PROJECT REPORT

Auditory Processing in Children with Speech Sound Disorders

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Abstract

Speech sound disorders (SSD) are known to interfere with communication. Auditory processing disorder being one of the major cause of SSD, hinders the phonemic representation in the brain which in turn affects speech perception. The aim of the present study was to investigate the auditory processing abilities and to establish their relationship in children with SSD. Auditory processing abilities and phonological skills were evaluated in two groups of participants in the age range of 6-10 years. Group I included 30 typically developing children and Group II included 20 children with SSD. The assessment for auditory processing included tests for binaural integration (dichotic CV), binaural interaction (masking level difference), auditory closure (speech perception in noise test-Kannada), temporal processing (gap detection and duration pattern test) and working memory (forward and backward digit span). Phonological evaluations were carried out using phonological sensitivity training kit in Kannada (PhoST-K). Results showed that there was a significant difference between both the groups in all tests of auditory processing and phonological skills except for masking level difference. Results also showed a correlation between duration pattern test and syllable oddity, speech perception in noise and segmentation and between working memory and segmentation and phoneme oddity tasks. Thus, it can be concluded from the present study that auditory processing plays an important role in phonological awareness and hence, assessment of central auditory processes in children diagnosed with SSD is recommended.

Index Terms: *Speech sound disorder, auditory processing tests, PhoST-K*

Chapter 1

Introduction

Speech is considered to be the verbal expression of an individual's cognitive content and process, and emotions. Impairment of speech can have a negative influence on social interaction, educational and occupational opportunities and also one's confidence and efficacy. The difficulties in speech that interfere with communication and produce impairment in functioning and distress are diagnosed as "speech sound disorders" (SSD) formerly known as phonological disorders (DSM-5 (Diagnostic and Statistical Manual of Mental Disorders, fifth edition 2013).

Children with SSD may possibly have an input problem characterized by fluctuating conductive hearing loss, a central processing disorder, a problem with speech production/output or even a cognitive linguistic difficulty that manifests as problem in phonological processing at the phonemic level (Broomfield & Dodd, 2004; Dodd & McIntosh, 2008). The causes of SSD include motor-based disorders (apraxia and dysarthria), structurally based disorders and conditions (e.g., cleft palate and other craniofacial anomalies), syndrome (e.g., Down syndrome), condition-related disorders (metabolic conditions, such as galactosemia) and sensory-based conditions (e.g., hearing impairment). One of the major causes of SSD could also be central auditory processing disorder (CAPD) because it hinders the formation of phoneme representation in brain and speech perception.

1.1 Auditory processing abilities in SSD

There have been quite a few studies done to examine the auditory perceptual difficulties in children with SSD. However, only a few studies have investigated the influence of central auditory processing on phonological abilities as well as the relationship between them in this population.

Rvachew and Grawburg (2005) examined the relationships among variables that may cause poor phonological awareness (PA) skills in preschool-aged children with SSD. For this purpose, PA, speech perception, articulation, receptive vocabulary, and emergent literacy skills were assessed in 95 children diagnosed with SSD in the age range of 4-5 years using linear structure equation model. Among these participants 50% of the children had difficulty with speech perception and PA in spite of their receptive language skills being within or above the average range. Results showed that speech perception is a crucial variable that has a direct effect on PA and an indirect effect on PA mediated by vocabulary skills. It was also reported that articulation accuracy did not have a direct effect on PA but emergent literacy skills were predicted by PA abilities. The authors thus concluded that children with SSD are at a greater risk of delayed PA skills if they have poor speech perception and/or poor receptive vocabulary skills.

Muniz, Roazzi, Schochat, Teixeir, and Lucena (2007) assessed the performance of temporal processing ability in children with phonological disorders (experimental) and a control group in the age range of 6-9 years using Random Gap detection test. The duration of the gap varied from 0 ms to 40 ms and was carried out for frequencies 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. The results showed a higher gap detection threshold in children with phonological disorders and the difference between the experimental and control group was statistically significant for each test frequency.

Caumo and Ferreira (2009) evaluated the relationship between auditory processing and phonological deviation of 15 children in the age range of 7-12 years. All the participants exhibited phonological processes related to syllable structure (in addition to sound substitutions) and at least one of the auditory processing being altered. Phonological evaluation and auditory processing evaluation was done using the pediatric speech intelligibility test, dichotic digit test, staggered spondee word test, pitch pattern sequence, and duration pattern sequence test. The results showed that when substitution and syllabic structure processes were compared with the auditory processing tests, a statistically significant correlation was established for the binaural integration for the right ear of the dichotic digit test and the naming condition of the pitch pattern sequence test. This suggests there is a relationship between auditory processing and phonological deviation, mainly in relation to the performance of the right ear.

In another study, Quintas, Attoni, Keske-Soares, and Mezzomo (2010) compared auditory processing performance among two groups of children (5-7 years); one group comprising of participants with deviant speech acquisition while the other was a control group with normal speech acquisition. Phonological awareness was assessed through the Protocol Task Awareness Test (PTAT), and auditory processing evaluation (screening) was done using staggered spondaic word test, dichotic listening test and the binaural fusion test. Results showed that children with deviant speech acquisition performed poorer on tests of auditory processing compared to the control group.

Attoni, Quintas, and Mota (2010) also evaluated auditory processing ability and phoneme discrimination in 22 children with phonological disorders and 24 children who had normally developing speech. Results showed that children with phonological disorders performed poorer in both phoneme discrimination and auditory processing tests compared to the control group.

In a study by Bartz et al. (2014), a relationship between binaural interaction ability assessed via masking-level difference (MLD) and varying degrees of speech intelligibility in children with phonological disorder (5-10 years) was measured. Results showed that there was no statistical difference in MLD between children with phonological disorder and typically developing children.

Hearnshaw, Baker, and Munro (2017) investigated whether children with SSD and typically developing children differ in their speech perception accuracy. They also tried to assess the differences in the perception of specific phonemes and whether there is any association among perception and speech production skills. The tests included routine speech and language evaluations along with experimental Australian-English lexical and phonetic judgment based on Ryachew's Speech Assessment and Interactive Learning System (SAILS) program. The test includes eight words across four word initial phonemes /k, ɹ, ʃ, s/. Results showed that children with SSD had significantly poorer perceptual accuracy on the lexical and phonetic judgment task compared to typically developing children. It was also noted that the perception of phonemes /ɹ/ and /s/ were most frequently affected in both groups. Additionally, the phoneme /ɹ/ was most commonly produced incorrectly. Further, there was a positive correlation seen among overall speech perception and speech production scores in both groups.

