Central Auditory Processing Abilities in Children with Non-Syndromic CleftLip/and Palate

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CERTIFICATE

This is to certify that this dissertation entitled '**Central Auditory Processing Abilities in Children with Non-Syndromic Cleft Lip and Palate'** is a bonafide work submitted as a part for the fulfilment for the degree of Master of Science (Audiology) of the student Registration Number: P01II21S0053. This has been carried out under the guidance of the faculty of the institute and has not been submitted earlier to any other university for the award of any other diploma or degree.

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DECLARATION

This is to certify that this dissertation entitled **Central Auditory Processing Abilities in Children with Non-Syndromic Cleft Lip and Palate’** is the result of my own study under the guidance of Dr. Chandni Jain, Associate Professor, Department of Audiology, All India Institute of Speech and Hearing, Mysuru and has not been submitted to any other University for the award of any Diploma or Degree.

Mysuru **Registration Number:** P01II21S0053
September

Dedicated to
my dear Appa

"Don't stop chasing your dreams

Because dreams do come true"

Sachin Tendulkar

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Abstract

The present study aimed to assess the central auditory processing abilities and working memory in children with non-syndromic cleft lip and palate (NSCLP) and to compare with the developed normative and craniofacially normal peers. The relationship between age and central auditory processing abilities in children with NSCLP was also measured. Sixteen NSCLP children aged 7 to 12 years were recruited in this study. Fifteen craniofacially normal peers participated to compare the working memory abilities and temporal resolution abilities among children with NSCLP. Speech perception in noise Kannada (SPIN-K), gap detection threshold (GDT), dichotic consonant-vowel (DCV), and masking level difference (MLD) tests were administered to assess various central auditory processing abilities. Working memory abilities were assessed by using forward-digit span and backward-digit span tests. The results showed significant differences in SPIN-K, dichotic CV, GDT, forward digit, and backward digit span scores between children with NSCLP and craniofacially normal peers. Estimating the relationship between age and central auditory processing measures revealed a positive correlation between age and single correct scores of dichotic CV in children with NSCLP. Thus, it can be concluded from the present study that children with NSCLP have a risk of developing auditory processing deficits. To conclude, assessment of central auditory processing abilities in children with NSCLP is recommended.

Keywords: Non-syndromic cleft lip and palate, auditory processing deficit, working memory.

Chapter 1

Introduction

Cleft lip and palate (CLP) is a congenital anomaly of the craniofacial structure. CLP prevalence is around 1 in 500 to 2500 births globally (Zarei et al., 2021). There are three different categories in the oro-facial cleft, which are cleft lip only (CL), cleft lip and palate (CLP), and cleft palate only (CP). Cleft palate poses a severe problem in affected children among these three categories (Zarei et al., 2021). A condition in which cleft disorder is isolated from other abnormal phenotypes is called non-syndromic cleft and palate (NSCLP), and 70% of cleft lip and palate are identified as NSCLP (Stanier & Moore, 2004).

Peripheral hearing loss is commonly seen in children with NSCLP due to the middle ear infection, and the hearing loss is majorly bilateral with mild to moderate degree (Yang & McPherson, 2007). Studies have shown that individuals with NSCLP have difficulty reading and are academic underachievers (Conrad et al., 2014; Persson et al., 2012). Feng and Lu (2016) reported poor academic achievement in children with NSCLP due to impaired auditory skills. Another potential contributing cause to learning and language delay is auditory processing disorder (APD), which has recently been flagged as an additional hearing deficit in children with NSCLP.

Several studies report that children with NSCLP had a history of conductive hearing impairment (Conrad et al., 2014; L J Jocelyn., 1996; Yang & McPherson, 2007). There is a higher prevalence of auditory tube dysfunction and glue ear in children with NSCLP (Doyle et al., 2016). Interference in the normal binaural hearing pathway and sound conduction due to the middle ear infection might impair the auditory processing abilities in children with NSCLP. (Ma et al., 2016). Also, the middle ear infection induces neural changes in the auditory system (Roberts et al., 2004). Children with middle ear infections are also associated with hyperacusis, which may impair the development of normal listening; because of the altered peripheral auditory system, there will be a problem in decoding the messages properly directed to the child (Cristina et al., 2008). Even mild hearing loss caused by otitis media may have long-term functional and structural changes in the synaptic connections of the central auditory nervous system (Zarei et al., 2021). Thus, there is a higher risk of developing auditory processing deficits in children with NSCLP.

APD is a perceptual condition hypothesized to be caused by brainstem and cortical function dysfunction (American Speech-Language-Hearing Association, ASHA, 2005). APD is defined as "deficits or poor performance in one or more of the following listening skills: auditory pattern recognition; auditory performance with competing acoustic signals and degraded acoustic signals; auditory localization and lateralization; auditory discrimination; temporal aspects of audition; auditory pattern recognition" (ASHA, 2005). Auditory processing difficulties most commonly manifest themselves in normal hearing, although they can also develop in children with recurrent middle ear infections.

Numerous studies have used various questionnaires and behavioral tests to assess auditory processing abilities in children with NSCLP (Hofer-Martini et al., 2021; Ma et al., 2015; Shaaban, 2021; Yang et al., 2012; Zarei et al., 2021). Results of these studies have shown that children with NSCLP have difficulty in speech perception in noise (Feng & Lu, 2016), difficulty in dichotic listening (Boscariol et al., 2009; Cristina et al., 2008), and difficulty in temporal resolution abilities (Zarei et al., 2021).

In children with NSCLP, auditory processing deficits may negatively impact speech, language, and communication development (Ma et al., 2015). It can also significantly affect the quality of life (Shaaban, 2021). Compared to their typical counterparts, children with NSCLP have lower language, learning, and communication skills (Feng & Lu, 2016). Several studies reported that children with NSCLP have academic underachievement compared to their craniofacially normal peers (Persson et al., 2012; Shaaban, 2021).

Differences in the cortical structures between the normal craniofacial groups and children with NSCLP have been reported (Nopoulos et al., 2002; Yang, McPherson, Shu, Xie, et al., 2012a). Children and adult men with NSCLP had abnormal cortical regions, especially in the left temporal lobe (Nopoulos et al., 2002). They had reduced grey and white matter volumes compared to the normal craniofacial groups (Yang, McPherson, Shu, Xie, et al., 2012b). Nopoulos et al. (2002) reported that infants with NSCLP had a smaller volume of the cerebral cortex and thalamus of the left cerebrum and a reduced volume of the CSF. Infants with NSCLP have been shown to have reduced volume and thickness in the left superior temporal plane and other developmental abnormalities in the cortical area (Yang & McPherson, 2007). As a result of these variances, the auditory cortex's functional capacities may be affected in children with NSCLP. Adamson et al. (2014) reported structural abnormality in the cerebellum in individuals with NSCLP and reported less maturation of cortical structure in females with NSCLP compared to males.

1.1 Need for the Study

Reports from recent studies suggest that an auditory processing deficit is an additional impairment associated with hearing in children with NSCLP that also accounts for language and learning delays. Based on the questionnaire, behavioural assessments, and electrophysiological testing results, children with NSCLP, particularly cleft palate, show a higher prevalence of APD. APD negatively impacts young children's academic performance, language development, and cognitive ability. It can also significantly impact these children's quality of life (Shaaban, 2021).

