Auditory Perceptual Acuity in Children who Stutter

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A Dissertation Submitted in Part Fulfillment of Final Year

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CERTIFICATE

This is to certify that this dissertation entitled ***“Auditory perceptual acuity in children who stutter”*** is a bonafide work submitted in part fulfilment for the degree of Master of Science (Speech Language Pathology) of the student Registration No.: 11SLP022. This has been carried out the under guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree

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This is to certify that this dissertation entitled ***“Auditory perceptual acuity in children who stutter”*** has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other university for the award of any diploma or degree.

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DECLARATION

This is to certify that this master's dissertation entitled ***"Auditory perceptual acuity in children who stutter"*** is the result of my own study and has not been submitted earlier to any other university for the award of any diploma or degree.

Mysore

May, 2013 **Register No. 11SLP016**

Acknowledgements

Those blessings are sweetest that are won with prayer and worn with thanks."
– Thomas Goodwin

I thank you my **God***, my savoir, for without him I never would have completed this work , for it was my belief in him which helped me through all the hardship, for it was he who stood shining at the end of the tunnel.*

I am eternally grateful to my guide **Dr. Santosh** *for his well directed sensible advises. Throughout the course of this study I have learnt many valuable points from you, without you I would not have accomplished the end sir. I thank you sir for being there for me throughout.*

I thank Dr. **S. R. Savithri***, director, All India institute of Speech and Hearing for permitting me to carry out this research work.*

I express my heartfelt thanks to **Mr. Nike Gnanateja** *for programming my stimuli and helping me with my doubts and queries regarding the same. Thank you sir for clearing whatever doubts I had repeatedly never even uttering a slightest inconvenience.*

I thank **Dr. Jayakumar** *and* **Dr. Vijakumar Narne** *for their timely helps.*

I thank all the **children** *who participated in the study with their full enthusiasm.*

I thank all those **IED teachers from block research centres** *who helped me acquire my data all around various schools. Very* special thanks to **Mrs. Smitha Sunil** who gave me the details regarding the participants. Thank you Smitha edati, without you I would not have been able to complete my data collection.

I thank my ever special **family** especially my **Amma and Perashi** for all those innumerable things which can never be put into words.

I thank my **friends** and **classmates** especially **Jyothsna and Sethu** for being there for me

And finally I thank my fiancé, **Hari** for suffering my tantrums and **his family** for supporting me throughout.

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Chapter 1

Introduction

Since centuries, the etiology of stuttering has been a highly debated topic. Stuttering has intensely interested the researchers because its characteristics are highly evident, yet it does not show any outward abnormalities. Hence, many speculations have been laid to explain as to why people stutter. The theories regarding the cause of stuttering vary from it being viewed as a complete physiological problem (Eisenson, 1958; Geshwind & Gallaburda, 1985; Hirano, 1996; Moore & Hayes, 1980; Orton & Travis, 1927; Perkins, 1976; Rosenfield, 1984; Travis, 1931; Van riper, 1971) to complete psychological problem (Barbara, 1982; Dalton, 1983; DiLollo, Neimeyer & Manning, 2002; Evesham and Fransella, 1985; Fransella, 1972; Landfield and Leitner, 1980; Manning, 2001; Santostefano, 1960; Williams, 1995). Earlier theorists considered stuttering as caused due to tongue abnormalities (Aristotle, 384 BC; Galen, AD 200; Hippocrates, 370 BC). However, with progress in medical sciences this view was discarded. The theories followed, contemplated stuttering to be caused due to a variety of other factors like physiological abnormalities at the level of various subsystems (Adams & Hayden, 1976; Alfonso & Watson, 1987; Carusso & Abbs, 1986; Hirano, 1996;), incomplete cerebral dominance (Orton & Travis, 1927), hormonal disorder (Geshwind & Galaburda, 1985), imbalance between demand and capacities of the child (Starkweather & Gottwald, 1990), delay in language acquisition (Bloodstein, 1981; Van Riper, 1982), speech motor control disorder (Alm, 2005; MacKay, 1970; Nelson & Nelson, 1987), dissociation between planning and execution (Howell,2002), over demanding parents (Johnson, 1955) and so on.

Another well researched theory postulates that stuttering is caused due to disordered auditory processing (Cherry & Sayers, 1956; Cherry, Sayers, & Marland, 1955). Many studies have firmly supported this view. The benchmark support include findings like poorer sound localization in persons with stuttering (Rousey, Goetzinger, & Dirks, 1959), poorer performance in central auditory processing disorder tests (Andrews, Craig, Feyer, Hoddinott, Howie, & Neilson, 1983; Blood & Blood, 1984; Hall, & Jerger, 1978; Moore, & Haynes, 1980; Rosenfield, & Goodglass, 1980; Toscher, & Rupp, 1978; Wynne, & Boehmler, 1982), lower prevalence of stuttering in hearing impaired population (Harms, & Malone, 1939; Montgomery, & Fitch, 1988) and improvements in speech fluency when stuttering individuals speak while hearing delayed auditory feedback (DAF), frequency-altered auditory feedback (FAF), masking noise, or the simultaneous presentation of a second speaker's voice (unison or choral speech) (Armson & Kiefte 2008; Ingham & Packman, 1979; Macleod, Kalinowski, Stuart, & Armson, 1995; Martin & Haroldson, 1979; Martin, Johnson, Siegel, & Haroldson, 1985; Max, Caruso, & Vandevenne, 1997; Soderberg, 1969; Stuart, Kalinowski, Armson, Stenstrom, & Jones, 1996; Stuart, Frazier, Kalinowski, & Vos, 2008).

Studies supporting this theory base themselves on various behavioural, electrophysiological and/or neuroimaging studies for assessing central auditory processing. The critical evaluation of the results from these studies presents a conflicting data. Some studies have shown disordered auditory processing (Blood, 1996; Blood, & Blood,1984; Curry, & Gregory, 1969; Foundas, Bollich, Corey, Hurley, Lemen, & Heilman, 2004; Hall, & Jerger, 1978; Hampton, & Weber-Fox, 2008; Peñaloza-López, Téllez, Pérez-Ruiz, Silva, & García-Pedroza, 2008; Wynne, & Boehmler, 1982) in these individuals where as some have totally refuted it (Blood, Blood, & Newton, 1986; Decker, Healey, & Howe, 1982; Dorman, & Portar, 1975;

Gruber, & Powel, 1974; Kramer, Greene, & Guitar, 1987; Newman, Bunderson, & Brey, 1985; Stager, 1990). On the whole, no conclusion has yet been made in this respect.

Auditory discrimination is one of the aspects through which the auditory processing can be studied in an individual. The ability with which an individual is able to discriminate the subtle differences between two sounds (speech as well as non-speech) can provide a thorough insight regarding the perceptual acuity in him/her (Wepman, 1960). If the individual is unable to discriminate two sounds varying only in small aspects in spite of having a normal peripheral hearing, then he/she might be having some difficulty at the level of central auditory system. This may be true in case of persons with stuttering as it is maintained that they have atypical auditory processing disability which compromises their perceptual accuracy.

Fine grained auditory discrimination (Elliot, Longinotti, Meyer, Raz & Zuker ,1981) is one of the tests which assesses the perceptual acuity in an individual. This procedure measures the minimum difference with which two stimuli are 1distinguished. During the course of testing, subjects are presented with a pair of stimuli varying in one parametric value and are asked to judge the minimum difference with which both the stimuli are perceived as different. This procedure has been widely used by many researchers to explore the auditory discrimination in a variety of populations including normal children (Elliot, Hammer & Scholl, 1989), children with language impairment (Elliot, Hammer & Scholl 1989; Tallal, 1990); adults with dyslexia (Steffens, Eilers, Gross-Glenn, & Jallad, 1992); learning disability (Bradlow, Kraus, Trent, Cunningham, Zecker, & Thomas, 1999; Powlin, 2009; Swapna, 2005) and adult with auditory neuropathy (Kraus, et.al, 2000) since last couple of years.