Similarly, Sayyahi, Soleymani, Akbari, Bijankhan, and Dolatshahi (2017) studied the relationship between phonetic gap detection threshold and speech error consistency in three groups of children in the age range of 5-6 years – those with typical speech, consistent speech disorders (CSD) and inconsistent speech disorders (ISD). The gap detection was assessed test using six syllables with inter stimulus intervals varying from 20-300 ms. The results showed that children with ISD could not differentiate the sound during limited phonetic discrimination, suggesting that inconsistency in speech is a representation of inconsistency in auditory perception.

Vilela, Barrozo, de Oliveira Pagan-Neves, Sanches, Wertzner, and Carvallo, (2016) analyzed phonological abilities and central auditory processing (CAP) measures in SSD children (7-11 years) with and without CAPD. The phonological assessment included measures of phonology, speech inconsistency, metalinguistics, and motor speech abilities. The CAP assessment included tests to measure auditory closure, binaural integration and temporal ordering. The results showed that children who had both SSD and CAPD showed a higher occurrence of phonological process of cluster reduction and also greater difficulty in PA, particularly rhyme and alliteration. Further, the group with SSD but without CAPD had lower values of percentage of consonants correct revised (PCC-R) and higher values of process density index (PDI). A cut off value for PDI was established indicating that children with an index >0.54 showed a strong tendency toward presenting a CAPD. The authors conducted another study to identify a cutoff value based on the PCC-R that could indicate the possibility of a child with SSD having a CAPD (Vilela et al., 2016). Language, audiological, and CAP evaluations were carried out on 27 children with SSD aged 7;0–10;11 years who were divided into two groups according to their CAP evaluation. The results indicated that the severity of SSD showed a positive correlation with the impaired auditory skills indicating that greater the severity of speech disorders in children higher is the probability of CAPD. It was also reported that the cutoff values of 83.4% in the picture naming task and 84.5% in the imitation of words task can be used as a cut off criteria to distinguish children with CAPD from those without CAPD.

1.2 Need for the Study

From the earlier studies describe above, it is understood that auditory processing abilities are altered in children with SSD. Although there are studies that show the influence of the auditory processing on SSD, only one study (Vilela et al., 2016) till date has tried to achieve a cutoff value in phonological test based on which a decision on the need for detailed auditory processing evaluation could be taken . In this study, it was noted that when CAPD was associated with speech disorder, children had a low score on phonological assessments as well as greater severity of speech disorder was related to more probability of having CAPD. It was observed that children with PCC-R scores below the cut off value had a very high likelihood of having a CAPD. However, all the CAP were not investigated in this population and which auditory process is more affected in these children remained unclear. The possible explanation for this could be due to the differences in the age of diagnosis of the two conditions. While the diagnosis of speech difficulty is usually done below the age of 6 years, CAPD assessment is mainly carried out after 7 years of age. In addition, there is scanty literature in this regard in the Indian population.

1.3 Aim of the Study

The aim of the present study was to investigate the relationship between auditory processing abilities and phonological abilities in children with SSD.

1.4 Objectives of the Study

1. To compare the auditory processing abilities in children with SSD and typically developing children.
2. To compare the phonological abilities in children with SSD and typically developing children.
3. To establish a relationship between auditory processing and phonological abilities in children with SSD.

Chapter 2

Methods

The aim of the present study was to evaluate the relationship between auditory processing abilities and phonological abilities in children with speech sound disorder (SSD).

2.1 Research Design

The research design utilized for this study was a standard group comparison.

2.2 Participants

Two groups of participants in the age range of 6-10 years were selected for the study. Group I included thirty typically developing children (TD) (Mean age=8.5 years), and Group II included twenty participants diagnosed with SSD (Mean age=7.035 years).

Participant Selection criteria

The inclusion criteria for both groups of participants were as follows:

- All the participants were native speakers of Kannada and from the city of Mysuru.
- All the participants were studying in school with English as their medium of instruction.
- All the participants had bilateral normal hearing sensitivity which is pure tone average thresholds of less than 15 dBHL in the octave frequency ranging from

250 Hz to 8000 Hz for air conduction and 250 Hz to 4000 Hz for bone conduction.

- All the participants had speech recognition threshold of +/- 12 dB relative to pure tone thresholds and normal middle ear functioning with ‘A’ type Tympanogram as depicted through immittance audiometry.
- None of the participants reported of any physical illness during the testing.

Selection criteria for the control group

Inclusion criteria

- The participants had age adequate language skills as assessed using Linguistic Profile test (Karanth, 1980) and also age adequate articulatory abilities assessed on the basis of Kannada Diagnostic Photo articulation test (Deepa & Savithri 2010).

Exclusion Criteria

- Participants with any structural, behavioural, emotional and sensory impairment were excluded. This was screened using the WHO ten question disability screening checklist (cited in Singhi, Kumar, Prabhjot & Kumar 2007)
- Participants with a history of delayed development, sensory issues, behavioural or neurological problems were excluded from the study. This information was collected through an informal interview with the parent/ teacher of the participant.

Selection criteria for the clinical group

Inclusion criteria

- Children diagnosed as SSD in a clinical setup by qualified Speech-Language Pathologists. The language and articulatory abilities of participants with SSD were assessed using Linguistic Profile test (Karanth, 1980) and Kannada Diagnostic Photo articulation test (Deepa & Savithri, 2010) respectively. The diagnosis was also cross verified with the diagnostic criteria for SSD specified by the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) (American Psychiatric Association, 2013).

Exclusion Criteria

- Participants with articulatory errors due to structural deficits (maxillofacial anomalies) or neurological disorders were excluded from the study.
- Participants with co-morbid conditions such as hearing loss, spoken language disorders, Attention Deficit Hyperactivity Disorder and developmental incoordination were also excluded from the study.

2.3 Test environment

All the audiological tests were carried out in a well illuminated acoustically and electrically shielded rooms with ambient noise levels well within the permissible limits (ANSI S3.1, 1991). Phonological tests were carried out in a quiet room in a clinical set up.

2.4 Instrumentation

The following instruments were used for the study.

