Comparison of Various Binaural Interaction Tests in Children who are at Risk for CAPD and Typically Developing Children

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A dissertation submitted in part of fulfillment of the degree of Master of Science (Audiology)

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May, 2019

CERTIFICATE

This is to certify that this dissertation entitled "**Comparison of various binaural interaction tests in children who are at risk for CAPD and typically developing children"** is a bonafide work submitted in part fulfillment for the degree of Master of Science (Audiology) of the student registration No: 17AUD025. This has been carried out under the guidance of faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru
May, 2019

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Mysuru
May, 2019

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DECLARATION

This is to certify that this dissertation entitled "**Comparison of various binaural interaction tests in children who are at risk for CAPD and typically developing children"** is the result of my own study under the guidance of Dr. Chandni Jain, Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Manasagangothri, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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Abstract

Binaural interaction refers to the way in which the two ears work together. Functions that rely on behavioural interaction include localization and lateralization of the auditory stimuli, binaural release from masking, detection of signals in noise and binaural fusion. The present study aimed to compare various binaural interaction tests in children who were at risk for central auditory processing disorders (CAPD) and typically developing children. A total of 41 children within the age range of 7-12 years participated in the study. They were divided into two groups: the control group consisted of 23 typically developing children, and the clinical group consisted of 18 children who were at risk for CAPD. Masking level difference (MLD), Binaural fusion test (BFT), localization and Interaural time difference (ITD) tests were done to assess the binaural interaction abilities. Results revealed that MLD and BFT differed significantly among two groups, but there was no difference noted for localization and ITD tests. Hence it can be concluded that a test battery including MLD and BFT would be more useful in identifying binaural interaction deficits clinically.

Key words; Masking level difference, Binaural fusion test, Localization and Interaural time difference (ITD).

Chapter 1

Introduction

Auditory processing refers to the efficiency and effectiveness with which the central auditory nervous system (CANS) uses auditory information. Auditory processing is the basis for complex actions such as understanding spoken language, not being a closed process, interacting intimately with other neural systems and being influenced by experience, environment, and active training; its alteration affects negatively the quality of life of many people. Auditory processing mechanisms underlie the following skills: auditory discrimination, temporal processing, binaural processing and auditory performance with competing or degraded acoustic signals including dichotic listening (ASHA, 2005). In short, the auditory processing is the effective use of auditory information; that is what a human being does with what he or she hears.

Central Auditory Processing Disorder (CAPD) refers to deficits in the neural processing of auditory information in the CANS which is not due to any higher order language or cognition, as demonstrated by poor performance in one or more of the skills listed above (ASHA, 2005). The diagnosis of CAPD is done using a test battery approach that would be able to detect different processing difficulties seen in children with CAPD (ASHA, 2005). In selecting tests, the clinicians should consider the age, gender, specific functional deficits, memory and attentional capabilities, cultural and linguistic background of each individual.

The prevalence of CAPD is estimated to be 5-7% with a 2:1 ratio between boys and girls (Chermak & Musiek, 1997). In an Indian study, Shivashankar and Gururaj (1993) reported that around 26.9% of academically backward students had CAP problems. In another study, the prevalence of CAPD was reported to be 3.2% on 3,120 school children aged 8 to 15 years (Muthu Selvi & Yathiraj, 2010).

The categorization of central auditory tests for the diagnosis of CAPD have been given by various authors (ASHA, 1996; Bellis, 1996; Bellis & Ferre, 1999 and Chermak & Musiek, 1997). The categorization is made based on the process (es) the tests assess and/or how the auditory signals are delivered to the ears. These authors categorized behavioral tests of central auditory function into – dichotic speech tests, monaural low redundancy tests, tests of temporal ordering and binaural interaction tests.

Auditory processing abnormalities are seen in a range of disorders like Attention deficit hyperactive disorder, Dyslexia, Learning disabilities, etc. Assessment includes a test battery of both behavioural and electrophysiological measurements. ASHA (2005) has recommended using behavioural measures for the assessment of CAPD as they are sensitive to CANS lesions in conjunction with electroacoustic and electrophysiological measures. However, there is little agreement with what tests should be used within the battery among the professionals. Most of the clinicians depend on both electroacoustic and behavioural tests in clinical settings, as they are readily available for diagnostic use than electrophysiological tests (Emanuel, 2002; Jerger & Musiek, 2000).

1.1. Binaural Interaction

Binaural interaction refers to the way in which the two ears work together. Functions that rely on binaural interaction include but are not limited to binaural release from masking, detection of signals in noise, localization, and lateralization of the auditory stimuli and binaural fusion (Durlach, Thompson & Colburn, 1981).

Binaural interaction tests assess the ability of the CANS to process different but complementary information presented to both ears. Difficulties in locating the direction of the sound source, perceiving speech in noisy environments, or perceiving speech in environments where there are many people speaking at the same time may be associated with impairment of normal binaural interaction functions (Chermak & Musiek, 1997). In summary, binaural interaction is the ability to perceive and organize the sounds of the environment, which depends heavily on the simultaneous use of the two ears, on the neural interaction that occurs with the signals received by the two ears, and on how the hearing information is processed.

The evaluation of binaural interaction consists of four main behavioural procedures including; The Binaural Fusion test (BFT), The Masking Level Difference (MLD) test, the Localization, the Lateralization/ Interaural time difference (ITD) tests and, the Rapidly Alternating Speech Perception (RASP) test. BFT help in assessing binaural interaction abilities in which low pass and high pass filtered speech stimuli are presented to both ears together. Filtering of the speech stimuli using low and high pass filter results in unintelligible speech when presented monaurally. However, presenting the filtered stimuli together to both ears show a fusion of this information thereby helping in recognition of stimuli (Wilson, Arcos & Jones, 1984).

The MLD is a psychoacoustic phenomenon in which the detection or recognition of a monaural or binaural signal presented is improved in the presence of competitive binaural noise. This improvement is due to our auditory system which makes use of a subtle binaural event to find out the differences in amplitude levels between simultaneously presented signals or masked signals. The MLD represents an advantage in the detection or recognition of the altered binaural phase in reference to the unchanged condition phase (Paula, Frota & Felipe, 2007).

Auditory localization is defined as the ability to identify signal positions. This location of sound provides an important cue for separating relevant information from irrelevant auditory information. Localization involves detecting the sound source in free-field whereas it will be termed as lateralization when the task is done using headphones. Children with CAPD may have problems in the localization of sound source especially in those children who were found to have auditory maturation delay (ASHA,1996).