Although many researchers have evaluated the auditory processing skills using fine grained auditory discrimination paradigm in different communication disorders, not much focus is given in the area of stuttering**.** Recently, Neef, Sommer, Neef**,** Paulus, Gudenberg**,** Jung and Wüstenberg (2012) assessed the auditory discrimination in adults who stutter using a similar procedure. In their study, the authors presented two stimulus continuums (/pa-ba/ & /da-ta/) and determined the minimum value with which the stimuli at one end of the continuum is discriminated from that of the other end. The results revealed that adults who stutter had poorer auditory discrimination ability as compared to their age and gender matched fluent speakers. The above mentioned study reveals the disordered auditory processing in adults.

However, studies have seldom tapped the auditory processing abilities in children who stutter. Studies in this population are indeed essential for understanding the role of any factor of interest that may play in the *etiology* of stuttering. If a reported difference between adults who do and adults who do not stutter cannot be replicated with children who are closer to the onset of the disorder, then it would seem unlikely that any limitations observed in the stuttering adults were already present during early childhood and may have contributed to the development of stuttering. To the best of our knowledge, no attempts have made to investigate fine grained auditory discrimination skills for the perception of phonetic categories in children who stutter. Hence, the present study focuses on exploring the auditory processing deficit in children with stuttering using fine grained auditory discrimination procedure.

Aim:

To investigate the auditory perceptual acuity in children who stutter and to compare it with age and gender matched control participants using fine grained auditory discrimination procedure.

Chapter 2

Review of literature

A fluent speaker can speak continuously with minimal physical and mental effort while maintaining a steady rate and rhythm. There are many disorders that disrupt smooth flow of speech. Stuttering is one such disorder where individuals have breakdown in speech fluency in terms of monosyllabic whole-word repetitions, part-word repetitions, audible sound prolongations, or silent fixations or blockages. These dysfluencies may or may not be accompanied by accessory (secondary) behaviours (i.e., behaviours used to escape and/or avoid these speech events) (ASHA, 1999).

The causes of stuttering are highly debated till date and have evolved over the years. Many theories have been proposed to explain the etiology of stuttering. Older theories were based on speculations rather than experimental evidences. Ancient Greeks believed stuttering as caused due to dryness of the tongue (Aristotle, 1500 A.D). Hence, as a management the mutilation and surgical incision for tongue was carried out as a cure for stuttering (Dieffenbach, 1841). Their successors in early 19th century considered defective speech mechanism as the culprit for causing stuttering. These theories ranged from stuttering caused due to elevated muscle activity (Stark weather, 1995), to inefficient adduction and abduction of vocal folds (Carusso & Abbs, 1986; Hirano, 1996). Some theories moreover proposed that inaccurate articulatory targets can be the main etiology of stuttering (Alfonso & Watson, 1987). However, 20th century brought about a drastic change in the belief system of the professionals. Whereas earlier stuttering was attributed to structural deformity, in this era it was completely viewed as a form of psychogenic disorder (Fransella, 1972, Plankers, 1999). Johnson's *diagnosogenic* theory (1955) wherein he implied that stuttering is in the parent’s ear not the child’s mouth, made way for this change in belief system of the individuals.

As both these schools of thought were mutually exclusive and most of the researchers seldom believed in either one exclusively, they started probing further into finding more about its etiology. Orton and Travis (1927) proposed the cerebral dominance theory which stated that stuttering may be caused due to conflict between the two cerebral hemispheres. This theory was supported with evidence from WADA test (Wada, & Rasmussen, 1960), dichotic listening tests (Curry, & Gregory, 1969) and Computer Tomography studies (Strub, Black, & Naeser 1987). A vast number of researchers also believed that stuttering may be inherited thus strengthening the genetic theory of stuttering. Evidence for this theory was given from studies done on twins who stutter (Falsenfeld, Kirk, Zhu, Sthatham, Neale, & Martin, 2000; Howie, 1981; Luchsinger, 1944; Morris-Yates, Andrews, Howie, & Henderson, 1990) and family segregation analysis (Andrew, and Harris, 1964; Kidd, 1977). All of these studies pointed towards a strong genetic factor behind stuttering.

With the advancement in technology, the etiological basis of stuttering has also been revised. One of the theories suggests that stuttering arises due to the speakers covert repair of erroneously selected phonological choice (Postma & Kolk, 1993), whereas other theories attribute stuttering to dysynchrony between planning and execution processes (Howell, 2002) and due to the conflict between the communication demands placed on the child and his existing capacities for the same (Starkweather, & Gottwald 1990).

Another prominent theory regarding stuttering is that it could be manifested because of the deficit at the level of auditory processing (Cherry & Sayers, 1956;

Cherry, Sayers, & Marland, 1955). The evidence for this hypothesis is based on studies on different aspects of auditory processing in individuals with stuttering. Harms and Malone (1939) compared prevalence of stuttering in congenital hearing impaired individuals to acquired ones. They reported three clear cut cases of stuttering acquired as a result of sudden acquired deterioration of hearing, whereas, they seldom came across case of congenital hearing loss with stuttering. These finding suggested that stuttering on one hand can be caused due to sudden sensory deprivation during the period of language development as in the case of acquired hearing loss. On the other hand, it can be eliminated due to faulty auditory feedback as in case of congenital hearing impairment where in these children lack the servo looping due to their hearing loss. Both of these findings support the theory that an accurate auditory processing is necessary for fluent speech. Montgomery and Fitch (1988) surveyed the prevalence of stuttering in hearing impaired population in America. Their results revealed a significantly less prevalence of stuttering among hearing impaired population in comparison to normal hearing population (1:8 ratios), implying the role of proper audition in maintenances of fluency.

The fact that fluency improves in presence of altered auditory feedback conditions also evidently suggests relationship between auditory processing and stuttering. Goldiamond (1965) was the first researcher who reported the improvement in fluency when persons with stuttering are placed under delayed auditory feedback (DAF). Following this Curlee and Perkins (1969) and Perkins (1973) formulated a management technique in which the fluency was induced in persons with stuttering by making participants speak under DAF with a delay of 250 milliseconds. Gradually the delay was reduced in 50 milliseconds until the fluent speech was generalized. Frequency altered feedback and delayed auditory feedback was utilized by Macleod, Kalinosky, Stuart and Armstrong (1995) to assess the processing abilities in adult with stuttering. Ten stutterers and nonstutterers read passage in presence and absence of altered feedback and combination of each (FAF & DAF). Results supported conventional finding of improved fluency in presence of altered feedback.

Yet another significant finding which shed light on the relationship between auditory processing and stuttering was the fact that persons with stuttering showed better fluency while performing choral reading (Ingham & Packman, 1979; Max, Caruso, & Vandevenne, 1997).

In light of the proposals that a difference in auditory processing, and auditory monitoring of self-produced speech, could cause or contribute to stuttering behaviour, a large body of research has focused on central auditory processing of speech and nonspeech sounds in individuals who stutter. Published studies in this area have made use of a wide variety of experimental approaches: behavioural studies, electric and magnetic studies, and neuroimaging studies.

2.1 Evidence from behavioural studies

Early attempts to uncover abnormalities in the peripheral or central auditory system of individuals who stutter relied mainly on behavioural tests. In general, various categories of behavioural tests have been used. These include dichotic listening tasks, monaural low redundancy speech tasks, binaural interaction tasks, temporal processing tasks, and other auditory tasks such as sound localization, auditory tracking, and loudness matching.