- A calibrated dual channel audiometer Inventis Piano with TDH-39 headphones and the B-71 bone vibrator was used to determine air and bone conduction thresholds respectively, of the participants. Masking level difference (MLD) to assess binaural interaction was also administered through the audiometer.
- A calibrated immittance meter Grason-Stadler Inc. Tympstar (GSI – Tympstar version 2 middle ear analyzer) was used to rule out middle ear pathology.
- A laptop (HP) installed with MATLAB version 7.10 (Mathworks Inc., 2014) was used to measure gap detection thresholds, and all the other tests of CAPD were routed via Inventis Piano audiometer. The same laptop was loaded with Smriti Shravan software (Kumar & Sandeep, 2013) to assess working memory abilities (forward digit span and backward digit span tests) in the participants

2.5 Test materials

1. Assessment of Central Auditory Processing
    - Auditory closure was assessed using speech perception in noise test in Kannada (SPIN-K) developed by Yathiraj and Vijaylakshmi (2005).
    - Binaural integration was assessed using the Dichotic CV test developed by Gowri andYathiraj (2001).
    - Temporal processing was assessed using gap detection test (GDT) and duration pattern test (DPT). The maximum likelihood procedure

(mlp) tool box implemented in MATLAB version 7.10 (Mathworks Inc., 2014) was used to administer GDT.

- Cognitive training module - Part 1 (Kumar & Sandeep, 2013) presented through the software Smriti Shravan was used to assess the working memory through auditory digit span.

2. Phonological processing was assessed using Phonological sensitivity training kit in Kannada (PhoST-K) developed by Prema (2012).

2.6 Stimuli and Procedure

All the participants were informed about the study, and written consent was taken from the parents of the children. An informal interview was carried out with the parent/teachers before starting the actual test. The participants were assessed individually for all the central auditory processing skills and phonological processing skills. The central auditory processes assessed were auditory closure, binaural interaction and binaural integration, temporal processing and working memory. Phonological processing was assessed using PhoST-K which includes assessment of various phonological skills including rhyming, syllable segmentation, syllable blending, syllable oddity, phoneme oddity, syllable deletion, phoneme deletion, and syllable manipulation.

Assessment of central auditory processing skills

Auditory closure. Auditory closure was assessed through speech perception in noise test in Kannada (SPIN-K) developed by Yathiraj and Vijaylakshmi (2005). The test stimuli consists of phonemically balanced words. The words were presented along with ipsilateral speech noise at 0 dB SNR and participants were asked to repeat the words. Two different lists of twenty-five words were presented to each ear at 40 dBSL (ref: SRT) and percent correct scores were calculated for both the ears.

Binaural integration. Dichotic CV test was performed to assess binaural integration (Gowri &Yathiraj, 2001). The stimuli consists of recorded six syllables /pa/, /t̪a/, /ka/, /ba/, /d̪a/, /ga/ and each syllable was presented five times in a random order to each ear simultaneously making it to a total of 30 presentations. The stimulus was presented at 0 ms lag at 40 dBSL under headphones, and the participants were asked to repeat what they heard in both ears. The single correct scores and double correct scores were calculated. For both the scoring procedure, a score of 'one' was given for the correct response and 'zero' for an incorrect response.

Binaural interaction. Binaural interaction was assessed using the MLD. The signal and the noise were given in both homophasic (S_0N_0) and antiphasic condition (S_oN_π) at 40 dBSL. The test was administered at 500 Hz. The difference between homophasic and antiphasic conditions was calculated to obtain the MLD. A difference of around 10 dB or 15 dB was considered normal, and if it was 5 or less than 5 dB, it was considered as a deficit in binaural interaction.

Temporal processing. GDT and DPT were utilized to assess temporal processing.

GDT. Noise with 0.5 ms cosine ramps at the beginning and the end of the gap were used for the estimation of gap detection threshold. In a three-block alternate forced-choice task, the standard stimulus was always a 500 ms broadband noise with no gap whereas the variable stimulus contained the gap. Among the three stimuli, the participants were asked to identify the one that had a gap. This was estimated using mlp toolbox employed in MATLAB. The minimum and maximum duration of the gap used was 0.1 ms and 64 ms respectively.

DPT. It consisted of three 1000 Hz tones with 300 ms intertone intervals. Tones in each pattern were either 250 ms or 500 ms and are designated as short duration (S) and a long duration (L) respectively. Six combinations (LLS, LSL, LSS, SLS, SLL, SSL) were presented five times to make it a total of 30 duration patterns (6 combinations*5 randomizations) with six seconds inter pattern interval. The participants were asked to repeat the pattern verbally.

Tests to assess Working Memory. Auditory working memory of the participants was assessed using auditory digit span tests administered in two phases; forward and backward phase. This was done through the 'Auditory Cognitive Module' presented through the software Smrithi Shravan (Kumar & Sandeep, 2013). Stimulus consists of digits from one to nine except seven. The numbers were presented in random order with increasing level of difficulty with a minimum of four digits and a maximum of ten digits with an inter-stimulus interval of 250 ms. In forward digit span test, the participants were presented with clusters of numbers, and they were asked to repeat the numbers in the same order and in the backward span test, they were asked to repeat the digits in the reverse order. Auditory working memory capacity was calculated as the total number of digits the participants could recall in the correct sequence.

Assessment of Phonological processing skills

The phonological processing ability was assessed using PhoST-K developed by Prema (2012). The domains of PhoST-K include rhyming, blending, segmentation, syllable oddity, phoneme oddity, syllable deletion, phoneme deletion, and manipulation task. Each domain had a total of 25 items organized hierarchically along five subsections based on the syllable length (the stimulus items in the first section comprises of two syllables where as the fifth section has multi-syllables). The details of each task to assess phonological skills are described below:

Rhyming. In the rhyming task, the participants were presented with minimal pairs of words which differed in one feature. The participants were instructed to say if the words were same or different. They were given 10 secs to respond after each stimulus presentation. This task included list of words that differed in 5 different features namely, vowel duration (eg: /bəla/-/bāla/), aspiration (e.g.:/əkkɪ/-/həkkɪ/), stress (eg:/ɪlɪ/-/ɪllɪ/), voicing (eg:/kərɪ/-/ɡərɪ/), and retroflex (eg:/ ənna/-/əɳɳ a/).

Blending. In this task, participants were presented syllables of a word and asked to combine those syllables to make a word. A time gap of 15 secs was given to respond after each presentation. E.g.: The participant was given only the syllables of the word /bəɭəpa/ as /ba/, /ɭa/, /pa/ separately. The participant's task was to combine the syllables and repeat the whole word.

