics. Spearman rank correlation test was used to check if there is any correlation between spectral resolution assessed through RND and FDL with speech perception in noise in children with normal auditory processing for both ears.

Results showed that there was no significant correlation between spectral resolution and speech perception in noise in children with normal auditory processing. Table 4.3 shows the Spearman rank correlation (ρ value) and significance (p value) values of spectral resolution and speech perception in noise for the right ear and the left ear, respectively.

Table 4.3

The correlation and significance values of RND, FDL scores with SPIN-K scores for right ear and left ear

Spectral resolution measures		Speech perception in noise	
		ρ value	p value
RND threshold (dB)	Right ear	.096	.735
	Left ear	-.098	.728
FDL (Hz)	Right ear	-.385	.157
	Left ear	-.293	.289

Chapter 5
Discussion

The aim of the present study was to investigate the relationship between spectral resolution and speech perception in noise in children with CAPD and children with normal auditory processing. The results of the study are discussed below:

5.1 Spectral resolution in children with CAPD and children with normal auditory processing

The present study assessed spectral resolution through ripple noise discrimination (RND) and frequency difference limen (FDL). As the number of participants were less in clinical group, analysis was not done to compare spectral resolution between two groups. However, on observation mean RND threshold and mean FDL was better in control group compared to clinical group for both ears.

5.1.1 Ripple noise discrimination in children with CAPD and children with normal auditory processing

In the present study, data revealed that mean RND threshold was better in control group as compared to clinical group. These findings are consistent with results of study by Ankmnal, Veeranna, Allan, Macpherson and Allen, (2019), which stated that spectral ripple discrimination threshold was better in children with normal auditory processing skills as compared to children with CAPD, but not significantly. In this study, variation was found for control group but not for clinical group, which can be attributed to less number of participants in the clinical group.

Not many studies have been done in assessing ripple noise discrimination in children with CAPD. But, development of ripple noise discrimination has been assessed in typically developing children or compared across normal, hearing impaired listeners and cochlear implant users.

5.1.2 Frequency difference limen in children with CAPD and children with normal auditory processing

Data reveals that mean FDL was better in control group as compared to clinical group for both ears. Similar findings are reported in the literature (Allan, 2011) where they found that frequency discrimination threshold were significantly poor and with greater variability in group of children diagnosed as CAPD as compared to children not diagnosed as CAPD. Similarly Rota-Donahueet al (2016) reported that typically developing children have better frequency discrimination than clinical groups (APD only, specific language impairment (SLI) only, both APD and SLI). Thus, it can be understood that children with CAPD experience greater difficulties in encoding signal frequency as compared to typically developing children. Also, frequency discrimination difficulties has been found in children with SLI and in children having difficulty in prosody recognition abilities, these two areas can be found as co-morbid condition to CAPD.

5.2 Speech perception in noise in children with CAPD and children with normal auditory processing

Speech identification in noise in Kannada (SPIN-K) (Vaidyanath &Yathiraj, 2012) was used to assess speech perception in noise abilities. As stated above, analysis was not done to compare the ability as number of participants in clinical group were less. On observation, data reveals better mean SPIN scores in control group as compared to clinical group.

Similar results were reported by Lagace (2011), they used four sentence lists given combined with a babble masker at four distinct signal-to-noise ratios, they found that children in control group performed better than CAPD group in terms of ability to recognise key words in sentences presented. In contrast to this study Nishi et al., (2019) reported no difference between children who failed CAPD screening and typically developing peers for speech in perception abilities assessed through SNR-70.

5.3 Correlation between spectral resolution and speech perception in noise in children with normal auditory processing.

In the present study, spectral resolution abilities were assessed through FDL and RND. The findings revealed that there was no significant correlation between spectral resolution and speech perception in noise in children with normal auditory processing.Contrasting results have been found in literature as Allen and Wightman, (1992) found that individuals having lower ripple- depth discrimination threshold found to have higher accuracy in discriminating speech sound in quiet and noisy conditions.Henry, Turner and Behrens (2005) found in their study that spectral peak resolution correlated significantly with vowel as well as consonant recognition in quite condition in normal hearing individuals, as well as in hard of hearing individuals and individuals using cochlear implant.

Similarly, Goldsworthy, (2015) found that pure tone frequency discrimination significantly correlated with phoneme identification in spectrally notched noise and non - significantly correlated with stationary and temporally gated speech shaped noise. In the present study, significant correlation was not found, which could be attributed to the less number of participants used for the study. Also as all the participants performed well, it is difficult to find a correlation. The correlation could not be done in CAPD group because of less number of participants.

Chapter 6

Summary and Conclusion

Spectral resolution is a complex phenomenon based on coding signals across frequency channels, and difficulty in spectral resolution coding may affect speech perception in noise abilities. Difficulty in listening to speech in the noisy background is one of the significant behavioral deficits in children with central auditory processing disorder (CAPD). The present study aimed to investigate the relationship between spectral resolution and speech in noise perception in children with CAPD and in children with normal auditory processing. The main objectives of the study were to compare spectral resolution through ripple noise discrimination (RND), frequency difference limen (FDL) and speech perception in noise (SPIN-K) in children with CAPD and children with normal auditory processing and to correlate between spectral resolution and speech perception in noise in children with normal auditory processing. A total of 20 children participated in the study. Control group comprised of 15 typically developing children, and the clinical group included five children diagnosed as CAPD with auditory closure deficit. Children in the control group were selected if they pass the Screening Checklist for Auditory Processing. RND, FDL and SPIN-K were assessed on each participant.

Results showed the following,

- On observation, mean RND threshold, mean FDL and mean SPIN-K scores were better in control group as compared to clinical group for both the ears.
- There was no significant correlation between spectral resolution and speech perception in noise in children with normal auditory processing.

6.1 Implications of the study

- The study helps us to understand that spectral resolution and speech perception in noise of children with CAPD lag behind children with normal auditory processing.
- The spectral resolution can be assessed clinically for the diagnosis of children suspected with CAPD with auditory closure deficits and if failed can be added in rehabilitation also.

6.2 Limitation of the study

Number of participants included in the clinical group was less as compared to control group. Thus, analysis could not be done to compare the abilities between two groups and to establish correlation between both abilities in clinical group.

6.3 Future direction

- Similar study can be conducted with more number of participants in the clinical group.
- Developmental trend for spectral resolution abilities can be studied in typically developing children and children with CAPD.
- Furthermore, if relationship is established, training on spectral resolution can be added in CAPD rehabilitation for speech perception in noise deficit management.

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