1.2. Need for the Study

In spite of the availability of the tests mentioned above of binaural interaction for the assessment of CAPD, MLD is the most often used test clinically. Studies have shown mixed results regarding the sensitivity of MLD in the diagnosis of CAPD. Olsen et al., (1976) reported low MLD thresholds in participants with subcortical central lesions such as multiple sclerosis. Similarly, Lynn et al., (1981) reported that cortical lesions have no significant effect on MLDs for pure tones as well as speech, but subcortical lesions such as multiple sclerosis or any other brainstem pathologies have MLDs that are significantly smaller than normal.

In contrary, Kumar, Singh, and Ghosh (2013) assessed MLD in children at risk for CAPD and with no reading difficulties. They found no difference in MLD scores between children at risk for CAPD and typically developing children. Similarly, Roush and Tait (1984) reported no significant difference in MLDs between normal children and children with risk for developing CAPD. Similar reports were noted by Jeena and Kumar (2017) who reported comparable performance among children who were at risk for CAPD and typically developing children in MLD.

Further, there are studies which have shown that BFT is more sensitive than MLD in identifying children with binaural interaction deficit (Singer, Hurley, & Peece, 1998; Roush & Tait, 1984; Welsh, Welsh, & Healy,1980). Roush and Tait (1984) assessed binaural interaction using BFT, MLD and auditory brainstem response (ABR) in a group of children with language learning disabilities. They reported that there was a significant difference for BFT but not for MLD between normal children and children with risk for developing CAPD.

Moreover, there is limited research regarding the use of localization and ITD tests for the assessment of binaural interaction abilities in CAPD. Zakaria (2007) reported that children with CAPD have significant difficulties in localizing front/back and up/down positions which were apparent when the two sounds were separated using interaural intensity difference (IID) and interaural level difference (ILD) cues. Dillon and Cameron (2013) also reported that a substantial portion of children with CAPD suffers from spatial processing disorder which interferes with sound source segregation and understanding speech in the presence of competing signal.

Thus, from the above literature, it can be noted that studies have been done to assess binaural interaction using either one test or a combination of behavioral and electrophysiological measures. However, all the behavioral tests have not been assessed in one individual to comment on which test is more sensitive for the assessment of CAPD. Hence, there is a need to study all the behavioural binaural interaction tests in children who are at risk for CAPD and to find out the most sensitive test among the four. At present, MLD is most often used test in clinical settings as it is easily available in audiometers, but as discussed above studies have shown mixed results related to its sensitivity for the diagnosis of CAPD.

1.3. Aim of the Study

The aim of the present study was to compare various binaural interaction tests in children who are at risk for CAPD and typically developing children.

1.4. Objectives of the Study

To fulfill the above aim following objectives were used:

- To compare binaural interaction abilities using masking level difference, binaural fusion test, localization and interaural time difference (ITD) test in children who are at risk for CAPD and typically developing children.
- To compare the findings of different binaural interaction tests in the diagnosis of children who are at risk for CAPD.

Chapter 2

Review of Literature

Auditory processing is referred to as the effective and efficient use of auditory information through the central nervous system (CNS). Auditory processing mechanisms underlie the following skills: auditory discrimination, temporal processing, binaural processing and auditory performance with competing or degraded acoustic signals (including dichotic listening; ASHA, 2005). In short, the effective use of auditory information; that is what a human being does with what he or she hears is termed as the auditory processing.

Central Auditory Processing Disorder (CAPD) refers to the deficits in the neural processing of auditory information in the CNS which is not a consequence of any higher order process involved in language or cognition, as revealed by reduced performance in any one or more of the skills listed (ASHA, 2005). CAPD assessment makes use of special tests that assess various auditory functions. However, before the testing of CAPD beings, each person must receive a routine hearing test to assess the functioning of the peripheral auditory system (Chermak & Musiek, 1997). The behavioural tests used in the assessment of CAPD include:

- Dichotic Tests (Musiek & Pinheiro, 1985)
- Monaural Low –Redundancy Speech (Jerger & Jerger, 1971)
- Temporal Processing Tests (Pinheiro, 1977)
- Binaural Interaction Tests (Matzker, 1959)

2.1. Dichotic tests

The two main categories of dichotic speech task used clinically are binaural separation and binaural integration tasks. Binaural separation includes directing attention to listen to a target stimulus while binaural integration task includes recognition of both signals in the dichotic paradigm. Commonly used binaural separation tests are competing sentences, and synthetic sentence identification with the contralateral competing message (SSI- CCM) (Musiek & Pinherio, 1985). Whereas binaural integration tests consist of dichotic digits, dichotic consonant-vowels, dichotic sentence identification (DSI) and staggered spondaic words (SSW) (Bellis, 1996; Musiek & Pinheiro, 1985).

2.2. Monaural Low- Redundancy Speech (MLRS) Tests

In monaural low- redundancy speech tests (MLRS)**,** the speech signals are found to be degraded or in the presence of competing acoustic signal. Speech stimuli that are filtered, compressed, expanded, interrupted or reverberated are used as the stimuli for MLRS tests (Musiek & Baran, 1987; Rintelmann, 1985). Also, the target speech signals in the presence of competing speech signals, noise, or are altered in intensity have been used in the assessment process in an individual. As a group, this category of tests does not have a high sensitivity or specificity; however, they do test processes that are different from the temporal and dichotic procedure (Musiek, Baran, & Pinheiro, 1994). Tests such as low pass filtered speech test (Rintelmann, 1985), the synthetic sentence identification with ipsilateral competing message (Jerger & Jerger, 1974), the compressed speech with reverberation test (Bornstein & Musiek, 1992) and the paediatric speech intelligibility test (Jerger, Jerger, & Abrams, 1983) are the most common tests used in MLRS assessment.

2.3. Temporal Processing Tests

Temporal auditory processing refers to the perception of sound or its alteration in a defined and restricted period, that is, it refers to the ability to perceive or differentiate stimulus that is presented in rapid succession, becoming a fundamental component for greater auditory processing (Paula, Frota & Felipe, 2007). Some commonly used temporal processing tests include; pitch pattern test (PPT) and duration pattern test for assessing temporal ordering, gap detection test (GDT) and gap-in-noise (GIN) for assessing temporal resolution, forward and backward masking for assessing temporal masking and temporal integration tests.