Segmentation. In this task, the participant was asked to break the given word into its syllables. The time gap of 15 secs was given to respond after each presentation. E.g., For the word /ʊɡʊrʊ/, the participant's task was to divide the word into individual units and repeat the syllables as /ʊ/, /ɡʊ/,/rʊ/.

Syllable oddity. In this task, the participant was supposed to pick the odd word out of the three words based on the syllable difference. After each stimulus presentation, a time gap of 15 secs was given to respond. E.g.: The participant was presented with three sets of words (/əmma/,/əɳɳa/, /ɪlɪ/) and asked to find out the odd word among the three words based on the syllable difference. Here, the first two words are beginning with the syllable /a/ where as the third word begins with /ɪ/. The child must be able to appreciate the difference between words in the beginning or ending. Hence, the response expected in this case is /ɪlɪ/.

Phoneme oddity. In this task, the participant was required to pick the odd word out of the three words based on the phoneme difference. After each stimulus presentation, a time gap of 15 secs was given to the participant to respond. E.g.: The participant was given a set of three words (/məra/, /səra/, /nərɪ/) and instructedto find out the odd word based on the phoneme difference. Here, the first two words are ending with the same phoneme /a/ where as the third word ends with phoneme /ɪ/. The child must be able to appreciate the difference between words in the beginning or ending. Hence, in this case, the response expected is /nərɪ/.

Syllable deletion. In this task, the participant was asked to delete the first or the last syllable of the word as instructed by the investigator and say the remaining part of the word. E.g., From the word /ʧəpāt̪ɪ/, the participant was asked to delete the syllable /t̪ɪ/ and say the remaining part i.e /ʧəpā/.

Phoneme deletion. In this task, the participant was asked to delete the first or the last phoneme of the word as instructed by the investigator and say the remaining part of the word.. From the word /kəɳɳʊ/, the participant was asked to delete the phoneme /k/ and say the remaining part i.e /əɳɳʊ/.

Manipulation. In this task, the participant was instructed to replace the given syllable with another syllable as instructed by the investigator and form a new word. E.g.: For the word /pəppa/, the participant was asked to replace /pa/ by /t̪a/ to form the word as / t̪əppa/**.**

Scoring. A score of 1 was given for every correct response and 0 for an incorrect response in each of the domains. The maximum score that can be obtained in rhyming task is 100 and 25 in all the other domains.

2.7 Statistical Analyses

The data of the present study was subjected to statistical analyses using the Statistical Package for the Social Sciences (Version 20). Descriptive statistics were done to compute the mean and standard deviation of all parameters in both groups of participants. The data obtained was subjected to Shapiro-Wilk's test for normality. The results revealed a non-normal distribution of data ($p<0.05$), and therefore non-parametric tests were administered. A Mann-Whitney U test was done to compare the scores obtained in tasks of auditory processing and phonological abilities between the two groups of participants. Further, Spearman's correlation analysis was carried out to examine the relationship between auditory processing abilities and phonological awareness in the SSD group.

Chapter 3

Results

The present study aimed to evaluate the relationship between auditory processing abilities and phonological abilities in children with speech sound disorder (SSD). To achieve the aim, tests for auditory processing and phonological evaluations were administered typically developing (TD) children and children with SSD. The results are discussed under the following headings.

3.1 Comparison of auditory processing abilities between TD children and children with SSD

3.2 Comparison of phonological abilities between TD children and children with SSD

3.3 Relationship between auditory processing and phonological abilities in TD children and children with SSD

3.1 Comparison of auditory processing abilities between TD children and children with SSD

The auditory processing abilities were assessed using speech perception in noise test, dichotic CV test, masking level difference, gap detection test, duration pattern test, and tests for working memory. Figure 3.1 shows the mean and standard deviation (SD) for various tests of auditory processing in TD and SSD groups and Table 3.1 shows the mean, median, range and standard deviation (SD) of the various auditory processing tests in both groups of participants. From Figure 3.1, it can be noted that participants with SSD had poorer mean scores on all tests of auditory processing compared to TD participants except MLD.