2.1.1. Dichotic listening tasks

The vast majority of behavioural studies have used dichotic listening paradigms. In dichotic listening tasks, auditory stimuli (most often words, but sometimes digits) are presented to both ears simultaneously, and the subject is asked to report what was heard in one or both ears. For most neurologically healthy, right-handed individuals, the percentage of correct responses is greater for the right ear than for the left ear. Thus, dichotic listening tasks are usually associated with a right ear advantage (REA). This REA is believed to be a direct result of the neuro-anatomical organization of the auditory pathways and—for most right-handed individuals—the left-hemisphere lateralization of cortical speech and language areas. Given that most auditory fibres ascending from the cochlear nucleus cross over to the contralateral side (although connections between the two sides exist at several levels), information from the right ear is transferred mainly to the language-dominant left hemisphere whereas information from the left ear is transferred mainly to the nondominant right hemisphere. Presumably, information reaching the right hemisphere then needs to cross over to the language dominant left hemisphere via the corpus callosum if the subject's task is to verbally report what was heard (Kimura, 1967). Hence, the widespread use of dichotic listening tasks was in keeping with the popular cerebral dominance theory of etiology of stuttering (Orton, 1927; Travis, 1931). According to this theory, individuals who stutter lack the typical left hemisphere dominance for speech and language, and they show either right hemisphere or bilateral dominance. Orton and Travis speculated that this situation would lead to a conflict between the hemispheres and consequently, breakdown in the control of speech movements.

Curry and Gregory (1969) were the first researchers to use a dichotic word task with individuals who stutter. They found that only about 50% of 20 adult right-handed stuttering participants showed the typical REA for consonant-vowel-consonant (CVC) words, whereas the other 50% of stuttering participants demonstrated a LEA. In the nonstuttering group, as many as 75% of the participants showed the expected REA. The same researchers compared the two groups of participants also with regard to the size of the between-ear absolute difference scores; that is, difference scores considered without regard for the direction of the ear superiority. The mean absolute between-ear score was more than twice as large for the nonstutterers as for the stutterers. The magnitude of such absolute between-ear scores is presumed to be determined by the difference between ipsilateral and contralateral auditory pathways. Curry and Gregory (1969) speculated that some individuals who stutter have reversed hemispheric dominance for speech and language and a smaller than normal difference between the ipsilateral and contralateral auditory pathways. They suggested that these differences in the auditory system and cortical lateralization are in some way related to the disruption of critical feedback processes that permit the uninterrupted forward flow of speech.

A between-group difference in the direction of ear superiority was further supported by Sommers, Brady, and Moore (1975) who found that a greater proportion of nonstuttering individuals than stuttering individuals demonstrated a REA for a dichotic listening task with digits rather than words. Sommers et al. (1975) suggested that the chances of developing stuttering may be significantly enhanced if either the normal degree of right-ear preference is reduced or if there is a left-ear preference. Additional supportive evidence was published by Strub, Black, and Naeser (1987) who observed no clear ear advantage for dichotically presented CV syllables in either of two stuttering siblings (a young adult woman and her brother).

A number of other researchers reported specifically that a *subgroup* of stuttering participants differed from nonstuttering participants in demonstrating a typical ear advantage on dichotic tasks. For instance, studies by Brady and Berson (1975) and Quinn (1972) showed that 17% and 20%, respectively, of stuttering participants demonstrated a LEA for dichotic CVC stimuli whereas such reversals were observed in 0% and 3.3% of the nonstuttering participants in each study. In a more recent publication, Foundas, Corey, Hurley, and Heilman (2004) reported that right-handed stuttering females and left-handed stuttering males differed from nonstuttering participants (both right and left-handed) as well as from right-handed stuttering males. Right-handed stuttering males, however, did not differ from nonstuttering participants.

Although the above studies provide evidence that at least some adults who stutter do demonstrate a LEA instead of the typical REA, there are also several studies that failed to find an ear advantage difference between stuttering and nonstuttering adults (Dorman & Porter, 1975; Meyers, Hughes, & Shoeny, 1989; Newton, Blood, & Blood, 1984; Pinsky & McAdam, 1980; Sussman & MacNeilage, 1975). The reasons for this discrepancy are not clear, but it appears that—besides a potential role for technical differences in construction of the dichotic tests themselves—at least some of the studies reporting no between-group difference have focused mainly on the statistically nonsignificant overall group comparison without in-depth exploration of the individual subject data. Such further exploration of the individual subject data could have increased the chance of indeed detecting a subgroup (based on the above studies perhaps 20%) of stuttering adults who do show a reversed ear advantage.

In addition to these studies with adult subjects, several dichotic listening studies have compared stuttering and nonstuttering children. Studies with children are indeed essential for understanding the role that any factors of interest may play in the *etiology* of stuttering. If a reported difference between adults who do and adults who do not stutter cannot be replicated with children who are closer to the onset of the disorder, then it would seem unlikely that any limitations observed in the stuttering adults were already present during early childhood and may have contributed to the development of stuttering. To the best of our knowledge, Slorach and Noehr (1973) completed the first dichotic listening study with children who stutter. Their results indicated that both stuttering and nonstuttering children showed a REA for a dichotic digits task with no statistically significant difference between the groups. In subsequent studies, Gruber and Powell (1974), using dichotic digits, and Liebetrau and Daly (1981), using monosyllables, also found no significant difference between stuttering and nonstuttering children in terms of ear preference. It is important to note, however, that in both these studies even the nonstuttering children did not show an ear preference.

Several other studies using dichotic testing with children who stutter did in fact find statistically significant between-group differences. For example, using a dichotic test with words, Sommers, Brady, and Moore (1975) found that 23 of 39 stuttering children failed to show the REA whereas only 11 of 39 nonstuttering children failed to show the REA. In other words, more than twice as many stuttering children did not show the expected REA for words. When considered in separate age groups, as many as 77% of stuttering children from 4-10 years and 61% of stuttering children from 11-16 years did not demonstrate the REA. In comparison, only 46 % of nonstuttering children from 4-10 years and 15% of nonstuttering children from 11-16 years did not demonstrate the REA. Similar results were observed by Cimorell-Strong, Gilbert, and Frick (1983): a REA was seen in only 55% of stuttering children but in 82% of nonstuttering children.

Similar to the above described situation for adult subjects, a number of dichotic listening studies with children resulted in the conclusion that the overall between-group difference was not statistically significant, but that a subgroup of stuttering children demonstrated a reversed ear preference. In one such study, Blood and Blood (1984) used a dichotic CV test with synthetic speech to test 16 stuttering and 16 control children. Although the overall comparison of the groups did not show a statistically significant difference, the investigators found that four of the stuttering children exhibited a LEA and three showed no ear advantage. In the control group, only one nonstuttering child showed a LEA and two showed no ear advantage. In a separate paper, Blood (1985) reported that stuttering children from 7 to 9 and from 10 to 12 years of age had significantly fewer right ear responses than their nonstuttering peers. However, stuttering and nonstuttering children from 13 to 15 years of age did not differ in terms of ear preference. This absence of an ear preference difference in the 13- to 15-year-old children is hard to reconcile with the differences found in younger children and, in other studies, adults.

Summarizing the overall results from dichotic listening studies with individuals who stutter is not straightforward because findings are largely inconsistent for both adults and children. For both age ranges, the number of published papers that report no difference between individual who stutter and individual who do not stuttering subjects is approximately equal to the number of papers reporting statistically significant ear advantage overall or a different ear advantage in at least a subgroup of the subjects. Although it seems reasonable to conclude that a subgroup of stuttering individuals may indeed show differences in dichotic listening performance as compared with individuals who do not stutter, the specific differences that have been reported based on this test procedure (i.e., absent or reversed ear advantage) only inform about the lateralization of cortical speech and language areas in general and not about auditory structures or processes *per se*.