Most studies cited above have investigated some auditory processing skills in individuals with NSCLP. Also, studies have not assessed working memory abilities in children with NSCLP, which is also a part of auditory processing. As per the author's knowledge, there are no studies on the effect of NSCLP on auditory processing abilities in the Indian context. Thus, the present study aims to assess central auditory processing abilities in children with NSCLP. It will provide evidence to the audiologist, which will help them in early diagnosis and management and improve the quality of life of these children.

1.2 Aim of the Study

The study aimed to assess the central auditory processing abilities in children with NSCLP.

1.3 Objectives of the Study

1. To compare the auditory closure abilities of children with non-syndromic cleft lip and palate with the developed normative.
2. To compare the temporal processing abilities in children with non-syndromic cleft lip and palate with craniofacially normal peers.
3. To compare the binaural processing abilities of children with non-syndromic cleft lip and palate with the developed normative.
4. To compare the working memory abilities of children with non-syndromic cleft lip and palate with craniofacially normal peers.
5. To estimate the relationship between age and central auditory processing measures in children with non-syndromic cleft lip and palate.

Chapter 2

Review of Literature

Cleft lip and palate (CLP) disorders are the most prevalent congenital deformities that account for many human birth problems. Allagh et al. (2015) reported that the overall birth prevalence of clefts in India is 1.3 per 1000 births. According to studies, peripheral hearing loss is common in children with non-syndromic cleft lip and palate (NSCLP) due to direct or indirect effects of Eustachian tube dysfunction. Auditory processing disorder (APD), which has recently been identified as an additional hearing deficiency in children with NSCLP, may also be a factor in learning and language delays. Several studies report that children with cleft lip and palate have deficits in auditory processing skills compared to typically developing children.

2.1 Eustachian Tube Dysfunction and Otitis media in Children with CLP

Eustachian tube dysfunction and otitis media are the major problems in children with CLP due to the abnormal connection of the tensor palatine and levator palatine muscle. Prevalence of otitis media with effusion in children with cleft lip and palate was assessed longitudinally by Flynn et al. (2009). 22 children with unilateral CLP and 20 normal children were followed retrospectively from 1 to 5 years. Oto-microscopy, tympanometry, and hearing assessment were done at four ages. The collected data showed that children with CLP had a higher prevalence of otitis media with effusion than children without CLP.

Sheer et al. (2012) assessed the anatomical properties of the Eustachian tube in young children and infants using three-dimensional (3D) finite element (FE) modeling techniques. This study included six adults, four young children, and five infants with cleft lip. Reduced tensor veli palatine muscle sensitivity was observed in all individuals with cleft lip.

Doyle et al. (2016) investigated the Eustachian tube's function in children with CLP by conducting an inflation-deflation test. Forty-one children and adults with CLP were evaluated. The results demonstrated that children with CLP had a reduced ability to open the eustachian tube during swallowing, which may lead to a recurrent middle ear infection. Severe functional obstruction was seen in children with CLP. This obstruction was principally brought on by the tensor veli palatine muscle's failure to dilate the ET while swallowing actively.

Thus, eustachian tube dysfunction is commonly seen in children with CLP. Reduced sensitivity of tensor veli palatine muscle and failure of the muscle to open the eustachian tube during swallowing leads to eustachian tube dysfunction in children with CLP.

2.2 Hearing Loss in Children with CLP

Hearing loss in children with CLP is commonly linked to recurrent middle ear infections and alters the normal binaural auditory pathway. Tunçbilek et al. (2003) evaluated the audiological status of 50 children with repaired CLP using pure tone audiometry and tympanometry. The results showed that normal hearing was seen in sixty-three ears out of 100 years. Also, normal middle ear pressure was seen in 40 ears.

Yang and McPherson. (2007) in a systemic review to study the prevalence of hearing loss in children with CLP, reported that conductive hearing loss was frequently seen in syndromic and non-syndromic clefts, and sensorineural hearing loss was majorly seen in children with syndromic cleft.

Do Amaral et al. (2010) studied hearing abilities in children with NSCLP using otoscopic examination, pure tone audiometry, and immittance. The study included 44 males and females aged 8 to 14 years. Pure tone audiometry results showed that 77.27%

had normal hearing, 13.6% of the participants had conductive hearing loss, and 2.2% had mixed hearing loss. In immittance, 21.2% showed a C-type tympanogram, 7.1% had a B-type tympanogram, and Ad-type was present in 3.5% of the participants.

Hee (2014) conducted a cohort study to review the results of newborn hearing screening of infants with CLP. Data from 123 infants were reviewed in this study. The outcome of the data shows that thirty-one of 123 infants presented with failed automated auditory brainstem response. Hearing loss was reported in 24.4% of infants with CLP. Conductive hearing loss was majorly seen in CLP infants rather than mixed and sensorineural hearing loss.

Skuladottir et al. (2015) conducted a retrospective study demonstrating hearing outcomes in children with CLP. A total of 317 children were taken in this study; 159 had cleft lip and palate, and 158 had cleft palate. Pure tone audiometry was done at ages 4, 6, and 15 years. The median pure tone average statistically improved with age, and there was no statistical difference in hearing loss between the two groups.

Thus, hearing loss is commonly seen in CLP children. Middle ear effusion can interrupt the normal binaural hearing pathway and lead to hearing loss in children with cleft lip and palate. Conductive hearing loss is majorly reported compared to sensorineural and mixed hearing loss.

2.3 Auditory Processing Deficits in Children With CLP

Auditory processing deficits are often associated in children with CLP (Cristina et al., 2008; Hofer-Martini et al., 2021; Ma et al., 2015). An electrophysiological study was conducted by Čeponiene et al. (2000) to assess the pre-attentive discrimination in infants with CLP. Thirty-two infants with oral cleft and 12 healthy infants aged 0 to 6 months were enrolled in this study. The infants were divided into cleft palate only (CPO) and CLP. Mismatch negativity responses showed infants with CPO had significantly smaller responses than their age-matched controls. MMN responses of the infants with CLP were comparable to that of healthy infants.

Cayres Minardi et al. (2004) utilized Fisher's auditory problem checklist to investigate auditory processing abilities in children with CLP. Fisher's auditory problem checklist was given to the parents of 100 children with CLP between the ages of 7 to 12 years. All the CLP children showed some indicative behaviors of a processing deficit.

Lemos et al. (2008) used the dichotic listening test to compare the central auditory processing abilities of craniofacially normal children and children with CLP aged 7 to 7.11 years. Children with CLP performed worse on the dichotic listening test and had lower scores than the control group. Girls in the clinical group were more affected compared to boys.

Using auditory fusion and dichotic digit tests, Boscariol et al. (2009) assessed central auditory processing abilities in children with CLP. Twenty children in the age range of 7 to 11 years were recruited in this study. Results revealed that children with CLP had significantly reduced scores in both tests. These results suggest that processing ability is affected in children with CLP.

Auditory evoked potentials, including auditory brainstem response, late latency response and mismatch negativity, were recorded in infants with NSCLP and normal controls by Yang, McPherson, Shu, & Xiao (2012). Both groups had normal wave latency and wave amplitude for auditory brainstem response and late latency response. However, results of mismatch negativity showed infants with NSCLP had smaller responses than their normal counterparts.

Ma et al. (2015) compared the temporal resolution abilities and picture identification in noise between craniofacially normal children and children with NSCLP. Sixty age-matched, craniofacially normal controls and 141 Mandarin-speaking children with NSCLP ranging in age from 6 to 15.67 years were recruited. Results showed that children with NSCLP had reduced temporal resolution abilities compared to their normal counterparts.