2.4. Binaural Interaction Tests

Binaural interaction tests include a variety of tests to assess the interaction between the two ears (Chermak & Musiek, 1997). Tests such as masking level difference (MLD) (Schoeny & Talbott, 1994), interaural Timing Tasks (Levine et al., 1993), rapidly alternating speech perception (RASP) (Willeford, 1977) and binaural fusion test (BFT) (Matzker, 1959) are used. The above mentioned tests generally assess the ability of the central auditory nervous system to process disparate as well as complementary information to the two ears. In binaural interaction task, the stimuli presented to each ear is composed of a portion of a whole message or presented in a non-simultaneous sequential condition (Bellis, 1996).

2.4.1. Masking Level Difference

MLD, a psychoacoustic phenomenon was first defined by Hirsh et al. (1948) and can be done using a pure tone stimulus or a speech one. The detection or recognition of a monaural or binaural signal presented is improved in the presence of competitive binaural noise. This improvement is due to our auditory system which makes use of a subtle binaural event to find out differences in amplitude levels between simultaneously presented signals or masked signals. The MLD represents an advantage in the detection or recognition of the altered binaural phase in reference to the unchanged condition phase.

Olsen et al., (1976) reported abnormally low MLD thresholds in participants with subcortical central lesions such as multiple sclerosis. Similarly, Lynn et al., (1981) reported that cortical lesions have no significant effect on MLDs for either pure tones or speech, but subcortical lesions such as multiple sclerosis or any other brainstem pathologies have MLDs that are significantly smaller than normal.

MLD is largest at low frequencies, typically between 300-500 Hz (Goldstein & Stephen, 1975; Hall et al., 1984), and often smaller or absent at high frequencies (Goldstein & Stephen, 1975). If pure tones are used in determining MLD, detection paradigm is employed, and if the speech stimulus is used, the speech recognition task is employed. MLD is abnormal in people with brainstem pathologies (Olsen & Noffsinger, 1976; Olsen et al., 1976; Quaranta et al., 1978).

Wilson et al. (2001) performed a series of tests to develop a protocol for MLD that could be used in clinical practice. The authors observed that 95% of the listeners presented MLD greater than or equal to 10 dB, this being the reference value of normality for the test. The version of the MLD that uses pure tones with the help of the audiometer consists of the presentation of a 500 Hz pulsatile tone presented to both the ears and simultaneously a narrow band masking noise is presented binaurally at 40 dB NA. The differential frequency breakpoint of the 500 Hz frequency is determined using steps of 1 dB between three different test conditions: Noise and pure tone presented in the same phase, reversed phase noise in one ear and pure tone in the two ears, pure tone in inverted phase in one of the ears and in phase noise in both ears. The patient is advised to warn when they no longer hear the stimulus presented. MLD is the difference in the masked thresholds in homophasic and antiphasic conditions. Thus, MLD refers to the detection of a breakpoint to the signal that can occur in two masking conditions - S0N0 (homophase) and SπN0 (antiphase) - both signal and masking; they are binaural in phase and out of phase (Ries et al., 2008). Listeners with normal CANS demonstrate masking suppression under MLD conditions, while listeners with CAPD have no/lesser masking suppression. Even though MLD is a central process of interaction of the two ears (sub thalamic), it can be affected by the peripheral auditory system.

In another study, Musiek et al. (2005) suggested performing MLD using a 500 Hz pure tone, presented in both ears along with a continuous broadband noise presented at 60 dBHL. They reinforced both the importance of symmetric and normal breakpoint for MLD research, as well as the variables that may interfere in the study as type of signal used (pure tone, spondee words); the type and level of sound pressure of the noise used and the condition of phase change of one of the stimulus. They reported that MLD values of more than 6 dB should be considered as normal for adults and is sensitive for brainstem lesions.

In contrary, Roush and Tait (1984) reported no significant difference in MLDs between normal children and children with risk for developing CAPD. Similarly, Kumar, Singh, and Ghosh (2013) assessed MLD in children who were at risk for CAPD without reading difficulties in the age range of 8 to 12 years, and they noticed no difference in MLD scores between children at risk for CAPD and typically developing children. Jeena and Kumar (2017) also reported comparable performance among children who were at risk for CAPD and typically developing children in MLD.

To conclude, there are contrary studies related to the sensitivity of MLD on the diagnosis of binaural interaction deficits and few reports suggests that BFT is more sensitive than MLD in the diagnosis of CAPD.

2.4.2. Binaural Fusion Test

Binaural fusion test helps in assessing binaural interaction abilities in which low pass and high pass filtered speech stimuli are presented in both ears together. Filtering of the speech stimuli using low and high pass filter results in unintelligible speech when presented monaurally. However, presenting the filtered stimuli together to both ears shows a fusion of this information thereby helping in recognition of stimuli (Wilson, Arcos & Jones, 1984).

Welsh, Welsh, and Healy (1980) evaluated 77 children with dyslexia but with typical functioning of end organs using competing sentence test, binaural fusion test, rapidly alternating speech perception test, and filtered speech test to. Results showed that over 50% of the children with dyslexia failed in two of the four tests and also found that each child failed at least in one of the test. Among the tests used in the experiment, they found both binaural fusion and filtered speech tests were most sensitive with less variation from the norm.

Roush and Tait, (1984) investigated the binaural interaction performance of 18 children with language learning disabilities with their age-matched typically developing children in the age range of 6 to 12 years. The assessment was carried out using BFT, MLD and auditory brainstem responses. Band pass filtered speech was presented in the dichotic and diotic mode to evaluate binaural fusion. For the binaural fusion tasks, results revealed poorer scores in the clinical group. Although for diotic condition performance of both groups was relatively higher. Their study suggests the efficiency of binaural fusion measures in the assessment of auditory processing abilities in children.

Singer, Hurley, and Peece (1998) investigated individual test efficacy and test battery efficacy of tests such as BFT, filtered speech test, dichotic digit test, SSW, pitch pattern test and time compressed speech test on ninety-one normal learning children and 147 children (7-13 years) with a classroom learning disability (CLD) and presumed CAP disorders (CAPDs). They concluded that the two samples were separated most effectively by BFT and the next most effective test was FST. The best battery approach was found to be the combination of BFT and FST or BFT and MLD when hit rate, false positive rate, and cost factors were considered.