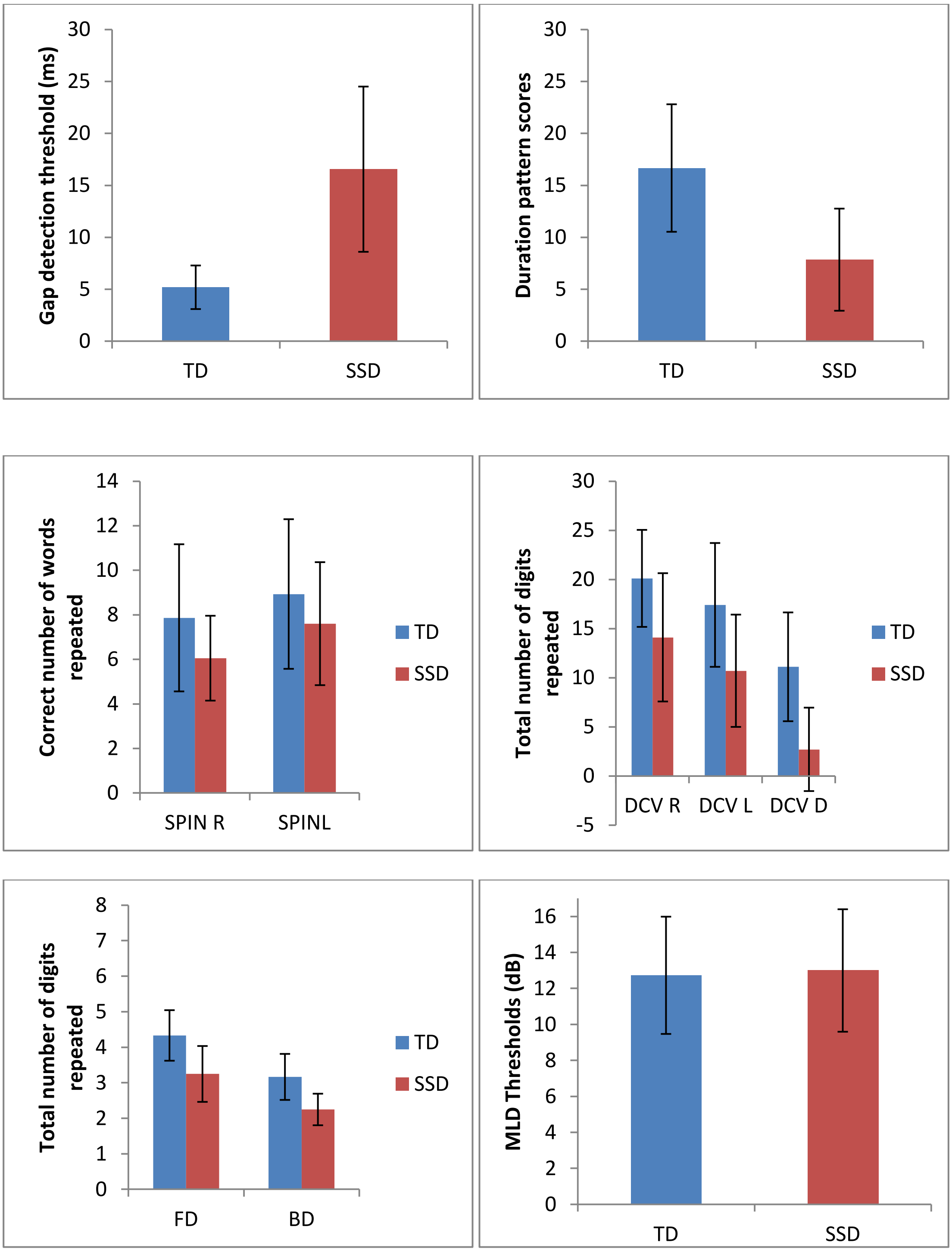

Figure 3.1. Mean and SD of various auditory processing tests for TD and SSD groups

(Note: TD – Typically Developing, SSD – Speech Sound Disorder, SPIN – Speech in Noise (R - Right Ear, L - Left Ear), DCV – Dichotic Consonant Vowel R - Right Ear, L - Left Ear, D – Double Correct), FD – Forward Digit span, BD – Backward Digit span, MLD – Masking Level Difference)

Table 3.1

Mean, Median, Range, and SD of various auditory processing tests for TD and SSD groups

Task	Mean		Median		Range				SD	
					Minimum		Maximum			
	TD	SSD	TD	SSD	TD	SSD	TD	SSD	TD	SSD
GDT (ms)	5.19	16.55	10.79	28.47	2.16	5.21	2.09	7.94	4.91	16.46
DPT (No. of patterns repeated)	16.67	7.85	28.00	17.00	6.00	0.00	6.13	4.19	16.50	6.50
SPIN R (No. of words repeated)	7.87	6.05	18.00	11.00	3.00	3.00	3.24	1.90	8.00	6.00
SPIN L (No. of words repeated)	8.97	7.60	17.00	15.00	4.00	3.00	3.30	2.76	9.00	8.00
DCV R (No. of syllables repeated)	20.10	14.10	30.00	26.00	6.00	2.00	4.93	6.52	21.00	15.50
DCV L (No. of syllables repeated)	17.40	10.70	27.00	21.00	2.00	2.00	6.30	5.71	18.50	10.00
DCV D (No. of syllables repeated)	11.10	2.70	26.00	15.00	0.00	0.00	5.53	4.24	12.50	1.00
FD (No. of digits repeated)	4.33	3.25	5.00	4.00	3.00	2.00	0.71	0.78	4.00	3.00
BD (No. of digits repeated)	3.17	2.25	4.00	3.00	2.00	2.00	0.64	0.44	3.00	2.00
MLD (dB)	12.73	13.00	17.00	20.00	5.00	10.00	3.25	3.40	15.00	12.50

Note: GDT= Gap detection Threshold
DPT= Duration Pattern test, Maximum score= 30
SPIN R= Right speech perception in noise; Maximum score= 25
SPIN L= Left speech perception in noise; Maximum score= 25
FD= Forward digit span
BD= backward digit span
DCV R= Right dichotic consonant vowel; Maximum score= 30
DCV L= Left dichotic consonant vowel; Maximum score= 30
DCS= Double correct score; Maximum score= 30
MLD= Masking level difference

Mann-Whitney U test was done to compare the scores obtained in various auditory processing tests across both groups of participants. The results revealed significant difference between TD and SSD groups in most tests of auditory processing except SPIN left ear scores and MLD (Table 3.2).

Table 3.2

Results of Mann-Whitney U tests comparing the scores for various auditory processing tests between TD and SSD groups

Auditory Processing tests	Z values	p-value
GDT	-4.894	.000
DPT	-4.374	.000
SPIN R	-2.236	.025
SPIN L	-1.514	.130
DCV R	-3.304	.000
DCV L	-3.414	.000
DCS	-4.594	.000
FD	-4.107	.000
BD	-4.445	.000
MLD	-0.212	.832

3.2 Comparison of phonological abilities between TD children and children with SSD

The phonological abilities in both groups were evaluated using the PhoST-K. The domains of PhoST-K included in the study were blending, segmentation, syllable oddity, syllable deletion, phoneme oddity, and phoneme deletion and manipulation task. Figure 3.2 shows the mean and SD obtained for the two groups of participants and Table 3.3 shows the mean, median, range and SD of the various phonological abilities in both groups of participants. It can be observed from Figure 3.2 that participants with SSD had lower mean scores in all the phonological tasks compared to TD participants. Further, Mann-Whitney U test was done to compare the scores obtained on phonological tasks between the two groups of participants. The results of Mann-Whitney U test, given in Table 3.4, shows that there was a significant difference for all the phonological tasks between TD and SSD groups.