Ma et al. (2016) used Fisher's auditory problem checklist to determine the prevalence of auditory processing deficits in children with NSCLP. The participants were divided into cleft lip, cleft palate, and cleft lip and palate. Caregivers of 147 school-aged children with NSCLP were employed. Results showed that children with cleft palate had the lowest score and higher risk of developing central auditory processing disorder than the other two groups.

Feng and Lu. (2016) investigated the central auditory processing abilities of eighteen participants with NSCLP aged 7 to 15. Hearing in noise test (HINT), the gap in noise test (GIN), and the dichotic digit test (DDT) were administered to assess central auditory processing abilities. Results showed that DDT scores did not differ among individuals with NSCLP and age-matched controls, indicating that binaural integration and separation abilities might be normal in individuals with NSCLP. Individuals with NSCLP performed significantly poorer in GIN and HINT tests than their normal peers.

Ma et al. (2016) utilized electrophysiological tests to compare the central auditory processing abilities in children with NSCLP and craniofacially normal children. The tests included auditory brainstem response, P1-N1-P2 complex, and P300. Results showed that children with NSCLP had prolonged ABR and N1 wave latency compared to their normal controls. Compared to other cleft subgroups, children with unilateral cleft lip and palate displayed a higher level of abnormality.

Hofer-Martini et al. (2021) evaluated auditory processing abilities in children and adults with NSCLP using a speech perception in noise test, a dichotic speech discrimination test, and a parental questionnaire. Forty-eight participants with NSCLP were recruited in this study. 16.7% of the participants had reduced dichotic speech discrimination scores, and 69% had lower scores in speech perception in noise. Parents reported no problem in the parental questionnaire.

Zarei et al. (2021) compared the binaural integration and temporal resolution abilities in children with NSCLP with normal peers aged 8 to 12 years. A dichotic digit test and a gap in noise test were compared across the two groups. Children with NSCLP had higher right ear scores than their normal controls, and no significant difference was noted in left ear scores between the groups. Gap detection in noise scores was significantly reduced in children with NSCLP compared to their normal controls.

In children with cleft lip and palate, auditory and language skills were assessed by Maximino et al. (2022). The study sample comprised 22 children aged 7 to 9 years with repaired unilateral CLP. Auditory skills were assessed by administering random gap detection, dichotic digit, and dichotic verbal tests. Only one participant had adequate performance in all the tests. Impaired performance in all the tests was seen in five participants, and 16 participants showcased deterioration of one to three auditory skills in that temporal resolution was majorly impaired.

Thus, auditory processing deficits are frequently seen in children with NSCLP. Recurrent otitis media in children with NSCLP alters the normal binaural auditory processing and leads to a deficit in auditory processing.

2.4 Brain Abnormalities in Children with CLP

Patients with NSCLP have different brain architecture than their craniofacially normal counterparts. Adults and children with CLP exhibit radiologically aberrant cortical areas compared to craniofacially normal individuals. Using Magnetic resonance imaging (MRI), Nopoulos et al. (2000) analyzed and compared the brain morphology of 14 adult men with isolated CLP with 14 healthy normal individuals. The frontal and temporal lobes of the males with CLP were substantially larger, and the cerebellum was significantly smaller than normal controls. Gray/white matter ratios and laterality did not differ significantly between the two groups.

A quantitative analysis was done to evaluate the brain morphology in adults with NSCLP by Nopoulos et al. (2002). 46 adult males with NSCLP were recruited in the study. MRI was done, and the results showed that the anterior region of the cerebrum was abnormally enlarged in adults with NSCLP. The posterior region of the cerebrum and cerebellum were decreased in volume. Overall, the left temporal lobe was severely affected in adults with NSCLP compared to other brain areas.

Using MRI, Nopoulos et al. (2007) compared the brain morphology of children with isolated CLP and with normal peers. Seventy-four children aged 7 to 17 years participated in this study. Children with isolated CLP had abnormally smaller brains with cerebrum and cerebellum than normal peers. Boys with isolated cleft lip and palate had an aberrant cortical grey matter and white matter tissue distribution in the cerebrum.

Yang, McPherson, Shu, and Xiao. (2012) performed an MRI of the central auditory nervous system in children with NSCLP. The study included 27 infants with NSCLP, ranging in age from 6 to 24 months, and age-matched controls. There was no statistical difference between the two groups in the brainstem and right hemisphere volume. The left thalamus and left auditory cortex were smaller in volume, and the left auditory cortex thickness was statistically substantially reduced in infants with NSCLP.

Devolder et al. (2013) examined and compared the cerebellar structure of the individual with isolated CLP. MRI was done for 107 individuals aged 7 to 27 years with isolated cleft lip and palate. The cerebellum volume was significantly lower in individuals with isolated CLP compared to normal individuals. Males with isolated CLP had smaller superior posterior lobes and proportionately larger anterior lobes. Only the overall cerebellum capacity was reduced in CLP males, with no regional variations.

Conrad et al. (2021) evaluated and compared brain structure and neural activity for males with isolated CLP. Males aged 8 to 11 years were included, and task-based functional MRI was done. Increased frontal grey matter volume was seen in males with isolated CLP. Further, the findings show that in males with isolated CLP, an increased occipital volume may be linked with inefficient compensation. In contrast, increased frontal grey matter volume may be related to effective compensation during reading.

Thus, children and adolescents with CLP exhibit altered brain morphology compared to healthy controls. The left temporal lobe has been reported to be significantly damaged in cleft lip and palate than other brain regions.

2.5 Speech, Language, and Academic difficulties in children with CLP

Children with CLP have language difficulties and academic underachievement (Shaaban, 2021). Jocelyn et al. (1996) compared the cognitive, speech, and language skills between children with CLP and craniofacially normal children longitudinally. A receptive-expressive emergent scale was administered to measure speech and language skills. Results suggest lower comprehension and expressive language abilities in children with CLP compared to craniofacially normal peers at 12 to 24 months of age.

Uccellin (1999) conducted a study to evaluate the prevalence of learning disability and academic underachievement in children with CLP. Eighty-four children with CLP participated in this study. Results showed that learning disability was present in 46% and academic underachievement was seen in 47% of children with CLP.

Scherer (1999) conducted a longitudinal study comparing speech and language development between children with NSCLP and craniofacially normal children. The speech and language development were longitudinally assessed from 0 to 30 months of age. Results revealed that younger children with CLP had receptive – expressive language impairment and severe speech sound inventory limitations.

Vallino et al. (2008) conducted a retrospective study to examine the prevalence of speech and language impairment prevalence in children with cleft lip (CL). A retrospective review of 95 children with CL between the ages of 2.8 to 3.7 years was included. The results showed that 13% of children with CL had speech impairment, and 18% of children with CL had language impairment.

Young et al. (2010) assessed the expressive language skills of 43 Chinese Singaporean preschoolers with NSCLP in the age range of 3 to 6 years. Singapore English action picture test was used to evaluate expressive language skills. Results showed that 33% of children with NSCLP had expressive language impairment.

In a retrospective study, Persson et al. (2012) compared the academic performance between children with CLP and craniofacially normal peers. Data was taken from the Swedish medical birth register. Five hundred-eleven participants with CP, 651 participants with CL, and 830 participants with CLP were included in this study. Compared to craniofacially normal peers, CLP children had reduced grades in all subjects. Children with CP were primarily affected, followed by children with CLP, and children with CL were least affected.

Bell et al. (2017) compared the academic performance of children with CLP and craniofacially normal children by conducting a retrospective study. Results showed that children with CLP, especially cleft palate only, had learning disabilities and poor academic performance compared to craniofacially normal children.