Stollman et al. (2003) compared the performance of a group of 20 children with specific language impairment (SLI) and 20 age-matched control children on several behavioural auditory tests. The behavioural auditory test battery they used consisted of following tests: a speech- in noise test, FST, BFT, a frequency pattern test, a duration pattern test, a temporal integration test, an auditory word discrimination test, an auditory synthesis test, an auditory closure test, and number recall test. The results reported that in almost all tests the SLI children obtained significantly lower (poorer) scores than those of the control group. A significant positive correlation was found between behavioural tests which are basic auditory processing measures and receptive language scores. This, in turn, suggests a relationship between auditory processing and language proficiency.

Penaloza-Lopez et al. (2009) assessed central auditory processing using BFT and filtered word test in 40 children with dyslexia and 40 children without dyslexia in the age range of 8 to 12 years. The results revealed that scores of binaural fusion test and filtered word test was poorer in the dyslexic group compared to children without dyslexia. They concluded that these results would help to expand the rehabilitation plan in these children.

To conclude, above studies show that that BFT is a sensitive tool in identifying children with binaural interaction deficits (Singer, Hurley, & Peece,1998; Roush & Tait, 1984; Welsh, Welsh, & Healy,1980).

2.4.3. Localization and Lateralization tests

Auditory localization is defined as the ability to identify signal positions. This location of sound provides an important cue for separating relevant information from irrelevant auditory information. Localization involves detecting the sound source in free-field whereas it will be termed as Lateralization when the task is done using headphones. Auditory localization and/or lateralization deficit is one of the characteristics of CAPD (ASHA,1996). However, the specific difficulties in CAPD in relation to auditory localization remains unclear and have not been well investigated.

It has been reported that children with CAPD have problems in the localization of sound source especially in those children who were found to have auditory maturation delay. Abnormal performances in auditory ITD tasks have also been found in individuals with auditory brainstem lesions (Zerlin & Mowry, 1980;

Russolo & Poli, 1983; Levine et.al., 1993a, 1993b; Furst et.al., 1995; Aharonson et.al, 1998) as well as lesions within the auditory cortex (Walsh ,1957; Yamada et.al., 1996).

In a study by, Furst et al., (1995), they evaluated the ability to lateralize dichotic clicks with either ITD or interaural level differences (ILD) on seven subjects with multiple sclerosis (MS). They found that two individuals with lesions involving the trapezoid body had normal performance with respect to the ILD. But with respect to dichotic clicks with different ITDs, they perceived those dichotic clicks in the center of the head. They also found that individuals with unilateral lesions in the lateral lemniscus region perceived dichotic clicks each time to the sides when presented. Thus they concluded there is a need for developing a practical as well as a reliable clinical tool to identify the extent to which it affects individuals with early and mild MS. It was also hypothesized that, compared to the standard cognitive tasks, tests such as sound lateralization is found to be more sensitive to detect processing speed deficits in individuals with mild MS.

Zakaria (2007) reported that children with CAPD have significant difficulties in localizing front/back and up/down positions which were apparent when the two sounds were separated using ITD and ILD cues. Dillon and Cameron (2013) reported that a substantial portion of children with CAPD suffered from spatial processing disorder which interferes with sound source segregation and understanding speech in the presence of competing signal.

Similarly, Bacon et al. (2014) assessed sound lateralization test (SLT) on ninety individuals with definite MS but with different severity (no, mild and moderate). They found an overall difference in performance between controls and the three MS groups. A significant difference was observed between controls and the no disability group. Hence, they concluded that SLT is useful in measuring the stages of MS. They also stated that SLT is rapidly applied, technically simple, and superior to other standard processing speed tests.

To conclude, there is limited research regarding the use of localization and ITD tests for the assessment of CAPD. Hence the sensitivity of localization and ITD in the assessment binaural interaction abilities in children at risk of CAPD needs to be studied.

Chapter 3

Method

The aim of the present study was to compare various binaural interaction tests in children who are at risk for central auditory processing disorder and typically developing children.

3.1. Research design

Between subjects, experimental research design was used to fulfill the aim of the study.

3.2. Participants

A total of 41 participants within the age range of 7 to 12 years participated in the present study. They were divided into two subgroups. The clinical group included 18 children (12 males and 6 females) with the mean age of 10.9 years who were at risk for CAPD selected based on scores of SCAP (Screening checklist for auditory processing) and STAP (Screening Test for Auditory Processing). The control group included age-matched 23 children with normal hearing sensitivity (13 males and 10 females) with the mean age of 8.81 years. The individuals who fulfilled the following criteria were included in the present study.

3.2.1. Participant Inclusion criteria

- Hearing sensitivity within normal limits, i.e., air conduction thresholds was less than or equal to 15 dBHL in the frequency ranges of 250 Hz to 8000 Hz for air conduction and from 250 Hz to 4000 Hz for bone conduction in both the ears and the air-bone gap was lesser than 10 dBHL at all frequencies.

- ‘A’ Type Tympanogram and stapedial reflexes present in both ears.
- All participants in the control group passed SCAP (Yathiraj & Mascarenhas, 2003 and 2004) and STAP (Yathiraj & Maggu, 2013). The clinical group was selected as at risk for CAPD based on scores of SCAP and STAP.
- Normal I.Q based on psychological evaluation.
- Studying in schools with English as a medium of instruction at least for two years.

3.1.2. Participant Exclusion criteria

- The participants with any history of otological, neurological and psychological problems or illness on the day of testing were excluded from the study. The details on the above were obtained through a detailed case history.

3.3. Instrumentation

The following instruments were used for the present study.

- Calibrated Inventis piano, dual channel diagnostic audiometer with TDH-39 supra-aural headphone housed in MX-41 AR cushion and B-71 bone vibrator was used for the routine audiological evaluation.
- Calibrated GSI Tympstar Immittance meter was used to assess tympanometry with a probe tone frequency of 226 Hz. The same equipment wase used for measuring ipsilateral as well as contralateral reflexometry at 500, 1000, 2000, and 4000 Hz.

- SCAP and STAP were administered to screen for auditory processing disorder.
- A personal laptop of windows 10 configuration with Intel Core i3 processor was used to present the target stimuli for binaural fusion experiment by connecting it to the audiometer auxiliary input. The Laptop was also loaded with MATLAB version 7.0 and Maximum Likelihood Procedure (MLP) toolbox which was used to measure ITD. The same personal laptop loaded with Adobe Audition version 3 was used to present the stimuli for binaural fusion test (BFT). Stimuli used for the binaural fusion test were words taken from BFT in English (Shivaprasad & Yathiraj, 2006).