2.1.2. Monaural low redundancy tasks

In Monaural low redundancy tasks, subjects are presented with stimuli only in one ear at a time, under different hard to hear conditions (e.g. in presence of noise, competing message compressed speech etc). It is based on the assumption that normally individuals without any deficit at the level of central auditory system will be able to successfully process the stimuli in different hard to hear condition because of their auditory closure. Contrary to this, individuals with auditory processing deficits fail to achieve this because of their pathology,

Compared to the ratio to dichotic tests, the studies done using monaural tests are lesser. One of the studies using this task was done by Guitar, McCauley and Absher (2000). The authors measured the scores of duration pattern in 20 individuals with stuttering in comparison with the control subjects. The individuals were asked to measure the length of the presented tone and that of silence. The authors stated that there exist a negative correlation between the degree of dysfluency and ability to determine the length of the short tones thereby supporting Kent’s temporal processing theory of stuttering.

Another study done by Peñaloza-López, Téllez, Pérez-Ruiz ,Silva and García-Pedroza (2008) compared the performance of 25 persons with stuttering with 25 normal age and gender matched fluent speakers on the tests of compressed speech in Spanish. Time compressed speech at 75% and 100% compression were presented to one ear at a time. Results revealed that stutterers could obtain only 60.98% correct response at 75% compressed condition where as normal had a correct score percentage of 80.04%. Similary, at 100% compressed condition stutterers had a score of 56.56% in comparison to 73.16% scored by nonstutterers. These results signified a superior temporal processing in nonstutterers in comparison to stutters.

2.1.3. Other tests results

Other tests which were used to assess the auditory processing in individual who stutter include synthetic sentence identification, staggered spondaic test, competing sentence test, forward and backward masking procedures etc.

Hall and Jerger (1978) administered a battery of seven audiometric tests on 10 stutterers and scores were compared with control subjects. the tests used by the authors included acoustic reflex threshold, acoustic reflex amplitude function, performance intensity function for monosyllabic phonetically balanced (PB) words, performance intensity function for Synthetic Sentence Identification, Synthetic Sentence Identification with Ipsilateral Competing Message, Synthetic Sentence Identification with Contralateral Competing Message, and the Staggered Spondaic Word test. The results showed significantly poorer performance by individuals with stuttering in comparison with their controls for three tests (Acoustic reflex amplitude function, synthetic identification with ipsilateral competing message, and staggered spondaic word test), thus signifying a poorer auditory processing in persons with stuttering. Similarly, Blood (1996) administered staggered spondaic test, Sentence Disambiguation task and pitch pattern test on ten persons with stuttering (18 – 25 years) and 10 nonstuttering control subjects. In sentence disambiguation test, subjects were presented with sentences whose meaning varied according to stress placement and the subjects were expected to point out the correct response picture. In staggered spondaic test, the second syllable of the first word and the first syllable of the second word is presented together (competing condition) and the other halves are presented separately (non-competing condition). The subjects are asked to integrate the syllables and identify the word. Pitch pattern test is a monaural non verbal test in which subjects are presented with tones of varying pitch (low low high, high low, low etc) and they were asked to imitate the pattern. The results revealed that most of the persons with stuttering (7 out of 10) consistently performed poorly in all of the above mentioned tasks suggestive of defective auditory processing in them.

Wynne and Boehmler (1982) used synthetic sentence identification test to explore the auditory processing in persons with stuttering. During this test, the subject is required to identify a set of sentences in presence of competing noise. The results showed that individuals with stuttering performed poorly on this test in comparison with their control subjects thereby giving less accurate response in presence of ipsilateral competing message, which again support the hypothesis of faulty auditory processing in these individuals. However, Kramer, Greene & Guitar (1987) found no significant difference in scores of synthetic speech identification in presence of ipsilateral competing message for stutterers as well as non stutterers.

Anderson, Hood and Sellers (1988) tested the relationship between auditory processing and stuttering by conducting a series of test batteries on adolescents (12 subjects) with moderate to severe stuttering. The battery included phonemic synthesis test, competing sentence test and staggered spondaic word test. On staggered spondaic test, the authors obtained significant differences between the scores of stutterers in comparison with nonstutterers, and concluded that in stutterers processing abilities mature much later in comparison with non-stutterers.

Sentence identification in the presence of ipsilateral and contralateral competing message was explored by Molt and Guillford (1979). The results obtained were quite interesting in nature. The stutterers and nonstutterers performed with equal proficiency in case of sentence identification in the presence of contralateral competing message. However, the performances of stutterers were poorer for sentence identification in ipsilateral competing condition. The authors attributed this difference in performance to the disordered neural mechanism in stutterers for processing auditory stimuli.

Bonin, Raming and Prescott (1985) obtained the results for sound fusion task in binaural synchrounous and asynchrounous conditions for adults with stuttering within the age group of 21-44years, and similar to the earlier findings he reported a significant difference in performance between stutteres and nonstutterers in case of lead-time presentation in case of asynchronous condition. This further supported the theory of poor auditory processing in persons with stuttering.

Backward masking is speculated as one of the most sensitive test in detecting auditory processing. In backward masking, the masking noise following the target stimulus obscures it, leading to elevation in its threshold. Howel, Rosen, Hannigan & Rustin (2000) measured the pure tone threshold of individuals who stutter in backward-masking condition. The results pointed towards a significant increase in threshold in these individuals in comparison to fluent speakers within the backward masking condition hence suggesting an evident processing deficit in them. Likewise, Howell and Willaims (2004) evaluated the auditory sensitivity in persons with stuttering under five listening conditions: Pure tone threshold, simultaneous masking, backward masking, notched backward masking, and simple dichotic (simultaneous) masking and reported that that the pattern of auditory maturation in adult with stuttering is quite different from that of normal control subjects. In the follow up study, Howell, Davis and Willaims (2006) the authors established a significant decrease in threshold in case of individuals who has recovered from stuttering as compared with persistent stuttering group in broadband backward-masked stimulus condition thereby sustaining the theory of defective auditory processing in persistent stuttering group.

Overall, behavioural studies of auditory processing have not been consistent in finding differences between the two groups of subjects. Even the extensively utilized procedure of dichotic listening has yielded inconsistent results, Although it seems likely that at least a subgroup of stuttering individuals do demonstrate a reversal or absence of ear advantage on this test.

2.2. Evidence from electrophysiological studies

Auditory evoked potentials are used as objective measures to evaluate the brain’s response to auditory stimuli at different levels along the auditory pathway. Using stimulus-locked epochs of electroencephalographic (EEG) recordings, both brainstem and cortical potentials have been recorded from stuttering and nonstuttering individuals as they listen to auditory stimuli. The Auditory Brainstem Response (ABR) and Auditory Middle Latency responses (AMLR) are recorded while subjects listen to clicks presented at high rates. Typical measurements made from the ABR recordings include the latencies of peaks I to V, the slope of the latency/intensity function, and the intensity required to observe a first definitive response. In addition, measures of the amplitude ratio between waves and latency shift in waves when the stimulus presentation rate is increased (e.g., from 20 to 90 clicks per second) have also been used to assess the auditory brainstem pathways in individuals who stutter.

2.2.1. Auditory brainstem response (ABR) studies

The ABR records responses of the brainstem for auditory stimuli. The responses are recorded as peaks labelled from I to V, occurring within 10 msec latency. Blood and Blood (1984) were one of the earliest researchers who attempted to provide evidence for disordered auditory processing in persons with stuttering using auditory evoked potentials. They recorded the auditory brainstem response of eight stutterers and compared it with eight nonstutterers. The recordings revealed that the inter-peak latency from first to fifth peaks were prolonged in stutterers, thus implying a longer central conduction times in these individuals. Smith, Blood and Blood (1990) supported this by recording greater absolute amplitude of wave I and Wave V to Wave I relative amplitude in individuals with stuttering as compared to their age matched nonstutterers. Similarly, Kedr, Al-Naseer, Haleem, Bakr, and Trakhan (2000) reported a significant delay in absolute latencies of peak I, III & V as well as inter-peak latencies of I-III & I-V in individuals with stuttering. However, studies done by other authors (Decker, Healey, & Howe, 1982; Newman, Bunderson, & Brey, 1985; Stager, 1990) suggested that there were no significant difference between the auditory brainstem response of stutterers and non-stutterers.