Thus, academic underachievement and speech and language impairment are commonly seen in children with CLP. Auditory processing deficits in children with CLP may negatively impact academic achievements. Abnormal cognitive ability in children with CLP may affect the development of speech and language skills.

Chapter 3

Methods

The current study aimed to investigate the central auditory processing abilities and working memory abilities in children with NSCLP.

3.1 Research Design

Between and within subject, experimental research design was used to fulfill the aim of the study.

3.2 Participants

Sixteen non-syndromic cleft lip and palate children between the ages of 7 to 12 years (Mean age: 9.78 years) were recruited in this study. According to age, children were divided into five subgroups. Group 1 included children aged 7 to 7.11 years; Group 2 from 8 to 8.11 years; Group 3 from 9 to 9.11 years; Group 4 from 10 to 10.11 years; and Group 5 from 11 to 11.11 years, respectively. Fifteen craniofacially normal peers were included as a control group to compare the working memory abilities and temporal resolution abilities among children with NSCLP. Table 3.1 shows the age, gender, and type of cleft of children with NSCLP.

Table 3.1

Age, gender, and type of cleft of children with NSCLP

Subject No	Age (years)	Gender	Cleft type
1	7.1	M	Bilateral RCLP
2	7.6	M	Bilateral RCP
3	7.2	F	RCP (soft palate)
4	8.1	F	Bilateral RCP
5	8.7	F	Bilateral RCP
6	8.9	M	Unilateral RCLP
7	9.7	M	Bilateral RCP
8	9.3	M	Bilateral RCLP
9	10.4	F	Unilateral RCLP
10	10.3	F	Unilateral RCLP
11	10.3	M	RCP (soft palate)
12	11.4	F	Bilateral RCLP
13	11.3	M	RCP (soft palate)
14	11.9	F	Bilateral RCP
15	12	M	Unilateral RCLP
16	11.8	M	Unilateral RCLP

3.2.1. Participation Selection Criteria for Children with NSCLP

INCLUSION CRITERIA

- ✓ Cleft lip and palate with normal hearing sensitivity and no active middle ear infection.
- ✓ Congenital non–syndromic cleft lip and palate with normal cognitive ability.

EXCLUSION CRITERIA

- ✓ Cleft lip and palate with the syndromic condition and other cognitive co-morbid conditions such as cognitive disability, hearing loss, and active middle ear infection.

3.2.2 Participation Selection Criteria for Carnaiofacially Normal Peers

INCLUSION CRITERIA

- ✓ Craniofacially normal children with normal hearing sensitivity and no active middle ear infection.
- ✓ Participants should pass the 'Screening Checklist for Auditory Processing (SCAP) developed by Yathiraj and Mascarenhas (2002).

EXCLUSION CRITERIA

- ✓ Craniofacially abnormal children with active middle ear infection and hearing loss.
- ✓ Children with any co-morbid conditions like Intellectual disability, syndromes, and developmental delay.

3.3 Testing Environment

All testing was conducted in an acoustically treated soundproof room within the permissible noise limit (ANSI S3.1, 1991).

3.4 Instrumentation

The following types of equipment were used in this study:

- A calibrated dual channel diagnostic audiometer GSI-61 (Grason-Stadler, Eden Prairie, MN, USA) with TDH-39 headphones and B-71 bone vibrator were used to establish air-conduction and bone conduction thresholds.
- The GSI-Tympstar (Grason-Stadler, MN, USA) Pro immittance meter to perform tympanometry and acoustic reflexes.

- Otodynamics DP ILO-V6 Echoport version 6.0 (United Kingdom) otoacoustic emission instrument was used to measure transient evoked otoacoustics emissions (TEOAEs).
- A Hewlett-Packard computer with Intel i7 and 16GB RAM running Windows 10 version 20H2 installed with MATLAB and Smiriti Shravan software (Kumar & Sandeep, 2013) was used to conduct gap detection test and working memory tests.
- Dual-channel calibrated audiometer (Inventis - Piano, Italy) with TDH-39 headphones was utilized to assess masking level difference (MLD).

3.5 Test Materials

- Auditory closure ability was assessed using speech perception in noise test in Kannada (SPIN/K) (Vaidyanath & Yathiraj, 2012).
- The binaural integration test was carried out using the Dichotic CV test (Yathiraj & Gowri, 2001).

3.6 Procedure

The study was carried out in two phases.

1st PHASE: A basic audiological evaluation, including pure tone audiometry, acoustic immittance, and otoacoustic emissions, was done to rule out hearing loss and middle ear dysfunction. This was done to ensure that participants fit the inclusion criteria.

2nd PHASE: This phase assessed all the central auditory processing skills. SPIN-K was done to assess auditory closure; GDT was carried out to assess temporal processing skills; dichotic consonant-vowel (DCV) and MLD were conducted to assess binaural processing skills, and the digit span test were administered to assess auditory working memory. All the CAPD tests were conducted at 60 dBHL.

3.6.1. Basic Audiological Assessment

In pure tone audiometry, the air conduction thresholds were established for octave frequencies from 250 Hz to 8000 Hz, and the bone conduction thresholds were established for octave frequencies from 250 Hz to 4000 Hz. The 226 Hz tympanometry was performed to detect the active middle ear infection. Acoustic reflex thresholds for 250 Hz, 500 Hz, 1000 Hz, and 2000 Hz were examined in both ipsilateral and contralateral modes. The functioning of the outer hair cells was checked by using TEOAE'S with the presentation of 83 dB SPL clicks stimulus. Participants with normal hearing sensitivity and no middle ear infections were included in the second phase.

3.6.2. CAPD Evaluation

Speech Perception in Noise Test: Speech perception in noise test in Kannada (SPIN-K) (Vaidyanath & Yathiraj, 2012) was done to assess auditory closure. The phonemically balanced words were used as a test stimulus (Yathiraj &Vijayalakshmi, 2005) and presented with speech noise at 0 dB SNR. The word list consists of 25 words, and two different wordlists were used. The participants were instructed to repeat the words. A score of one was given for the correctly repeated words and zero for incorrect responses.

Gap Detection Test: Temporal resolution abilities were measured using a gap detection test. In this test, the subjects were given a stimulus with a gap; the minimum gap which the participant can perceive is called the gap detection threshold. The GDT was estimated using MATLAB's maximum likelihood procedure (MLP) function. Three alternate force choice method was used, and the standard stimulus was 500 ms broadband noise. At the beginning and end of the gap, a noise with 0.5ms cosine ramps was given to estimate the gap detection threshold. The participants were asked to identify the stimulus with a gap among the three stimuli.

Binaural Processing: The binaural integration and interaction abilities were assessed here. Binaural integration was evaluated through the dichotic consonant-vowel (DCV) test (Yathiraj and Gowri, 2001). This test presented the consonant-vowel segment simultaneously in both ears through headphones. The six different syllables /pa/, /ta/, /ka/, /ba/, /da/, and/ga/ were presented in a random order five times simultaneously to each ear with 0ms lag. The participants were instructed to repeat the words that they heard. A score of 'one' was given for every correct response; a score of 'zero' was given for an incorrect response. Additionally, responses were scored as single correct and double correct scores. A single correct score was given when the subject repeated the syllable presented in one ear. Double correct scores were given when the participants repeated the syllable presented in both ears.