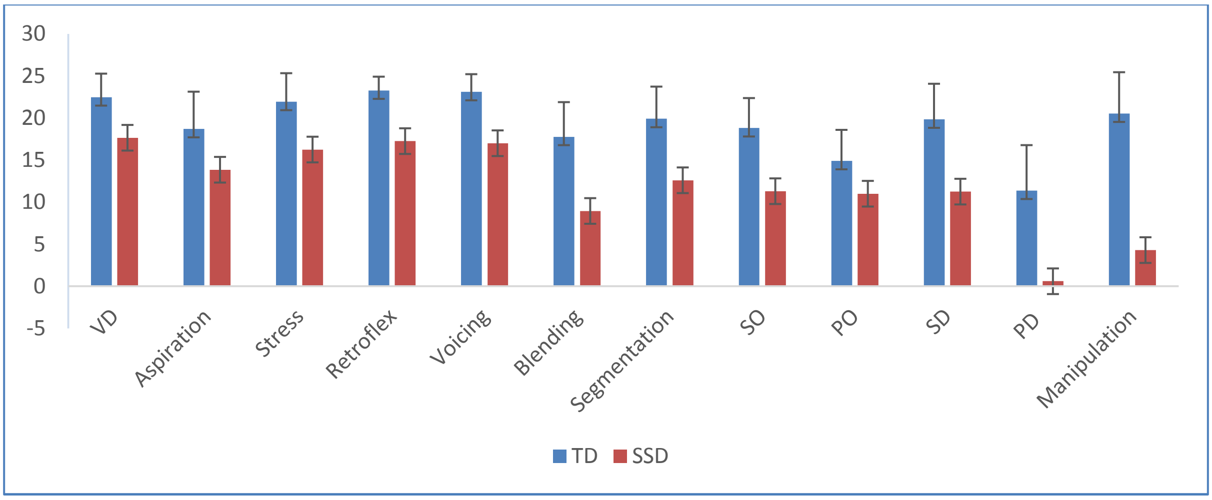

Figure 3.2. Mean and SD of various phonological measures in TD and SSD groups
(Note: VD = Vowel duration, SO = syllable oddity, PO = Phoneme oddity, SD = syllable deletion, PD = Phoneme Deletion)

Table 3.3

Mean, Median, Range, and SD of various phonological abilities in TD and SSD groups

Task	**Mean**		**Median**		**Range**				**SD**	
					Minimum		**Maximum**			
	TD	**SSD**	**TD**	**SSD**	**TD**	**SSD**	**TD**	**SSD**	**TD**	**SSD**
VD	22.47	17.65	23.50	17.00	16.00	9.00	25.00	25.00	2.800	4.76
Aspiration	18.70	13.85	18.70	14.00	10.00	3.00	25.00	23.00	4.42	6.07
Stress	21.93	16.25	23.00	16.00	11.00	8.00	25.00	25.00	3.39	5.14
Retroflex	23.27	17.25	23.00	17.00	19.00	8.00	25.00	23.00	1.64	4.62
Voicing	23.10	17.00	24.00	17.50	17.00	3.00	25.00	23.00	2.11	5.05
Blending	17.77	8.95	17.50	11.00	10.00	0.00	25.00	16.00	4.12	5.14
Segmentation	19.90	12.60	21.00	14.00	11.00	0.00	25.00	22.00	3.83	5.98
SO	18.80	11.30	20.00	11.50	12.00	0.00	25.00	20.00	3.53	4.78
PO	14.90	11.00	15.00	11.00	7.00	0.00	23.00	16.00	3.68	3.52
SD	22.47	17.65	21.5	10.00	11.00	0.00	25.00	18.00	4.23	4.56
PD	18.70	13.85	12.00	0.00	3.00	0.00	24.00	4.00	5.40	1.35
Manipulation	21.93	16.25	23.00	4.50	10.00	0.00	25.00	11.00	4.91	3.91

Note: VD= Vowel duration, SO = syllable oddity, PO= Phoneme oddity, SD= syllable deletion and PD= Phoneme Deletion

Table 3.4

Results of Mann-Whitney U tests comparing the scores for various phonological measures between TD and SSD groups

Phonological measures	Z values	p-value
Vowel Duration	-3.585	.000
Aspiration	-2.728	.006
Stress	-3.713	.000
Retroflex	-4.865	.000
Voicing	-5.056	.000
Blending	-4.854	.000
Segmentaion	-4.354	.000
Syllable oddity	-4.787	.001
Phoneme oddity	-3.343	.000
Sylllable deletion	-4.907	.000
Phoneme deletion	-5.998	.000
Manipulation	-5.876	.000

3.3 Relationship between auditory processing and phonological abilities in TD children and children with SSD

The relationship between auditory processing and phonological abilities in the SSD group was examined using Spearman correlation. The correlation of various auditory processing skills was done with the production tasks of PhoST-K namely blending, segmentation, syllable and phoneme oddity, syllable and phoneme deletion, and manipulation. The results showed that the duration pattern test positively correlated with syllable oddity ($\rho=0.541$, $p<0.05$), indicating children who had better scores in DPT performed better in syllable oddity task. A negative correlation was seen between SPIN scores of the left ear and segmentation task ($\rho=-0.500$, $p<0.05$), indicating that children who had better scores in SPIN scores of the left ear had poorer segmentation ability. Among the working memory tasks, forward digit span showed a positive correlation with segmentation ($\rho=0.481$, $p<0.05$) and phoneme deletion task ($\rho=0.511$, $p<0.05$). Similarly, backward digit span also showed a positive correlation with segmentation (ρ=0.536, p<0.01) and phoneme deletion task (ρ=0.616, p<0.01). This indicated that children who performed better in working memory tasks had better segmentation and phoneme deletion ability. Figure 3.3 shows the scatter plots for the significant correlation between various auditory processing and phonological abilities in the SSD group.