Overall, the results from studies done using ABR responses report conflicting results. On one hand, a significant number of studies report positively that disruptive auditory processing at the level of brainstem in persons with stuttering and is manifested as relatively weaker absolute amplitude and delayed latencies of the peaks. Whereas, on the other hand, a handful of studies report that there exist no significant difference in ABR peaks recorded from stutterers and nonstutterers.

2.2.2. Auditory Middle latency response (AMLR) studies

Middle latency responses occur within 10-50 msec following stimulus onset. Studies on middle latency response are comparatively lesser. Nevertheless, a few of the researchers did attempt to evaluate MLR potentials in individuals who stutter. Deitrich, Barry and Parker (1995) reported a significant delay in the waveform Pb of middle latency responses that were recorded from ten stutterers thus pointing to a auditor processing delay in these individuals.

2.2.3. Studies based on late latency response (LLR)

LLR occurs after 50 msec following stimulus presentation. The peaks recorded include N1, (90 msec) and P2 (180 msec). Endogenous LLR recorded using odd ball paradigm can yield P300 (300 msec) and Mismatch negativity (200ms). LLR provides a much clearer picture of auditory processing as it records the responses of cerebral cortex for the auditory stimulation. For this reason, it is one of the most widely used test for assessing the central auditory processing in various populations including stutterers. Finitzo, Pool, Freeman, Devous, and Watson (1991) compared late latency event related potentials in persons with stuttering and age matched controls. The N1 and P2 waves were found to have reduced in amplitude for stutterers as compared to nonstutterers. On the other hand, Hampton and Weber-Fox (2008) findings suggested early occurrence of N100, P200 and P300 as well as reduced absolute amplitude of P300 in persons with stuttering. Their results indicated a diminished representation of auditory stimuli at cortical level.

Liotti, Ingham, Takai, Paskos, Perez and Ingham (2010) recorded high density evoked potential response in eight adults with persistent stuttering and their age and gender matched nonstutterers. The task included “SPEAK” in which each speaker was asked to say “ah” repeatedly, and the next task “LISTEN” where subjects were asked to listen to same spoken sample. ERPs were recorded throughout both the tasks. The findings revealed an overall reduction in N1 & N3 amplitude over right inferior temporo-occipital scalp in persons with stuttering. The authors interpret their results by stating that there is an “early increased activation of right rolandic area and late reduced activation in right auditory cortex” for persons with stuttering in comparison with normal fluent speaking controls and emphasize disordered auditory processing in persons with stuttering.

Exogenous LLR has also been widely used for research in stutterers to explore the finer discrimination abilities in them. Corbera, Corral, Escera, and Idiazabal (2010) measured the mismatch negativity (MMN) in individuals who stutter. The authors recorded the MMN for simple tones as well as phonetic contrast tones and found that MMN was similar for nonstutterers and stutterers for simple tones, but it was enhanced for phonetically contrasted stimuli for stutterers thus signifying abnormal permanent traces for speech sounds in these individuals. However, the P300 component recorded during conscious shift of attention during speech discrimination was reported to be equal for individuals with and without stuttering (Ferrand, Gilbert, & Blood, 1991; Kedr, Al-Naseer, Haleem, Bakr, & Trakhan, 2000). On the contrary, Morgan, Cranford, and Burk (1997) did record a mixed pattern of hemispheric lateralization for speech discrimination in individuals who stutter as compared to fluent speakers. They reported that all the normal subjects (8) had higher P300 activation over right hemisphere for tonal stimuli, whereas five out of eight individuals who stutter had left hemispheric activation for P300.

Overall, evidence from electrophysiological recordings confirm millisecond-level delays in brain stem activity (as examined by ABR analyses) also result in continued delays in signal transmission (and thus presumably information processing) at later stages of the central auditory pathways (as examined by AMLR and ALR analyses). In fact, the ALR data more often have suggested amplitude rather than latency differences, but even these findings regarding amplitude of the N100/M100 wave have not been fully consistent in either the direction or localization of any between-group differences. Clearly, further investigations into how these differences might affect the monitoring of speech production are necessary

2.3. Evidence from neuroimaging studies

Several recent studies have used anatomical and/or functional neuroimaging techniques to investigate the neural basis of auditory processing in individuals who stutter. The equipments that are used to study the neuroimaging basis for stuttering include Computed tomography (CT), Magnetic resonant imaging (MRI), positron emission tomography (PET), Magnetoencephalograph (MEG), Electroencephalograph (EEG), voxel based morhometry etc. The main advantage of this method is that it gives a means for direct visualization of neuronal activity during speech perception. However, the instruments are expensive and sophisticated thus demanding high capital as well as special training for its acquisition and proper use.

Braun et.al (1997) in their study using PET scan reported absent left hemispheric activation during speech in individuals with stuttering. The activation was either absent or lateralized to right hemisphere in these individuals during fluent as well as dysfluent utterances.

Salmelin, Schnitzler, Schmitz, Jäncke, Witte, and Freund (1998), using MEG found out that functional organization of auditory cortices was altered in stutterers. Further, Biermann-Ruben, Salmelin and Schnitzler (2005) noticed an additional activation of right rolandic area in stutterers during speech perception task which was not obtained in normal subjects using MEG.

Another significant discovery by Foundas, Bollich, Corey, Hurley and Heilman (2001) using the widely followed technique of magnetic resonant imaging (MRI), was the presence of Anomalous asymmetry in planum temporale in individuals with stuttering. Voxel based morphometry images also have showed increased grey matter density in right superior temporal gyrus, left superior temporal lobe (Beal, 2011) in addition to a significant increase in white matter volume in the right hemisphere (Jäncke, Hänggi & Steinmetz, 2004), reduced grey matter volume in the left inferior frontal gyrus and bilateral temporal regions (Chang, Erickson, Ambrose, Hasegawa-Johnson, & Ludlow, 2008) in persons with stuttering in comparison with normal subjects.

Brown, Ingham, Ingham, Laird, and Fox (2005) reviewed the earlier studies using all the imaging techniques. They used activation likelihood estimation (ALE) to compare the activation sites during dysfluent utterances of individuals with stuttering and fluency utterances of normal controls. The results suggested an over activation of primary motor cortex, supplementary motor area, cingulate motor area, and cerebellar vermis and anomalous activation of Frontal operculum, Rolandic operculum, and anterior insula in individuals with stuttering. Further, a reduced activation for self-feedback was detected in these individuals.

Cykowski et.al (2008) analyzed the perisylvian sulcal patterns in persons with stuttering using 3-dimensional sulcal identification and extraction. They found out that there is a significant increase in number of sulci connecting second segment of the right Sylvian fissure and in the number of suprasylvian gyral banks (of sulci) along this segment in individuals with stuttering. This finding can be correlated with functional imaging studies to support the theory of increased right-hemisphere activity during stuttered speech.

A recent study done by Beal, Quraan, Cheyne, Taylor, Gracco, and De Nil (2011) recorded MEG in 11 children with stuttering and 11 age matched controls during 3 tasks namely listen tone, listen vowel and speak vowel. The findings disclosed that children with stuttering possess a prolonged auditory M50 during vowel production and perception based on which the authors concluded that these children exhibit deficits in auditory integration.

To summarize, evidence from neuroimaging studies have reported anatomical abnormalities in stuttering subject's auditory cortical regions, but the reported differences are inconsistent across different studies. Functional imaging studies during passive listening have been few in number, and the methodologies have been very different, thereby failing to reach any unanimous conclusions. By far the most consistent finding across functional neuroimaging studies is that, during speech production, stuttering individuals show absent or reduced activation of the cortical auditory areas.