The MLD was done to assess the binaural interaction. Masked thresholds were obtained for homo phasic (S_0N_0) and antiphasic (S_0N_π) and ($S_\pi N_0$) signal and noise conditions for 500 Hz test stimuli. The difference between the homo phasic and antiphasic was calculated to obtain MLD. A difference greater than 10 dB between homophasic and antiphasic conditions was considered normal, and less than 5dB was considered a binaural interaction deficit (Jain & Priya, 2019).

Working Memory: An auditory digit span test assessed the auditory working memory. 'Auditory cognitive module' was presented through Smrithi Shravan software (Kumar & Sandeep, 2013). Digits from one to nine except seven were given in a random order, and the number of digits presented increased from a minimum of four digits to a maximum of ten digits to increase the difficulty of the test with 250 ms of inter-stimulus interval. The clusters of numbers were presented, and the participants were asked to repeat the digits in the same order for the forward digit span test. The participants were instructed to repeat the digits in reverse order for the backward digit span test. The scoring was based on the number of correct digits the participants reported in the same order. The midpoint of the forward and backward digit span test was taken for analysis.

3.7 Statistical analyses

The obtained data from the present study was subjected to statistical analysis by utilizing the subjective package for the social science. A descriptive statistical analysis determined each parameter's means and standard deviations. Shapiro Wilks normality test was done to analyze the normality distribution of this study data. A One-sample Wilcoxon signed rank test was administered to compare the auditory closure, binaural integration, and binaural interaction abilities between children with NSCLP and the developed normative. Mann-Whitner U test was carried out to compare the temporal resolution abilities between NSCLP and craniofacially normal groups. An independent t-test was done to compare the working memory abilities between children with NSCLP and craniofacially normal peers. Spearman’s correlation test was conducted to assess the relationship between age and central auditory processing abilities in children with NSCLP.

Chapter 4

Results

The present study aimed to compare the central auditory processing abilities and working memory of children with non-syndromic cleft lip and palate (NSCLP) with the developed normative. A total of sixteen children with NSCLP with normal hearing sensitivity were recruited in this study. Among them, eight were bilateral repaired cleft palate (RCP), five were unilateral repaired cleft lip and palate (RCLP), and three were bilateral RCLP. Fifteen craniofacially normal peers participated to compare the working memory abilities and temporal resolution abilities of children with NSCLP.

Before subjecting the data to statistical analysis, a test of normality was done to assess whether the data was normally distributed. The Shapiro-Wilk test showed that the data did not fulfill the assumptions of normality ($p<0.05$) for all the central auditory processing tests. Hence, non-parametric statistics were used to evaluate the significance of the difference of various tests. However, for working memory tests, the data fulfilled the assumptions of normality ($p>0.05$). Hence, parametric tests assessed the significant difference in working memory between children with NSCLP and craniofacially normal peers. The results of the study are discussed under the following headings:

1. Comparison of auditory closure abilities between children with NSCLP with the developed normative.
2. Comparison of temporal processing abilities between children with NSCLP with the craniofacially normal peers.
3. Comparison of binaural processing abilities between children with NSCLP with the developed normative.

4. Comparison of working memory abilities between children with NSCLP with the craniofacially normal peers.
5. Estimating the relationship between age and central auditory processing measures in children NSCLP.

Speech in noise test in Kannada (SPIN-K) was used to assess auditory closure abilities, dichotic CV and masking level difference (MLD) were administered to examine binaural processing and temporal resolution ability was assessed by using a gap detection test (GDT). Forward and backward digit tests were utilized to assess auditory working memory. Table 4.1 shows the mean, median, range, and standard deviation (SD) for all the central auditory processing tests in children with NSCLP.

Table 4.1

Mean, Median, Range, and SD of various auditory processing tests for children with NSCLP

Auditory processing test	Mean	Median	Range		SD
			Minimum	Maximum	
SPIN R (No. of words repeated)	12.38	12.50	5	16	2.87
SPIN L (No. of words repeated)	12.06	12.50	7	16	2.86
GDT R (ms)	10.31	9.14	3.15	20.20	6.25
GDT L (ms)	10.42	8.60	3.12	21.30	6.54
DSC R (No. of syllables repeated)	12.87	13.00	8	16	1.96
DSC L (No. of syllables repeated)	12.00	13.00	7	15	3.29
DDC (No. of syllables repeated)	4.69	5.00	2	7	1.99
MLD (dB)	12.91	10.00	10	15	2.56
Forward digit span	2.79	3.00	1.0	4.4	1.06
Backward digit span	1.91	2.05	0	3.1	0.92

SPIN R= Speech perception in noise scores of the right ear
SPIN L= Speech perception in noise scores for left ear
GDT R = Gap detection thresholds for right ear
GDT L = Gap detection thresholds for left ear
DSC R= Dichotic single correct score for right ear
DSC L= Dichotic single correct score for left ear
DDC = Dichotic double correct scores
MLD = Masking level difference

4.1 Comparison of auditory closure abilities among children with NSCLP with the normative

A speech-in-noise test in Kannada (SPIN-K) was administered to assess auditory closure abilities. Scores were calculated as the number of words correctly repeated by the participants. Table 4.1 shows the mean and SD of SPIN-K scores for the right and left ear. For comparison, normative data were taken from the study by Nigam and Jain (2020). Table 4.2 shows the mean SPIN scores for the current study and the developed norms.

Table 4.2

Mean and SD of established norms for SPIN-K (Nigam & Jain, 2020) and NSCLP group.

Auditory processing test	Normative		NSCLP	
	Mean	**SD**	**Mean**	**SD**
SPIN R (No. of words repeated)	18.53	1.73	12.38	2.87
SPIN L (No. of words repeated)	18.33	1.91	12.50	2.86

Table 4.2 shows that the SPIN scores derived from the present study were less than developed normative. Further, a One-sample Wilcoxon signed-rank test was used to compare the SPIN-K scores between NSCLP children and established norms. The results showed that there was a significant difference in SPIN scores between NSCLP children and established norms for the right ear ($Z= -3.526$; $p=<0.001$) and left ear ($Z= -3.529$;

p=<0.001). It was also noted that SPIN R was affected in 93% (cut-off =16.8; mean-1SD) of the NSCLP children, and SPIN L was affected in 87% (cut-off =16.4; mean-1SD) of the NSCLP children. Also, the mean SPIN-K scores and SD for different types of clefts are represented in Table 4.3. It can be noted from Table 4.3 that the SPIN K scores were poorer in the RCP group compared to both the other types of clefts. However, no statistical comparison was done as the number of participants in each group was less.

Table 4.3

Mean and SD of SPIN-K in different types of clefts

Auditory processing test	U/L RCLP		B/L RCLP		B/L RCP	
	Mean	SD	Mean	SD	Mean	SD
SPIN R (No. of words repeated)	13.60	2.40	13.00	2.64	11.38	3.15
SPIN L (No. of words repeated)	12.80	3.11	12.00	2.64	11.63	3.06

4.2 Comparison of temporal processing abilities among children with NSCLP with the craniofacially normal peers

Temporal resolution ability was measured through GDT. The GDT thresholds were measured using the MLP function in MATLAB in children with NSCLP and the craniofacially normal peer control. Table 4.4 displays the mean and SD of the GDT thresholds for both groups.

Table 4.4

Mean and SD of GDT in children with NSCLP and control group.