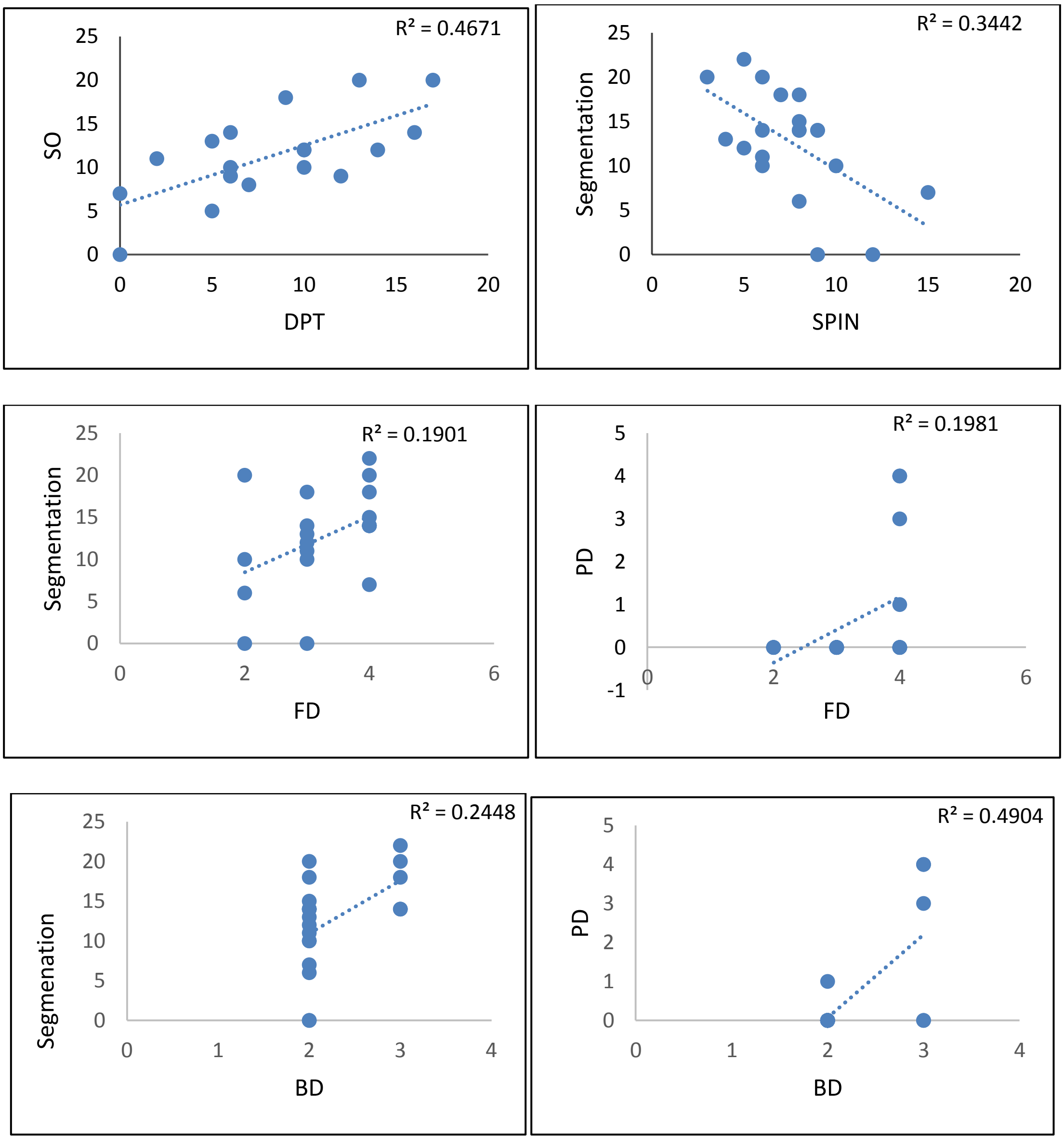

Figure 3.3. Scatter plot of phonological tasks as a function of auditory processing abilities

(Note: DPT- Duration Pattern test, SPIN - speech perception in noise, FD- Forward digit span , BD- backward digit span, PD-Phoneme Deletion)

Chapter 4

Discussion

Speech sound disorders (SSD) are known to interfere with communication. Auditory processing disorder being one of the major causes of SSD, hinders the phonemic representation in brain and in turn, speech perception. The current study aimed to investigate auditory processing abilities and phonological abilities in children with SSD and typically developing (TD) children and establish a relationship between the two abilities.

4.1 Comparison of auditory processing abilities in TD children and children with SSD

The auditory processing abilities were assessed using the speech perception in noise (SPIN) test, dichotic CV test, masking level difference, gap detection test (GDT), duration pattern test (DPT), and tests of working memory. The results showed that children with SSD performed significantly poorer in all the auditory processing abilities except for SPIN in the left ear and MLD.

Children with SSD performed poorer than TD children in SPIN task, and there was a significant difference in the right ear performance. This indicates that the functioning of left hemisphere is affected compared to the right hemisphere in children with SSD. In addition, phonological awareness is related to an individual's ability to identify and manipulate the structure of a speech sound (syllables/phonemes) and may also be related to the ability to understand speech in noise (Mody et al., 1997). Thus, children ideally experience difficulty in phonological awareness task when listening in the presence of background noise. This could also be attributed to other cognitive factors including attention, memory, and fatigue (Oh, Wightman & Lutfi., 2001; Wightman et al., 2003).

In the present study, children with SSD showed poor performance on the Dichotic CV task in comparison to the control group. These results are in consensus with earlier studies reporting compromised performance of children with phonological disorders in dichotic digit task is (Attoni et al., 2010). Studies have shown that patients with temporal lobe lesion show an abnormal dichotic digit performance (Kimura, 1961) whereas patients with cortical lesions excluding their temporal lobe do not exhibit a significant decrease compared to their control group (Mueller, Beck and Sedge, 1987). These studies show the importance of temporal lobe in sound processing on a dichotic task. The posterior temporal lobe, especially on the left side, plays a vital role in the development of speech perception and production. Poor performance in the dichotic digit task can be attributed to any mild cortical dysfunction in this area (Vilela et al., 2016).

Results of the present study showed that temporal processing abilities as evident through GDT and DPT are affected in children with SSD. These results are supported by the studies done in the past where authors have reported that the temporal processing performance is affected in individuals with phonological disorders. They exhibit difficulty in discriminating, sequencing or remembering brief stimuli in rapid succession compared to the control group (Mann & Brady, 1988; Tallal & Newcombe, 1978).

Few studies in the literature have reported poor performance of children with phonological disorders in working memory tasks (Eaton, 2014; Farquharson 2012; Waring et al., 2017). Similar findings were obtained in the present study. The poor performance can be attributed to poor short term memory and working memory in children with phonological disorders. It was also noted in the present study that both the groups had better performance in the forward digit span compared to the backward digit span. This is probably due to the relative difficulty of the two tasks. The forward digit span task involves storage and retrieval of numbers whereas, backward digit span task involves an additional step of manipulation (reversal of the order), thereby making it more complex.

There was no significant difference in MLD between the two groups of participants in the current study. This is in consonance with Bartz et al. (2015) who reported similar findings upon comparison of children with phonological disorder and TD children. This could primarily be due to the difference in the brain regions involved in the two tasks. Test for MLD evaluates the functioning of lower brainstem whereas phonological processing is majorly a function occurring at the cortical level. Thus, similar performance of TD children and children with SSD could plausibly indicate intact lower brainstem functioning in the two groups of participants.

4.2 Comparison of phonological abilities in TD children and children with SSD

The phonological abilities were evaluated using the PhoST-K that included tasks such as blending, segmentation, syllable oddity, syllable deletion, phoneme oddity, and phoneme deletion and manipulation task. The results revealed that children with SSD had significantly poorer phonological abilities compared to TD children. These findings are in agreement with the well established literature that children with SSD are at significant risk of delay in the development of phonological awareness (Bird, Bishop, & Freeman, 1995; Larrivee & Catts, 1999; Raitano, Pennington, Tunick, Boada, & Shriberg, 2004; Rvachew, Ohberg, Grawburg, & Heyding, 2003).