Thus, the literature provides evidences where in various methods have been used to investigate the auditory processing in persons with stuttering. Although, there are contradicting findings, the overall results suggest that individuals with stuttering possess specific deficits at the level of auditory processing.

2.4. Fine grained auditory discrimination

One other means of behavioural study of auditory processing is through employing the method of "*fine grained auditory discrimination*". This procedure was established originally by Elliot, Longinotti, Meyer, Raz and Zuker (1981). According to these authors, the procedure is named so as it measures 'Just noticeable difference' that is "it assesses the smallest differences associated with speech-like consonant sounds that may be discriminated" (Elliot et al., 1981). In this procedure, the continuum of synthetic stimuli which differed in any one of the parameters (ex-VOT, transition etc.,) were used. The minimum difference in the parametric value with which the subject perceived the stimuli at one end of the continuum as that at the other end will be determined. For example, the minimum value of "voice onset time" at which subject perceived /ba/ as /pa/ is measured.

Following the establishment of this systematic procedure, the fine grained auditory discrimination gained momentum in the field of research in auditory processing. Elliot and Hammer (1988) used fine grained auditory discrimination to track the longitudinal changes occurring in normal children and children with learning disability. An eight item "/pa-ba/" continuum differing in VOT values and a 13 item "/ba-da-ga/" continuum with altered second and third formant frequency values were used for the purpose of study. The results revealed that learning disabled children exhibited poorer just noticeable difference (JND) scores across 3 years as compared to the normal children. Similar procedure was employed by the Elliot, Hammer and Scholl (1989) to determine auditory processing in children with language learning problem and established that the JNDs are poorer in 80% language delayed children as compared to their normally developing peers. Three continua- /a/-/i/, /ba-da/ and /sta/-/sa/ were utilized by Steffens, Eilers, Gross-Glenn and Jallad (1992) to assess auditory processing in adults with dyslexia and found out that there is a reduction in overall performance of dyslexic subjects on the discrimination tasks.

Bradlow, Kraus, Trent, Cunningham, Zecker, and Thomas (1999) assessed the effects of lengthened formant transition duration on discrimination of /da/ & /ga/ for normal and learning disabled children using synthetic /da-ga/ continuum differing only in formant transition. The results implied that lengthening the formant transition does not yield better discrimination for learning disabled children in comparison with normal subjects. Kraus et.al (2000) employed fine grained auditory discrimination to study central auditory processing in 24 year old female diagnosed with auditory neuropathy. The authors used /ba/ to /wa/, /da/ to /ga/, and /da/ to /ga/ continua varying in the F2 formant transition values. The authors concluded that the subject had difficulty discriminating stimuli differing in spectral domain where as she did not exhibit much difficulty for stimuli varying in temporal domain.

Two studies have been done in Indian context using this paradigm. Swapna (2005) and Powlin (2009) have evaluated the auditory processing in children with learning disability and children who are late talkers respectively. As a part of her thesis, Swapna (2005) assessed fine grained auditory discrimination in children with learning disability. She used synthetic /pa-ba/, /ta-da/ and /ka-ga/ continuum and recorded the just noticeable difference for VOT value in all the three continuums. The results revealed that children with LD required longer VOT as compared to their age matched peers in judging the stimuli as different. Powlin (2009) evaluated effect of temporal and spectral variations on phoneme identification skills in late talking children using similar procedure. She used synthetic tokens of /pa-ba/ and /pa-ta/ continuum and recorded the JND. The results pointed to the direction that there was a significant difference between the temporal and spectral processing of late talkers in comparison with typically developing children.

Although many researchers have evaluated the auditory processing disabilities using fine grained auditory discrimination paradigm in different communication disorders like learning disability, delayed speech and language cases, late talkers etc, not much focus is given in the area of stuttering. Recently Neef, Sommer, Neef, Paulus, Gudenberg, Jung and Wüstenberg (2012) attempted to assess the auditory processing skills in adults who stutter using auditory discrimination. The stimuli used were tokens of /pa-ba/ and /da-ta/ continuum. Twenty seven adult stutterers with mean age of 32 years participated in the study. Twenty four age and gender matched control subjects were taken up for the purpose of comparison. The voiceless syllable was generated using AT &T bell research lab speech synthesizer and format value for the vowel was extracted from the computation of this synthesized syllable in PRAAT. The vowel and consonant was segmented and the resulting segments were superimposed using algorithms made in Matlab programming language (release 2007a) with 1ms step width to form each token. The tokens were randomized and presented to the subjects via headphones and were asked to press left mouse button if they hear /ba/ or /da/ and right mouse button if they hear /pa/ or /ta/. The phonemic boundaries were determined by noting down the minimum VOT value at which subjects switch to the other end of the continua. The results supported the theory of reduced auditory perception in individuals with stuttering. The study gave a brief outlook on the auditory perceptual deficits in adults who stutter.

Most of the studies on auditory processing in stuttering are done in adults but are seldom replicated in children. Similar studies needs to be done on children as this group of population is closer to the onset. Hence, reproducing analogous results in case of children can positively support the theory of disordered auditory processing as being the etiology for stuttering rather than it being a characteristic feature.

To the best of our knowledge, no studies have been done to assess the auditory perceptual acuity in children using fine grained auditory discrimination paradigm. Using this procedure, the difference in finer discrimination ability of an individual can be determined. If these children who stutter have deficits in auditory processing, then they will exhibit discrimination abilities poorer than their age and gender matched children who do not stutter. Hence, the objective of the present study is to compare the auditory discrimination in children who stutter with age and gender matched children who do not stutter using fine grained auditory discrimination paradigm.

Chapter 3

Method

3.1. Participants

Two groups of Malayalam speaking children participated in the study. Group I consisted of twenty children who stutter (4 females and 16 males). These children were within the age group of 5 to 12 (mean age of 9 ± 2 years) years. The children were identified from Block resource centers of Malappuram district in Kerala. Apart from stuttering, these children had no other complaint of mental retardation, hearing impairment, articulation problem or any other neurological problems. Each child was selected based on the following inclusion criteria.

1. Stuttering children should have at least very mild severity of stuttering on Stuttering Severity Index- 4 (Riley, 2009).
2. Their receptive and expressive language scores should be well within the normative of the respective ages on administration of Linguistic Profile Test – Malayalam (Asha, 1997).
3. They should have hearing thresholds within normal limits on pure tone audiometric evaluation done using ELKON audiometer EDA 3N3 Plus, for both the ears.
4. They should have 'A' type tympanogram with normal reflexes at all the frequencies (70-120 db HL) on Immitance audiometry done using GSI Tympstar.
5. They should not have any history of neurological illness as reported by any of the parent or teachers.

Group two consisted of age and gender matched typically developing children with no compliant of stuttering. Similar inclusion criteria were adopted to recruit the typically developing children. Table 1 and table 2 describe the demographic details of children who stutter and children who do not stutter respectively.