Auditory processing test	Control group		NSCLP	
	Mean	**SD**	**Mean**	**SD**
GDT R (ms)	4.28	1.16	10.31	6.25
GDT L (ms)	4.31	1.43	10.42	6.54

From Table 4.4, it can be noted that GDT thresholds are higher in children with NSCLP compared to the control group. Further, the Mann-Whitney U test was administered to find the significant difference in GDT thresholds between the two groups. The results showed a significant difference in GDT thresholds among children with NSCLP and the control group for the right ear (Z= -2.753; p=0.006) and left ear (Z= -2.375; p=0.018). It was also noted that GDT for the right ear was affected in 81% (cut-off =3.12; mean-1SD) of NSCLP children, and GDT for the left ear was affected in 93% (cut-off =2.88; mean-1SD) of NSCLP children. Also, the mean GDT thresholds across different cleft types are displayed in Table 4. 5. It can be noted from Table 4.5 that the GDT is the poorest in the RCP group, followed by U/L RCLP and then B/L RCLP. However, no statistical comparison was made as the number of participants in each group was less.

Table 4.5

Mean and SD of GDT thresholds for different types of clefts

Auditory processing test	U/L RCLP		B/L RCLP		B/L RCP	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
GDT R (ms)	10.08	6.04	7.56	7.08	11.49	6.93
GDT L (ms)	10.94	5.37	6.12	4.37	11.70	7.44

4.3 Comparison of binaural processing abilities among children with NSCLP with the normative

A dichotic consonant-vowel test was administered to assess binaural integration, and scores were calculated as right single correct, left single correct, and double correct scores. Table 4.1 represents the mean and SD of right single correct, left single correct and double correct scores of dichotic CV. For statistical comparison purposes, normative data of dichotic CV were taken from Gowri and Yathiraj (2001). Table 4.6 shows the mean scores of dichotic CV for the current study and developed normative.

Table 4.6

Mean and SD of established norms for Dichotic CV (Gowri & Yathiraj, 2001) and NSCLP group.

Auditory processing test	**Normative**		**NSCLP**	
	Mean	**SD**	**Mean**	**SD**
DSC R (No. of syllables repeated)	21.68	3.41	12.87	1.96
DSC L (No. of syllables repeated)	20.44	3.52	12.00	3.29
DDC (No. of syllables repeated)	14.24	5.35	4.69	1.99
Right ear advantage (DSCR-DSCL)	1.24		0.87	

Table 4.6 shows that the dichotic CV scores obtained from the present study were lesser than the established normative. Statistical analysis was done through a One-sample Wilcoxon signed rank test to compare the dichotic CV scores between NSCLP group children and developed normative. The results suggested that there was a significant difference in dichotic CV scores among the children with NSCLP with the developed normative for right single correct (Z= -3.535; p=<0.001), left single correct (Z= -3.526;

p=<0.001), and double correct scores (Z= -3.533; p=<0.001). It was also noted that 100% of children with NSCLP had affected dichotic CV single correct and double correct scores. Table 4.7 depicts the mean dichotic CV single correct and double correct scores across different types of clefts. It can be noted from Table 4.7 that the dichotic scores were poorer in the RCP group compared to both the other types of clefts. It can also be noted that the RCP group had a larger right ear advantage (REA) compared to the other two cleft groups. However, no statistical comparison was done as the number of participants in each group was less.

Table 4.7

Mean and SD of dichotic CV for different cleft types

Auditory processing test	**U/L RCLP**		**B/L RCLP**		**B/L RCP**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
DCV R (No. of syllables repeated)	13.60	1.86	13.33	1.15	12.25	2.25
DCV L (No. of syllables repeated)	13.00	1.86	13.00	2.64	11.00	2.44
DCV D (No. of syllables repeated)	6.00	1.87	6.00	1.73	4.00	2.07
REA (DSCR-DSCL)	0.60		0.33		1.25	

4.3.2 Comparison of binaural interaction abilities among children with NSCLP with the developed normative

MLD was utilized to assess the binaural interaction ability. MLD values are calculated as the masked threshold difference between antiphasic and homophasic conditions. The higher the threshold difference, suggests better release from masking. Table 4.1 demonstrates the mean and SD of MLD for children with NSCLP. The normative developed by Lavanya and Jain (2019) was used for statistical comparison. Table 4.5 displays the mean MLD thresholds for the current study and the established norms.

Table 4.8

Mean and SD of developed norms (Lavanya & Jain, 2019) and NSCLP group.

Auditory processing test	Normative		NSCLP	
	Mean	**SD**	**Mean**	**SD**
MLD (dB)	13.45	2.21	13.43	2.56

A One-sample Wilcoxon signed-rank test was used for statistical analysis to compare the MLD scores derived from the current study and developed normative. The results showed no significant difference in MLD thresholds (Z= -0.108; p=0.914) between the children with NSCLP and the norms. The mean MLD thresholds of different cleft groups are represented in Table 4.9.

Table 4.9

Mean and SD of MLD thresholds for different types of clefts.

Auditory processing test	U/L RCLP		B/L RCLP		B/L RCP	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
MLD (dB)	12.00	2.73	13.33	2.88	11.88	2.58

4.4 Comparison of working memory abilities among children with NSCLP with craniofacially normal peers

Forward-digit and backward-digit tests were administered to evaluate working memory abilities in children with NSCLP and on craniofacially normal peers. Table 4.10

shows the mean and SD of forward and backward digit tests in children with NSCLP and craniofacially normal peers.

Table 4.10

Mean and SD of forward digit and backward digit test in NSCLP children and craniofacially normal peers.

Auditory processing test	Normal		NSCLP	
	Mean	**SD**	**Mean**	**SD**
Forward digit	4.26	1.01	2.79	1.06
Backward digit	2.77	0.81	1.91	0.92

It is evident from Table 4.10 that the forward-digit and backward-digit scores of NSCLP children were lesser than those of craniofacially normal children. As the working memory data was normally distributed based on the Shapiro-Wilk test (p>0.05), an independent t-test was done to compare the forward-digit and backward-digit scores between NSCLP children and craniofacially normal children. The results revealed that there was a significant difference in both forward digit (t= 3.928; p=<0.001) and backward digit span test (t= 2.722; p=0.011) between children with NSCLP and craniofacially normal peers. Further, it was noted that, in the forward digit span test, 50% (cut-off= 3.25; mean-1SD) of children with NSCLP were affected and 56% (cut-off= 1.96; mean-1SD) of the NSCLP children had affected backward digit span scores. Also, the mean and SD of forward-digit and backward-digit span test scores for different cleft groups are shown in Table 4.11. It can be noted from Table 4.11 that the working memory scores were poorer in the RCP group compared to both the other types of clefts.

Table 4.11

Mean and SD of forward digit and backward digit in different cleft group

Auditory processing test	U/L RCLP		B/L RCLP		B/L RCP	
	Mean	SD	Mean	SD	Mean	SD
Forward digit	3.00	1.09	3.63	0.83	2.35	1.00
Backward digit	2.04	0.89	2.36	0.80	1.67	1.01

4.5. Relationship between age and central auditory processing abilities measures in children with NSCLP

The relationship between age and central auditory processing abilities was analyzed in children with NSCLP. The Spearman correlation test was administered for statistical analysis. The results showed a significant positive correlation between age and dichotic single correct scores for the right (r= 0.742, p=0.038) and left ear (r= 0.892, p=0.020) among all the central auditory processing measures. The scatter plots for the significant correlations and the linear regression lines are shown in Figures 4.1 and 4.2. From the Figures, it can be noted that as the age increases, there is an improvement in scores.