Nathan, Stackhouse, Goulandris, & Snowling, (2004) reported that children with SSD performed poorer on tests of phonological awareness than children with typical speech skills. They also suggest that the risk of phonological awareness is greatest when it reaches school age along with a language delay. Studies have also found that lack of phonological awareness exists even with normal speech skills during school age as well as typical developing speech and language (Raitano et al., 2004, Rvachew et al., 2003). This difference could be attributed to lesion in the posterior left temporal lobe which plays a major role in the development of speech perception and speech production. Any mild cortical dysfunction in this area can explain the poor performance in the phonological abilities in children diagnosed with SSD (Vilela et al., 2016). It has also been reported that in approximately 3.9% of children, abnormal speech sound production persists past the age of 8 years (Lewis et al., 2015; Roulstone, Miller, Wren, & Peters, 2009; Wren, McLeod, White, Miller, & Roulstone, 2013), and the participants in the present study werein the age range of 6-10 years.

4.3 The relationship between auditory processing and phonological abilities in TD children and children with SSD

The relation between auditory processing and phonological abilities were analyzed, and the results showed that there was a correlation between duration pattern test and syllable oddity, SPIN scores of the left ear and segmentation task and working memory with segmentation and phoneme deletion task. Thus, it could be understood that there is a relation between auditory processing and phonological ability but it’s difficult to conclude whether it’s a base deficit or one process is influencing the other process (cited in Vilela et al., 2016). Vilela et al. (2016) found that when CAPD was present in association with a speech disorder, the children tend to have a lower score on the phonological assessments. Similarly, the greater severity of speech disorder was related to the greater probability of the child having CAPD. They also established a cut off value for the PCC- R scores to differentiate children with and without a CAPD.

In the present study, the temporal measure viz DPT showed a relation with the syllable oddity task. The processing of temporal aspects of a sound is dependent on the integrity of the auditory system for perfect transmission of acoustic information through the auditory pathway, and it is an important central auditory process responsible for the perception of sound or alteration of duration characterization within a restricted time interval (Amaral, Casali, Boscariol, Lunardi, Guerreiro, & Colella-Santos, 2015). Thus, the temporal processing skills are very important in the initial six to seven years of life and play an important role in the knowledge of speech sounds and acquisition and learning of the language. It is also reported that auditory temporal processing is crucial for speech perception and discrimination of similar-sounding consonants and other speech sounds. It is integral to phonological awareness mainly in the detection, isolation, and manipulation of individual phonemes in words (Tallal et al., 1997). Moreover, temporal processing is particularly important in perceiving temporal cues in speech, particularly discriminating between consonants noted for tasks such as oddity tasks.

In the present study, working memory showed a positive correlation with segmentation and phoneme deletion task. These results are in consensus with earlier literature (Cabbage, Farquharson, & Hogan, 2015; Lewis et al., 2015) reportingthat children with SSD had lower nonverbal intelligence. Further, working memory significantly contributes to important activities such as acquiring language, reading,, word learning,, mathematical processing and reasoning (Gathercole, Alloway, Willis, & Adams, 2006). It is also essential to store sounds and readily and appropriately retrieve them during speech production (Oakhill & Kyle, 2000). Thus, poor working memory is likely to manifest as a phonological deficit as observed in the present study.

A negative correlation between SPIN scores of the left ear and segmentation task was also observed in the current study. These results indicate that as the SPIN scores of left ear increased, there was a decrease in the scores obtained in the segmentation task. These findings are not in agreement with the studies done in the past. Few studies have shown a positive relation between speech perception in noise and phonological awareness (Hassan, 2013) whereas other studies have reported contrasting findings in TD children as well as children with phonological disorders (Lewis, Hoover, Choi, & Stelmachowicz, 2010; Pinheiro, Oliveira, Cardoso & Capellini, 2010; McAnally, Castles, & Bannister, 2004). The difference observed between the present study and previous studies could be attributed to the difference in the materials used. In the present study, speech perception in noise was assessed using only word stimuli whereas in other studies speech perception in noise was assessed using syllables (Cabbage et al., 2015). Further, we expected a positive correlation between SPIN and phonological awareness task, however the segmentation task majorly happens from the left hemisphere and no correlation between right SPIN and segmentation was justifiable. Thus, further studies on SPIN and phonological awareness in children diagnosed with SSD with more number of participants is needed to better understand the relationship between the two.

Chapter 5

Summary and Conclusions

The present study investigated auditory processing abilities in children with speech sound disorders (SSD) and typically developing (TD) children. The study also assessed the relationship between auditory processing abilities and phonological abilities in children with SSD. A total of 50 participants in the age range of 6-10 years with normal hearing sensitivity were included in the study. They were divided into two groups. Group I included thirty TD childrenand Group II included twenty participants diagnosed with SSD. Auditory processing abilities and phonological abilities were assessed in both groups of participants. The assessment for auditory processing included tests for binaural integration (dichotic CV), binaural interaction (masking level difference), auditory closure (speech perception in noise test-Kannada), temporal processing (gap detection and duration pattern test) and working memory (forward and backward digit span). Phonological evaluations were carried out using phonological sensitivity training kit in Kannada (PhoST-K).

The results showed that there was a significant difference in the performance of TD children and children with SSD. It was observed that children with SSD had poor scores on all tests of auditory processing and phonological abilities compared to the TD group. The results also showed that there exists a relationship between auditory processing and phonological abilities as revealed by correlation analysis. It was noted that duration pattern had a significant correlation with syllable oddity, speech perception in noise had a significant correlation with segmentation, and working memory had a significant correlation with phoneme oddity and segmentation.

The findings of the present study add support to the existing literature confirming the important role of auditory processing in tasks of phonological awareness. Phonological awareness involves children's ability to detect and manipulate individual sounds in words. This is absolutely essential in children with SSD to be able to perceive rapid acoustical changes in speech stimuli. Thus, it is recommended to assess the central auditory processes in children with SSD. There is a need to identify the problem in the initial stages and provide suitable rehabilitation to the child to acquire compensatory strategies in order to overcome their difficulties. Early identification and rehabilitation is also essential to ensure that difficulties in these areas do not hinder the process of literacy acquisition in children, thereby affecting their scholastic performance.

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