3.4. Ambient Noise and Environment

All the tests were carried out in a sound-treated double room set up. It was ensured that the ambient noise level within the test room is within the permissible limits (ANSI S3. 1999).

3.5. Procedure

Written consent was taken from the parents/ guardian of the children before participating in the study. The routine audiological assessment included pure-tone audiometry and immittance evaluation. Audiometric thresholds of both air conduction and bone conduction were estimated from 250 Hz to 8000 Hz and from 250 Hz to 4000 Hz respectively using modified Hughson and Westlake procedure (Carhart & Jerger, 1959). Average of air conduction thresholds at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz was used to arrive at the pure tone average.

Immitance evaluation was carried out on all the participants who had thresholds within 15 dB HL to check the middle ear function. Further SCAP and STAP were administered on all the participants to categorize them into control and clinical group based on the pass and refer results.

3.5.1. CAPD Screening

CAPD screening was done for the selection of participants into control and clinical group using a screening questionnaire (SCAP) and the screening test (STAP). Screening checklist for auditory processing given by Yathiraj and Mascarenhas (2004) was administrated on both the groups. This checklist consisted of 12 questions. Each question is scored on a 2 point rating scales as 'Yes' or 'No.' Each answer marked as yes give a score of 'one,' and each answer marked as no was given a score of 'zero.' Based on the above questionnaire, those children who scored more than 50% were referred for audiological CAPD screening test. The above pass refers criteria of SCAP was recommended by the developer of the screening test.

Screening Test for Auditory Processing given by Yathiraj and Maggu (2012) was administered on children referred based on SCAP, to check for at risk of central auditory processing disorder. The STAP audiological test contains four subsections, i.e., speech-in-noise test, dichotic consonant-vowel test, gap detection test, and auditory memory test. The pass/fail criteria were considered as per normative developed by Yathiraj and Maggu (2012).

Based on the scores of SCAP and STAP children were grouped into typically developing children (control group) and who are at risk of CAPD (clinical group).

3.5.2 Assessment of Binaural interaction abilities

Binaural interaction was assessed using a group of tests including masking level difference (MLD), binaural fusion test (BFT) and localization and interaural time difference (ITD) tests.

Masking Level Difference. For MLD, a calibrated dual channel diagnostic audiometer and compatible headphones were used to present the stimulus. A 500 Hz tone was presented in the presence of a narrowband noise centered at 500 Hz. Both tone and the noise were presented simultaneously to both ears in which the level of noise was kept constant at a most comfortable level, and the level of tone was varied in 1dB steps to find out the masked threshold. Thresholds were obtained for both homophasic (SoNo) as well as antiphasic (SoNπ) conditions. Finally, the difference in threshold between homophasic and antiphasic conditions was taken to find the threshold and then it was noted manually by the presenter.

Binaural fusion test. BFT in English developed by Shivaprsad and Yathiraj (2006) which consisted of 4 lists of 25 words each was used in the present study.

Recording of the material. Two lists of 20 words were selected from the above material and were recorded for the present study. The recording was done using a female speaker who spoke English fluently. The words were recorded using a calibrated, noise-free and distortion free microphone (Behringer condenser microphone through Motu to SD card) by using the MOTU software. To ensure that the intensity of all words was maintained scaling of the words was done using the same software. A six seconds inter-word interval was maintained. These words were then band passed using the Adobe Audition (Version 3.0) software. A low band pass of 500 Hz to 700 Hz and a high band pass of 1800 Hz to 2000 Hz was used to filter the words. The band width for the high and low band passes was the same, i.e., 200 Hz. The recorded list was band-passed in such a manner that both list one and two were filtered and the low pass band was presented to the left ear and the high band-pass to the right ear. (Appendix 1)

Administration of the test. The recorded word list was presented to all the participants at a comfortable listening level (approximately 40dB SL). The stimulus was presented with the help of Adobe Audition that was routed through the audiometer to the earphone. The children were required to repeat the words they heard. The responses were scored, and the correct response was given a score of one and a wrong response a score of zero. The maximum score possible in BFT was 40.

Localization test. Localization test is a behavioral test in which the accuracy of real source location judgments in free-field was assessed for participants in both the groups. Stimuli consisted of a series of wide band noise (WBNs) of 250 msec duration generated using AUX viewer software at 32 bits and 44,100 Hz sampling rate. Stimuli were presented through one of the four loudspeakers randomly using a stimulus control box which was connected to a two-channel diagnostic audiometer to control the frequency and level of the stimulus. The interstimulus interval was varied adaptively (Nisha & Kumar, 2017). The arrangement of the test setup is shown in Figure 3.1 below.

Participants were instructed that “You will hear a sound of short duration and once that sound stops, you are required to say the direction from which the sound was heard. That is, whether the sound came right/left or front/back”. Then the response was manually noted by the experimenter who controlled the stimulus presentation. The maximum score possible in localization was 20.

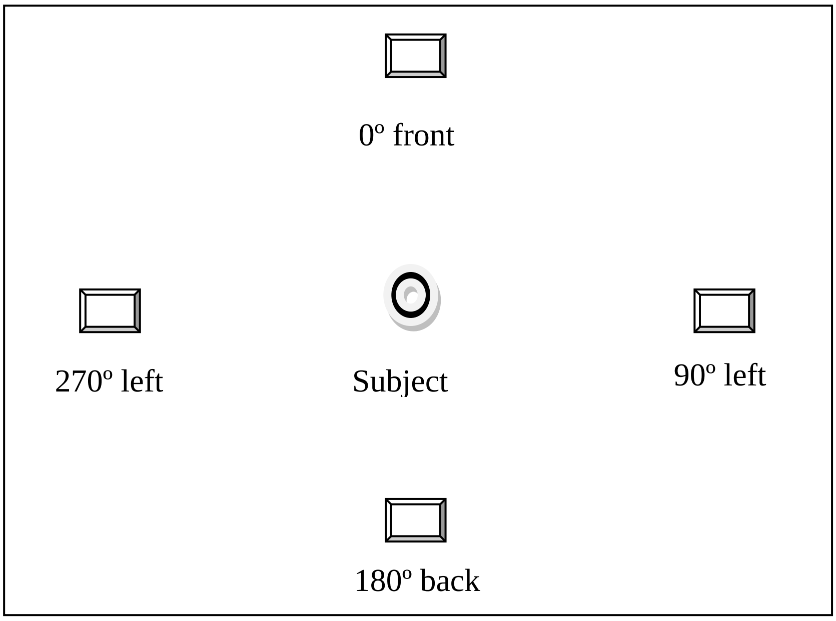

Figure 3.1. Graphical representation of the localization test set up.