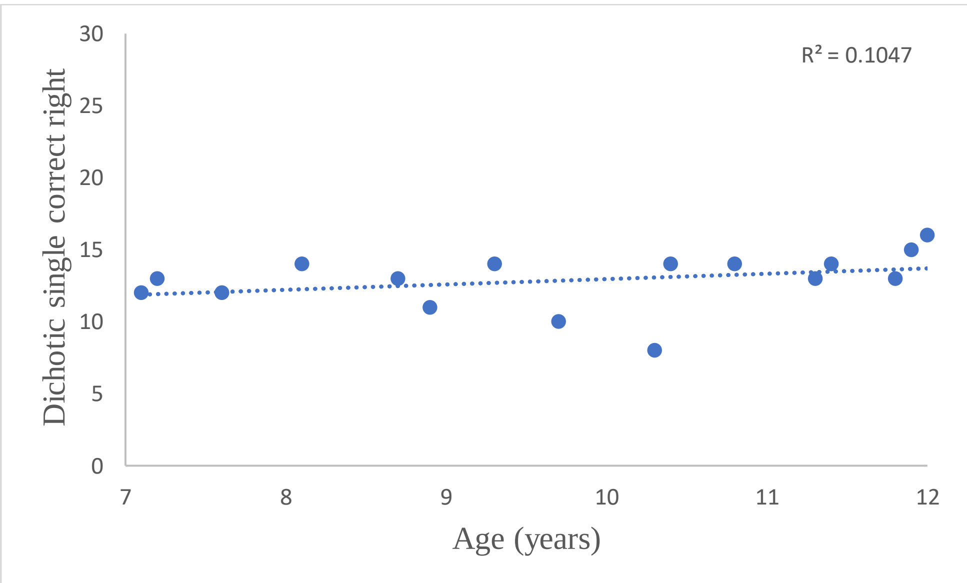

Figure 4.1

Scatter plot depicting the positive correlation between age and dichotic CV right ear scores.

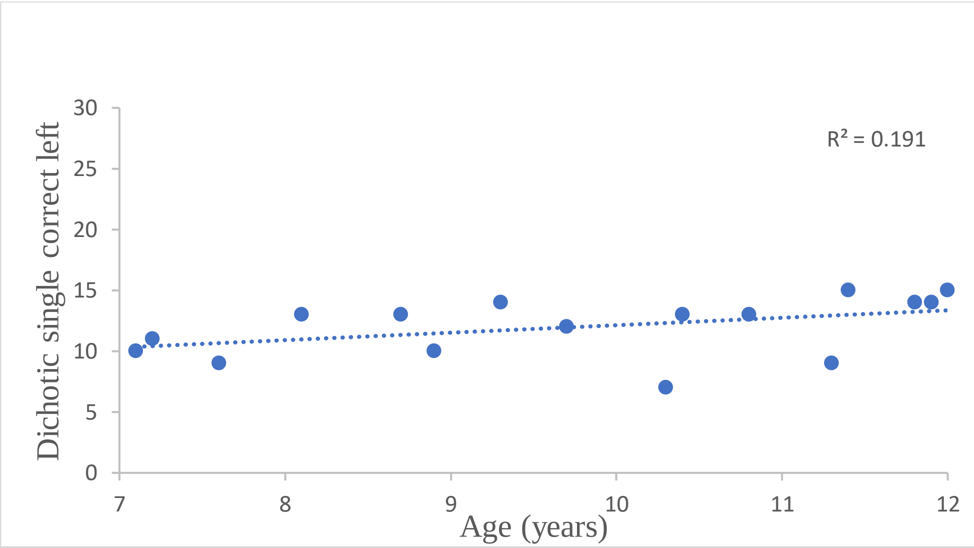

Figure 4.2

Scatter plot depicting the positive correlation between age and dichotic CV left ear scores.

Chapter 5

Discussion

The purpose of the present study was to evaluate the central auditory processing abilities in children with NSCLP. The study's main objective was to compare the central auditory processing abilities of children with NSCLP with developed normative and to compare the working memory and temporal resolution of children with NSCLP with craniofacially normal age-matched controls.

5.1 Central auditory processing abilities in children with NSCLP

Auditory processing deficits are commonly linked in children with NSCLP. Studies have assessed various central auditory processing abilities in NSCLP children (Cayres Minardi et al., 2004; Feng & Lu, 2016; Ma et al., 2015; Zarei et al., 2021). Results from these studies suggest that children with NSCLP are at risk of developing central auditory processing deficits. Because of their malformed palate, children with NSCLP have a higher risk of recurrent middle ear infections. Middle ear infections in the early stages lead to anatomical and functional alterations in the children's auditory system. Khavarghazalani et al. (2016) stated that recurrent otitis media in children can lead to auditory processing disorder due to interruption in the auditory information during the critical period. Fluctuations in hearing loss caused by middle ear infections lead to inconsistent auditory information transmission and impact neural connection formation (Zarei et al., 2021).

Several brain imaging studies show that individuals with NSCLP have radiologically abnormal cortical regions and noticeable variations in the left temporal lobe (Chollet et al., 2014; Nopoulos et al., 2007). According to Nopoulos et al. (2002), the anterior cerebrum was larger in children with NSCLP than the posterior cerebrum, leading to various processing deficits. The developmental pattern of the brain might be abnormal in children with NSCLP compared to typically developing children (Feng & Lu, 2016).

The current study evaluated different central auditory processing abilities in children with NSCLP. Speech perception in noise (SPIN), gap detection threshold (GDT), dichotic CV, and masking level difference (MLD) were utilized to assess various central auditory processing abilities. Working memory was assessed by administering forward and backward digit span tests.

5.2. Auditory closure abilities in children with NSCLP

The ability of the normal person to utilize intrinsic and extrinsic redundancy to fill in missing or distorted portions is referred to as auditory closure (Musiek & Chermak, 2013). Auditory closure ability in the current study was assessed using SPIN-K. Results of the current study suggest a significant difference in SPIN-K between children with NSCLP and developed normative. Studies in the literature also suggest that speech intelligibility in the presence of noise is impaired in children and adults with NSCLP (Feng & Lu, 2016; Hofer-Martini et al., 2021; Zarei et al., 2021). In the current study, children with repaired cleft palate (RCP) had poorer mean SPIN-K scores than children with repaired cleft lip and palate (RCLP). As per the author's knowledge, this is the first study to report the effect of cleft type on auditory closure ability.

Normal cortical structure and function are required to perceive speech in a noisy environment (Ma et al., 2016). Shriver et al. (2006) reported that structural malformation in the superior temporal plane may cause higher auditory processing deficits in children with NSCLP. It has been reported that individuals with NSCLP had smaller temporal and parietal lobes than normal individuals. So, a cortical deficit in children with NSCLP may have a negative effect on auditory closure abilities (Nopoulos et al., 2007).

5.3 Temporal processing abilities in children with NSCLP

Temporal processing refers to the abilities related to processing of acoustic signal's time-related aspects (Bellis, 2001). In the present study, temporal resolution ability was assessed using GDT. The results showed that GDT significantly differed among the two groups, and children with NSCLP had larger GDT than craniofacially normal peers. Similar findings have been reported in the literature (Feng & Lu, 2016; Ma et al., 2015; Maximino et al., 2022; Zarei et al., 2021). The findings of these mentioned studies show that children with NSCLP have problems perceiving the rapid changes in the stimulus and have the risk of developing temporal resolution disability (Feng & Lu, 2016; Ma et al., 2015; Maximino et al., 2022; Zarei et al., 2021).