Table 1:

Demographic details of children who stutter

SL.No	**CWS**	**Age**	**Gender**	**SS**	**Lang**	**PTA**	
						Right	Left
1	F1	6.5	F	Very mild	252 (WNL)	6.6	6.6
2	F2	6.3	F	Mild	253(WNL)	6.6	10
3	F3	12.7	F	Very severe	284(WNL)	10	8.6
4	F4	12.9	F	Very mild	287(WNL)	8.3	8.3
5	M1	6.3	M	Mild	254(WNL)	12	8.3
6	M2	7.2	M	Moderate	257(WNL)	8.8	6.6
7	M3	7.8	M	Mild	257(WNL)	8.6	13.3
8	M4	8.6	M	Moderate	264(WNL)	6.6	6.6
9	M5	9.4	M	Mild	268(WNL)	6.6	3.3
10	M6	9.5	M	Mild	267(WNL)	5	6.6
11	M7	9.5	M	Mild	267(WNL)	6.6	6.6
12	M8	10.2	M	Mild	275(WNL)	3.3	6.6
13	M9	10.6	M	Moderate	279(WNL)	6.6	3.3
14	M10	10.9	M	Mild	276(WNL)	8.3	6.6
15	M11	11.4	M	Moderate	280(WNL)	6.6	11.6
16	M12	11.4	M	Mild	280(WNL)	6.6	9
17	M13	11.7	M	Mild	278(WNL)	5	8.3
18	M14	11.8	M	Moderate	281(WNL)	9	9
19	M15	12.5	M	Mild	287(WNL)	8.3	8.3

Table 1:

Demographic details of children who stutter continued.

SL.No	**CWS**	**Age**	**Gender**	**SS**	**Lang**	**PTA**	
						Right	Left
20	M16	12.9	M	Mild	286(WNL)	11.6	6.6

Note. CWS= children who stutter, F=female, M=Male, SS= stuttering severity, Lang= Language scores, WNL=Language scores are within normal range of respective age group based on LPT, PTA= pure tone audiometry thresholds.

Table 2:

Demographic details of children who do not stutter

SL.No	**CWNS**	**Age**	**Gender**	**Lang**	**PTA**	
					Right	Left
1	F1	6.5	F	250(WNL)	8.3	6.6
2	F2	6.3	F	258(WNL)	6.6	8.3
3	F3	12.7	F	288(WNL)	10	8.3
4	F4	12.9	F	288(WNL)	8.3	8.3
5	M1	6.3	M	251(WNL)	11.6	8.3
6	M2	7.2	M	254(WNL)	10	8.3
7	M3	7.8	M	254(WNL)	6.6	13.3
8	M4	8.6	M	264(WNL)	8.3	6.6
9	M5	9.4	M	268(WNL)	6.6	5
10	M6	9.5	M	268(WNL)	5	6.6
11	M7	9.5	M	270(WNL)	6.6	6.6
12	M8	10.2	M	280(WNL)	3.3	8.3

Table 2:

Demographic details of children who do not stutter continued

SL.No	**CWNS**	**Age**	**Gender**	**Lang**	**PTA**	
					Right	Left
13	M9	10.6	M	276(WNL)	5	3.3
14	M10	10.9	M	276(WNL)	8.3	8.3
15	M11	11.4	M	278(WNL)	8.3	10
16	M12	11.4	M	281(WNL)	6.6	8.3
17	M13	11.7	M	283(WNL)	3.3	8.3
18	M14	11.8	M	284(WNL)	10	8.3
19	M15	12.5	M	287(WNL)	8.3	6.6
20	M16	12.9	M	282(WNL)	10	5

Note. CWNS= children who do not stutter, F=female, M=Male, Lang= Language scores, WNL=Language scores are within normal range of respective age group based on LPT, PTA= pure tone audiometry threshold

Independent t-test was done to compare the means of pure tone thresholds and language scores between the children who stutter and children who do not stutter. The right pure tone average revealed a value of [(t(1,19)= .224, p=.824)], left pure tone average as [(t(1,19)=.314, p=.755)], and language score yielding a value of [(t(1,19)= -.246, p=.807)]. No significant difference was obtained between the children who stutter and children who do not stutter for all the three variables.

3.2. Stimuli:

Two sets of stimuli were used in this study. The first set consisted of continuum from /ba/ to /pa/ varying in voice onset time (VOT). The second set consisted of continuum from /pa/ to /ta/ varying in F2 value.

3.2.1. Set 1: /ba/-/pa/ continuum

A /ba/ stimulus was recorded as spoken by a 23 year old male using the Cool edit 2.0 software at 44100 KHz sampling frequency and 16 bit quantization. The voice onset time was measured from the onset of voicing till the burst (lead VOT). The VOT obtained for the recorded stimuli was truncated in the steps of 3 ms till 0 msec. subsequently, silence were added between the burst and onset of vowel using the same step size. A total of 21 stimuli were generated using this procedure. These 21 stimuli were combined with the anchor stimuli to generate 21 tokens of /ba/-/pa/ continuum. Figure 1 shows examples of token stimuli with different VOT values; Table 3 shows the VOT values of individual token stimuli generated using manipulation of anchor stimuli.

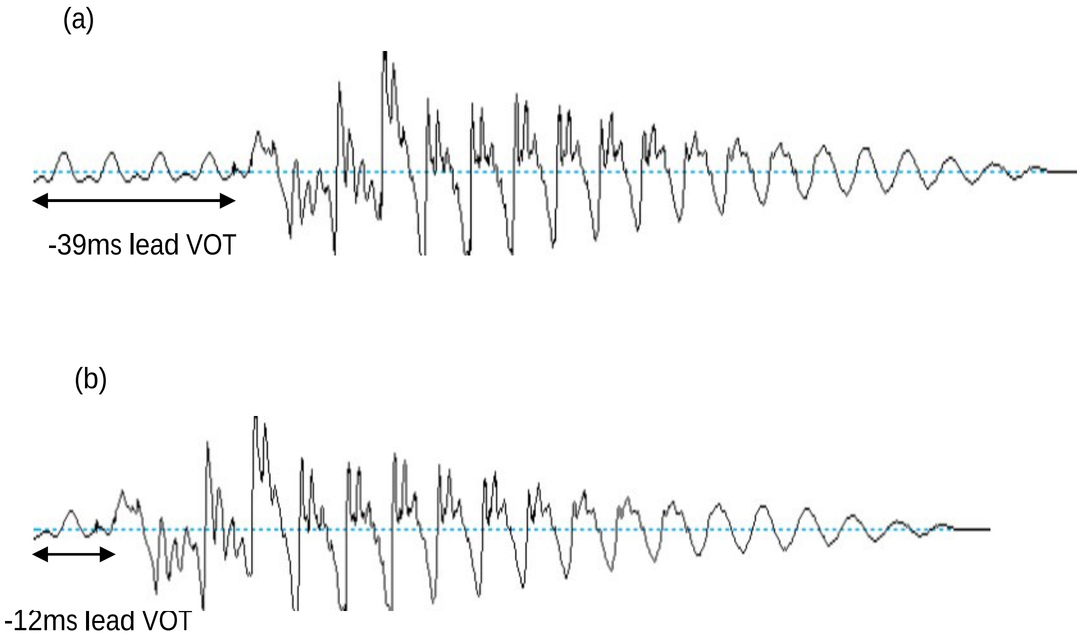


Figure 1: Waveform showing (a) original stimuli with lead VOT of -39ms (b) synthesized stimuli with lead VOT of -12ms (c) synthesized stimuli with Lag VOT of +21ms.

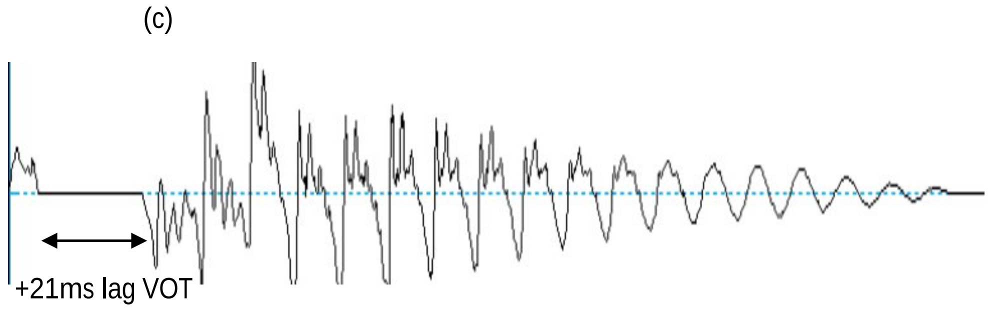


Figure 1: Waveform showing (a) original stimuli with lead VOT of -39ms (b) synthesized stimuli with lead VOT of -12ms (c) synthesized stimuli with Lag VOT of +21ms continued.