ITD: ITD test was carried out using MLP (maximum likelihood procedure) toolbox implemented in MATLAB. The MLP makes use of a large number of participant's psychometric function which gives the highest likelihood of the stimulus to be presented in the next trial. In each trial, it estimates the likelihood of arriving at the listener's response for all the stimuli that have been presented. The 44,100 Hz sampling rate was used to generate the stimulus in MLP.

Stimulus contained a tone of 330Hz of 250 msec which was presented binaurally at 40 dBSL using MLP toolbox in MATLAB. This stimulus was routed through the two-channel diagnostic audiometer. Presentation of stimulus included a standard tone in the right ear whereas in the left ear it included different delays which automatically varied depending on the response of the patient. A two interval alternate forced choice was used where in both the tones had a certain ITD. The ITD of the variable tone (left tone) was varied. The same ITD value was used for the standard tone but with the opposite sign. The starting level was kept at 300 msec wherein the first midpoint was at 0.0001 and last midpoint at 0.30. Low frequency was chosen because it is the main cue which is important for right-left localization in ITD. For this reason, it was easy to localize and may serve as a standard stimulus.

The participants were instructed that "you will hear two tones one after the other. First, you will hear in right following in left or vice versa. The task is to identify in which ear you heard the tone first". Criteria of 80% were used to get the threshold which was a default setting in MLP software.

3.6. Statistical Analysis

Data from both the groups were compiled, tabulated and then statistically analyzed using Statistical Package for Social Sciences (SPSS V.20). Shapiro Wilks test of normality was done to check the normality of data. Descriptive statistics was used to obtain the mean and standard deviation for each of the tests for both the groups. The between-group comparison was done using the Mann Whitney U test to compare the results of all the tests.

Chapter 4

Results

The present study was aimed to compare various binaural interaction tests in children who are at risk for CAPD and typically developing children. First objective of the study was to compare binaural interaction using masking level difference, binaural fusion test, localization and interaural time difference in children who are at risk for CAPD and typically developing children. The second objective was to compare the findings of different binaural interaction tests in the diagnosis of children who are at risk for CAPD.

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 ($p<0.05$). Hence non-parametric statistics was used to evaluate the significance of the difference of various tests between the two groups.

4.1. Comparison of binaural interaction abilities using MLD, BFT, Localization and ITD tests in control and clinical group

Table 4.1 shows the mean, median, standard deviation (SD) and range of all the four tests for both the groups. Figure 4.1 shows the bar graph depicting the mean and SD of all the tests for both the groups. From Table 4.1 and Figure 4.1 it can be noted that mean MLD and BFT scores differed among the two groups whereas the mean localization and ITD test scores were comparable between the groups.

Table 4.1

Mean, median, SD, and range for MLD (in dB), BFT, LOC and ITD (in msec) for the control and clinical group.

Tests	Mean		Median		SD		Minimum		Maximum	
	Con.G	Cli.G	Con.G	Cli.G	Con.G	Cli.G	Con.G	Cli.G	Con.G	Cli.G
MLD	13.45	11.00	14.00	11.00	02.21	02.93	10.00	07.00	18.00	17.00
BFT	30.40	18.50	31.00	19.00	03.15	05.65	22.00	05.00	34.00	29.00
Loc	19.85	19.17	20.00	20.00	00.49	01.50	18.00	20.00	15.00	20.00
ITD	00.25	00.26	00.29	00.30	00.06	00.07	00.15	00.04	00.30	00.30

Note: Con.G- control group, Cli.G- clinical group, Loc- localization test

4.1.1. Comparison of MLD among control and clinical group

MLD values are given in dB for two groups, and more the dB value is, better is the release from masking which in turn indicates normal binaural interaction processing. It can be inferred from the Table 4.1 that mean MLD thresholds were high (by 2.45 dB) for the control group (mean = 13.45 dB) which included typically developing children compared to clinical group (11 dB) with CAPD children. As mentioned earlier, non-parametric statistics were used to evaluate significant differences between the groups since data was not normally distributed. Mann Whitney U test was used to assess the significant difference among two groups for all the four tests (Table 4.2). From Table 4.2. it can be noted that the MLD thresholds differed significantly among the two groups (Z=-2.618, p=0.009).