The presence of recurrent middle ear infections in children with NSCLP can disrupt normal auditory processing and may have a negative impact on temporal processing (Zarei et al., 2021). Boscariol et al. (2009) also mentioned in their study that middle ear infection can lead to a longer period of sensory deprivation in children with NSCLP, which may affect their temporal processing ability.

Temporal processing ability is also sensitive to cortical and interhemispheric lesions (Bellis, 2001). Ma et al. (2016) suggested that normal cortical function is required for temporal processing ability. Studies have reported abnormal cortical regions in children with NSCLP compared to craniofacially normal peers, which also can lead to temporal processing deficits (Chollet et al., 2014; Nopoulos et al., 2007).

5.4 Binaural processing abilities in children with NSCLP

5.4.1 Binaural integration abilities in children with NSCLP

Binaural integration is the ability to process the information presented to both ears simultaneously, with the information presented to each ear being different (Musiek &

Chermak, 2013). The present study used a dichotic CV test to assess binaural integration ability in children with NSCLP. Results showed a significant difference in dichotic CV single correct and double correct scores between children with NSCLP and established normative. Similar reports have been reported in the literature (Boscariol et al., 2009; Cristina et al., 2008; Do Amaral et al., 2010). Studies have shown that children with NSCLP had significantly reduced dichotic scores compared to craniofacially normal peers (Boscariol et al., 2009; Cristina et al., 2008; Do Amaral et al., 2010). Higher right ear advantage (REA) has also been seen in children with NSCLP compared to craniofacially normal peers (Zarei et al., 2021). On the contrary, Feng & Lu. (2016); Hofer-Martini et al. (2021) noticed no significant difference in dichotic digit scores between children with NSCLP and craniofacially normal peers. The difference in findings can be attributed to the different stimuli used for assessing binaural integration abilities in these studies (Jäncke et al., 1992). It can be concluded that dichotic CV is a sensitive measure to differentiate the two groups regarding binaural integration abilities.

Binaural integration requires a normal and integrated auditory system. Structures like the corpus callosum and cortex are involved in binaural processing (Zarei et al., 2021). Borges et al. (2013) reported that a deficit in dichotic tests could result from maturational delay or poor neural connectivity caused by recurrent otitis media in children. Fluctuations in the binaural hearing caused by recurrent otitis media may have a negative effect on the development of binaural integration ability (Boscariol et al., 2009).

5.4.1 Binaural interaction abilities in children with NSCLP

Binaural interaction refers to how the two ears interact. Localization and lateralization of auditory stimuli, binaural release from masking, detection of signals in noise, and binaural fusion are all functions that rely on binaural interaction `(Durlach et al., 1981). In the present study, MLD was used to assess binaural interaction, and the results showed no significant differences in MLD thresholds between children with NSCLP and developed normative. Similar results have been reported in the literature (Boscariol et al., 2009; Do Amaral et al., 2010). Studies have shown normal binaural interaction abilities in children with NSCLP. It can be concluded from the results of the present study that the lower brain stem structures are not affected in children with NSCLP.

However, only a few studies have been done to examine binaural interaction abilities in children with NSCLP, and further studies are needed to assess binaural interaction abilities in children with NSCLP with various tests.

5.5 Working memory abilities in children with NSCLP

Working memory refers to a brain's ability to store temporarily and manipulate information necessary for complex cognitive tasks (Baddeley, 1992). The present study used forward-digit and backward-digit span tests to assess auditory working memory. Results of the study showed that children with NSCLP had significantly poorer forward and backward digit scores compared to craniofacially normal peers. Previous research has reported similar findings (Bodoni et al., 2020; Conrad et al., 2009; Richman & Ryan, 2003). Studies have shown that children with NSCLP had reduced working memory abilities compared to craniofacially normal peers. In contrast to the above findings, Boscariol et al. (2009) reported normal working memory abilities in children with NSCLP.

Abnormal brain structures in children with NSCLP can cause working memory deficits and reduced cognitive function (Devolder et al., 2013; Nopoulos et al., 2007). Temporal lobe enlargement in children with NSCLP is directly associated with lower cognitive functions and reduces working memory (Conrad et al., 2014). Reading–related language disorder in children with NSCLP leads to early language problems, such as working and auditory memory deficits between the ages of 4 and 6 years (Richman & Ryan, 2003). Reduced cortical thickness in bilateral parietal lobes, supramarginal gyrus, and pars orbitalis are also responsible for working memory deficits in children with NSCLP (Bodoni et al., 2020).

5.6 Relationship between age and central auditory processing abilities measures in children with NSCLP

Results of the present study showed that only single correct dichotic scores showed a positive correlation with age in children with NSCLP. None of the other auditory processing abilities showed a relationship with age in children with NSCLP. Similarly, Ma et al. (2015) reported no relationship between age and temporal resolution abilities measures in children with NSCLP. The authors stated that age does not affect temporal resolution abilities in children with NSCLP.

However, only one study has been done to estimate the relationship between age and central auditory processing abilities in children with NSCLP. It is difficult to conclude these limited studies. Future studies should be done with a larger population to estimate the relationship between age and central auditory processing abilities in children with NSCLP.

Chapter 6

Summary and Conclusion

The present study assessed the central auditory processing and working memory abilities of children with non-syndromic cleft lip and palate (NSCLP). The study's main objective was to compare the central auditory processing abilities of children with NSCLP with developed normative and to compare the temporal resolution and working memory of children with NSCLP with craniofacially normal peers. A total of 16 children with NSCLP between the ages of 7 and 12 years were recruited in the study. Fifteen craniofacially normal peers participated to compare the working memory abilities and temporal resolution among children with NSCLP. The assessment of central auditory processing measures included speech perception noise in Kannada (SPIN-K), gap detection threshold (GDT), dichotic CV (DCV), and masking level difference (MLD). Forward-digit and backward-digit span tests were administered to assess the working memory. Further, the relationship between age and central auditory processing abilities measures was also assessed in children with NSCLP.

Results revealed that,

- There was a significant difference in mean SPIN-K scores between children with NSCLP and normative.
- There was a significant difference in GDT thresholds between children with NSCLP and craniofacially normal peers.
- Mean dichotic CV single and double correct scores were significantly poorer in children with NSCLP compared to normative.
- MLD thresholds were not affected in the NSCLP group, indicating spared binaural interaction abilities in children with NSCLP.

- There was a significant difference in forward and backward digit span test scores between children with NSCLP and craniofacially normal peers.
- Relationship between age and central auditory processing measures showed a positive correlation between age and dichotic CV single correct scores in children with NSCLP.

The present study's findings support the previous literature confirming the important role of central auditory processing assessment in children with NSCLP. Thus, assessing the central auditory processing abilities in children with NSCLP is recommended. There is a need to identify the problem in the initial stages to provide suitable rehabilitation.

6.1 Implications of the study

- An APD screening checklist for all children with NSCLP is recommended. It is also advised that diagnostic CAPD tests be administered for children with NSCLP for early identification and rehabilitation.
- The study provides evidence to counsel parents on the importance of diagnosing and managing CAPD in children with NSCLP.

6.2 Future direction

- Future research on larger participants with NSCLP to assess the effect of different cleft types, to compare the effect of unilateral vs. bilateral cleft, and to estimate the relationship between age and central auditory processing ability in children with NSCLP is recommended.
- More studies are required to assess the effect of otitis media on auditory processing, such as the number and duration of episodes, chronicity of occurrence, and history of hearing loss.

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