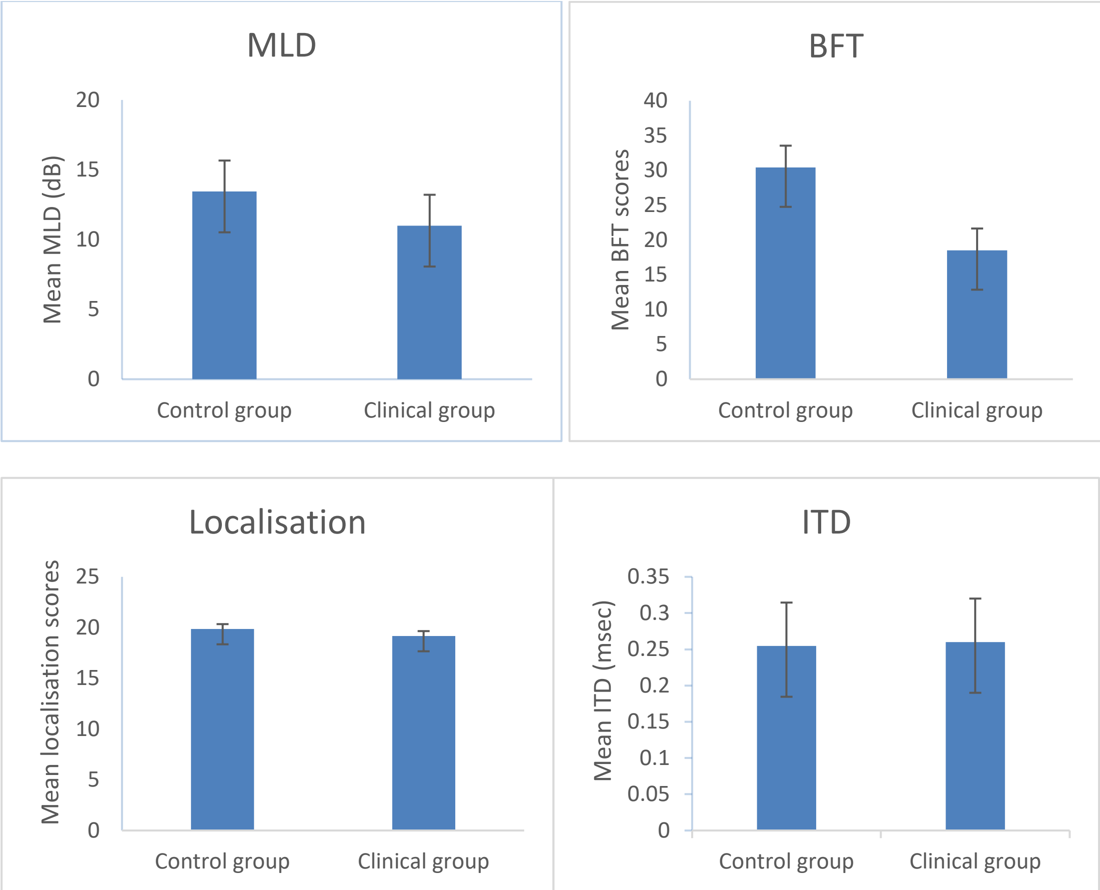

Figure 4.1. Bar graph depicting mean and SD of MLD (in dB), BFT, LOC and ITD (in msec) for the control and clinical group.

Table 4.2

Mann Whitney U test results of MLD (in dB), BFT, LOC, and ITD (in msec) between the control and clinical group

Tests	Z value	Asymp.sign (2-tailed)
MLD	-2.618	0.009*
BFT	-5.013	0.000*
Localization	-1.806	0.071
ITD	-0.798	0.425

*Note : * - significant at 0.01 level*

4.1.2. Comparison of BFT among control and clinical group

The total words correctly repeated is documented in BFT and thus more the score obtained in BFT, better is the child's ability to make use of internal redundancy which is very much essential for communication in adverse listening conditions. It can be noted from Table 4.1 that the control group had higher mean BFT scores compared to children at risk for CAPD. From Table 4.2 it can be noted that the Mann Whitney U test showed a significant difference in BFT scores between the two groups (Z=-5.013, p=<0.01).

4.1.3. Comparison of Localization among control and clinical group

The mean, median, SD and range for localization of both groups are also presented in Table 4.1. In localization, higher scores reflect greater ability of a child to locate the sound source. From Table 4.1 and Figure 4.1 it can be noted that the mean scores of the clinical group is lesser compared to the control group. Further to assess significance, Mann Whitney U test showed no significant difference in localization between the two groups (Z=-1.806, p=0.071).

4.1.3. Comparison of ITD among control and clinical group

The mean, median, SD and range for ITD of both the groups are also presented in Table 4.1. In ITD, lower scores reflect greater ability of a child to differentiate ITD cues which helps in locating the sound source within the head. It was seen from Table 4.1 that there was no much difference in the mean scores of ITD between the two groups and Mann Whitney U test also showed no significant difference between the groups for ITD test (Z=-0.798, p=0.425).

4.2 Comparison of findings of different binaural interaction tests in the diagnosis of children who are at risk for CAPD.

In the present study, four different tests (MLD, BFT, localization, and ITD) were used to compare their ability in assessing binaural interaction in normal and children at risk for CAPD. Results showed that MLD and BFT differed significantly among the two groups, whereas localization and ITD didn't show any significant difference among the two groups. So, it can be said that BFT and MLD are better measures to assess binaural interaction in children who are at risk for CAPD. Among BFT and MLD, it was noted that 13 out of 18 children who were at risk for CAPD had poorer scores in BFT (mean -1SD lesser than the control group) and 7 out of 18 had poorer scores in MLD (mean -1SD lesser than the control group). So it can be concluded that the sensitivity of BFT (65%) is higher as compared to MLD (35%) in the assessment of binaural interaction abilities in children who are at risk for CAPD.

Chapter 5

Discussion

The aim of the present study was to compare various binaural interaction tests in children who are at risk for CAPD and typically developing children. The results of the study are discussed below.

5.1. Comparison of binaural interaction using MLD, BFT, localization and ITD tests in children who are at risk for CAPD and typically developing children.

The present study assessed binaural interaction abilities through MLD, BFT, localization and ITD tests. Results showed that MLD and BFT differed significantly between typically developing children and children at risk for CAPD, whereas localization and ITD scores did not differ significantly among the two groups.

5.1.1. Comparison of MLD among control and clinical group

MLD differed significantly among the two groups in the present study. These results are in consensus with the literature (Olsen & Noffsinger, 1976; Olsen et al., 1976; and Quaranta et al., 1978) in their study reported low MLD thresholds in participants with subcortical central lesions such as multiple sclerosis. Similarly, Lynn et al., (1981) reported that subcortical lesions such as multiple sclerosis or any other brainstem pathologies have MLDs that are significantly smaller than normal. In the present study, mean MLD in the control group was 13.45 with one standard deviation of 0.21. It can be said that children whose MLD falls below this are at risk to have binaural interaction deficit.

Few studies have found contrary findings compared to the present study (Kumar, Singh, & Ghosh, 2013; Jeena & Kumar, 2017; and Singer, Hurley, & Peece, 1998). In these studies, MLD scores were comparable among typically developing children and children with CAPD. The variation in the results of these studies compared to the present study could be attributed to the step size used during testing. Kumar, Singh, and Ghosh (2013), and Jeena and Kumar (2017) used 5dB step size, and Roush and Tait (1984) used a 2dB step size to arrive at the MLD threshold whereas in the present study 1dB step size was used to arrive at the MLD thresholds. This could be one of the reasons for the presence of a difference between the groups. However, in our study also it was seen that BFT is more sensitive than MLD which is in congruence with results of the above mentioned studies.

5.1.2. Comparison of BFT among control and clinical group

In the present study BFT differed significantly among the clinical and control group. Similar results are reported in the literature (Singer, Hurley, & Peece,1998; Welsh, Welsh, & Healy, 1980; Roush & Tait, 1984; and Sollman, 1997). Welsh, Welsh, and Healy (1980) reported that binaural fusion and filtered speech tests were most sensitive for the assessment of CAPD. Singer, Hurley, and Peece (1998) also reported that children with CAPD and children with classroom learning disability were separated most effectively by BFT and the next most effective test was FST. This is attributed to the reduced internal redundancy in children with CAPD. In the present study mean BFT scores in the control group was 30.40 with one standard deviation of 3.15. It can be said that children whose scores fall below this are at risk to have binaural interaction deficit.

5.1.3. Comparison of localization among control and clinical group

In the present study, localization abilities did not differ significantly between typically developing children and children with CAPD. In contrary, Zakaria et al., (2007) and Buchholz, Dillon and Cameron, (2013) reported abnormal performances in localization test in subjects with brainstem lesions. Buchholz, Dillon, and Cameron, (2013) used complex tones as both target and distractor to assess localization whereas in the present study 1000 Hz tone was used. This methodological differences could be one of the reasons for the variation in results among studies. Another reason could be that in the present study finer localization skills were not assessed and testing was done using only four loudspeakers and moreover, children with CAPD exhibit more difficulties in finer localisation aspects than gross localisation (Moosavi et.al., 2014).

5.1.4. Comparison of ITD among control and clinical group

In the present study, lateralization abilities did not differ significantly between typically developing children and children with CAPD as assessed through ITD. In contrary, abnormal performances in auditory lateralization have been found in individuals with auditory brainstem lesions (Levine et al., 1993a, 1993b; Furst et al., 1995; Aharonson et al., 1998; Cameron and Dillon, 2006; Zakaria (2007); and Moosavi et al., 2014). Moosavi et al., (2014) stimulated nine imaginary positions within the head and Zakaria (2007) stimulated four positions whereas in the present study just right and left lateralization was assessed. Cameron and Dillon (2006) used three virtual conditions under headphones and stimuli used was a target story with competing speech sentences whereas stimuli used in the present study was 330Hz pure tone. Hence, these procedural variables could have lead to the variation in results among different studies.

5.2. Comparison of findings of different binaural interaction tests in the diagnosis of children who are at risk for CAPD.

In the present study, MLD and BFT differed significantly between the two groups whereas localization and ITD did not show any significant difference. Further, BFT was more affected in children who are at risk for CAPD compared to MLD. Similar results have been reported in the past wherein studies have shown that BFT is more sensitive compared to MLD in the diagnosis of CAPD (Kumar, Singh, & Ghosh 2013; Roush & Tait, 1984; Singer, Hurley, & Peece, 1998; and Jeena & Kumar, 2017).

However, few studies have reported that BFT is more sensitive to brainstem lesion whereas MLD had a comparable performance among children who were at risk for CAPD and typically developing children (Kumar, Singh, & Ghosh 2013; Roush & Tait, 1984; Singer, Hurley, & Peece 1998; and Jeena & Kumar, 2017). The variation in the results of these studies compared to the present study could be attributed to the step size used during testing. Kumar, Singh, and Ghosh (2013), and Jeena and Kumar (2017) used 5dB step size, and Roush and Tait (1984) used a 2dB step size to arrive at the MLD threshold whereas in the present study 1dB step size was used to arrive at the MLD thresholds. This could be one of the reasons for the presence of a difference between the groups. However, in our study also it was seen that BFT is more sensitive than MLD which is in congruence with results of the above mentioned studies.

Hence it can be concluded that MLD and BFT are sensitive tool to assess binaural interaction deficits, with BFT being more sensitive than MLD. Further Localization and ITD tests didn’t show any difference between the groups. Moreover, the screening tool used in the study i.e., STAP has no subsection to assess binaural interaction ability and hence not all participants considered as at risk for CAPD in the clinical group might have binaural interaction deficits. Hence this needs to be taken into consideration in future studies.

Chapter 6

Summary and Conclusion

Binaural interaction refers to the way in which the two ears work together. Functions that rely on behavioural interaction include localization and lateralization of the auditory stimuli, binaural release from masking, detection of signals in noise and binaural fusion. The present study aimed to compare various binaural interaction tests in children who are at risk for CAPD and typically developing children. The main objectives of the study was to assess binaural interaction abilities through Masking level difference (MLD), Binaural fusion test (BFT), Localization and ITD tests between typically developing children and children who are at risk for CAPD. A total of 41 children were included in the study. They were divided into a control group with 23 typically developing children and clinical group with 18 children at risk for CAPD. Children were divided into control and clinical group based on the results of Screening Checklist for Auditory Processing and Screening Test of Auditory Processing. Followed by screening, MLD, BFT, localization and ITD tests were administered on each participant.

Results revealed that,

- Mean MLD and BFT scores differed significantly between control and clinical group.
- Mean localization and ITD scores didn't differ significantly between the control and clinical group.
- Among MLD and BFT, BFT was found to be more sensitive than MLD.

6.1. Implications of the Study

- The study gives a better understanding of the extent of the clinical utility of various binaural interaction tests in the diagnosis of CAPD.
- Specifically, the study was helpful to arrive at a conclusion that BFT and MLD are more sensitive to assess binaural interaction deficits.

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APPENDIX 1

BFT WORD LISTS

List 1	List 2
1. Sell (sɛl)	1. Fact (fækt)
2. Please (pli:z)	2. Bad (bæd)
3. Note (no:t)	3. Drop (drɒp)
4. Tell (tɛl)	4. Front (frʌŋt)
5. Nice (nais)	5. Hurt (ha:t)
6. Road (ro:d)	6. Love (lav)
7. Jar (dʒa:)	7. Neat (ni:t)
8. Comb (ko:m)	8. Cage (kedʒ)
9. Talk (ta:k)	9. Smile (smʌIl)
10. Well (vɛl)	10. Name (ne:m)
11. Wire (vair)	11. Crow (krɔ)
12. Gun (gʌn)	12. Bird (ba:d)
13. Shout (ʃaʊt)	13. Start (sta:t)
14. Thin (Ɵin)	14. Root (ru:t)
15. Closed (klo:zd)	15. Cup (kʌp)
16. Ring (rIŋ)	16. Moon (mu:n)
17. Wheat (vi:t)	17. Fan (fæn)
18. Case (ke:s)	18. Teach (ti:tʃ)
19. Key (ki:)	19. Coat (ko:t)
20. Rain (rein)	20. Ten (tɛn)