Table 3:

VOT values of individual tokens in /ba/-/pa/ continuum

Stimuli	**VOT (ms)**
ba1 (anchor)	-39
ba2	-36
ba3	-33
ba4	-30
ba5	-27
ba6	-24
ba7	-21
ba8	-18
ba9	-15
ba10	-12
ba11	-9
ba12	-6

Table 3:

VOT values of individual tokens stimuli in /ba/-/pa/ continuum continued

Stimuli	**VOT (ms)**
ba13	-3
ba14	0
ba15	3
ba16	6
ba17	9
ba18	12
ba19	15
ba20	18

3.2.2. Set 2: /pa/-/ta/ continuum:

The stimuli used for /pa/-/ta/ continuum were developed by Jayakumar, and Vijaikumar (2012) for their ARF funded project done at All India institute of Speech and hearing.

A base stimulus /pa/ was synthesized using Klatt synthesizer (Klatt, 1980) in Matlab (R2009a, Math work Inc). For the synthesis of this stimulus 33 parameters were used as input to be fed into the synthesizer. Table 4 gives the list of parameters used for the synthesis of the base stimuli. Normative values for burst were obtained by analysis of the recorded burst sample from ten Kannada speaking males. These values were used to synthesis burst which was then combined to the base stimuli to obtain /pa/. The vowel /a/ was kept constant for all the stimuli and F2 transition was varied in steps of 100 Hz to obtain /pa/-/ta/ continuum (Jayakumar, & Vijaikumar, 2012). Thirteen tokens of individual stimuli were generated from the anchor stimuli (the stimuli synthesized at first) using this procedure. Each synthesized stimuli was combined with the anchor stimuli thus generating a total of 13 tokens of /pa-ta/ continuum. Figure 2 shows spectrograms of three token stimuli used for the study; Table 5 shows the F2 transition values for all 13 stimuli.

Table 4:

Details of the 33 parameters used in Klatt synthesizer for /pa/ stimuli generation.

Parameter	details
FGD	Glottal resonator 1 frequency (Hz)
FGZ	Glottal zero frequency (Hz)
FGS	Glottal sinusoidal frequency (Hz)
FNP	Nasal pole frequency (Hz)
FNZ	Nasal zero frequency (Hz)
F1	First Formant frequency (Hz)
F2	Second Formant Frequency (Hz)
F3	Third Formant Frequency (Hz)
F4	Fourth Formant Frequency (Hz)
F5	Fifth Formant Frequency (Hz)
F6	Sixth Formant Frequency (Hz)
BGP	Glottal resonator 1 bandwidth (Hz)
BGZ	Glottal zero bandwidth (Hz)
BGS	Glottal sinusoidal resonator (Hz)
BNP	Nasal pole bandwidth (Hz)

Table 4:

Details of the 33 parameters used in Klatt synthesizer for /pa/ stimuli generation continued

Parameter	details
BNZ	Nasal zero bandwidth (Hz)
BW1	First formant bandwidth (Hz)
BW2	Second formant bandwidth (Hz)
BW3	Third formant bandwidth (Hz)
BW4	Fourth formant bandwidth (Hz)
BW5	Fifth formant bandwidth (Hz)
BW6	Sixth formant bandwidth (Hz)
A2	Second formant frequency Amplitude
A3	Third formant frequency Amplitude
A4	Fourth formant frequency Amplitude
A5	Fifth formant frequency Amplitude
A6	Sixth formant frequency Amplitude
AB	Bypass path amplitude
AH	Amplitude of aspiration
AF	Amplitude of frication
AV	Amplitude of voicing
AVS	Amplitude of sinusoidal voicing
Weight	A constant term value is 1 for consonant and varies between 0.8 to 1 for vowels

Note. Table adapted from "behavioral corelate of P300 responses to voice onset time (VOT) and place of articulation continuum in Kannada & Hindi speaking individuals" by Jayakumar, T., and Vijaikumar, N (2012), ARF project, AIISH. Adapted with permission.

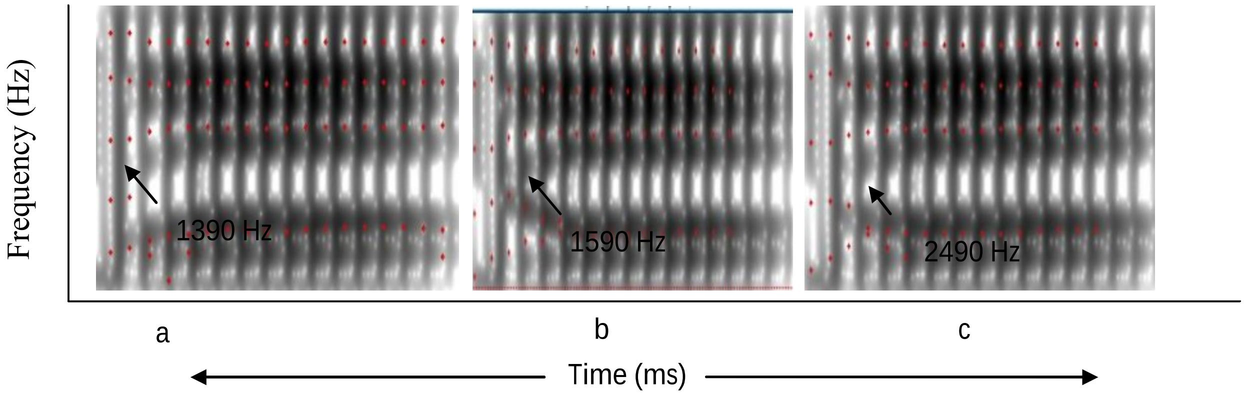


Figure 2: Spectrogram showing (a) original F2 transition of 1290 Hz (b) synthesized stimuli with F2 transition of 1590 Hz (c) synthesized stimuli with F2 transition of 2490 Hz

Table 5:

F2 transition values for individual tokens in /pa-ta/ continuum (Hz)

Stimuli	F2 value in Hz
pa1 (anchor)	1290
pa2	1390
pa3	1490
pa4	1590
pa5	1690
pa6	1790
pa7	1890
pa8	1990
pa9	2090

Table 5:

F2 transition values for individual tokens in /pa-ta/ continuum (Hz) continued.

Stimuli	F2 value in Hz
pa10	2190
pa11	2290
pa12	2390
pa13	2490

3.3. Procedure

The testing was carried out in two sessions. During the first session, each child was evaluated for the stuttering severity, language and articulation. Video recording was done for picture description task using the pictures from SSI-4 (Riley, 2009). This session was carried out in their respective schools. For the second session, the children were called to the block resource centres. Here, audiometric evaluations and immitance evaluations were carried out. Following this, the stimulus presentation for actual experiment was done.

Each child was made to sit comfortably in front of the laptop at a distance of 20-25 cm from the monitor. The testing was done in a quiet room using CIRCLE concerto live-200 multimedia headphones. The headphones were calibrated using Fonix 7000 real ear analyzer. RMS SPL was measured in a 2 CC coupler. Volume control and output level from the standard sound end of the laptop was modified such that the RMS level read in the real ear analyzer was 60 dB SPL.

The stimuli were presented through the software APEX 3 (Francart, Wieringen, & Deun, 2008). The software determines the phoneme boundary through adaptive threshold estimation. It was programmed using notepad application of Microsoft. The program written in XML format was fed to the software. When the software processes and accepts the written codes, it generates a screen with three response pictures. The response pictures for /ba-pa/ continuum included that of bus, pen and shirt and for /pa-ta/ continuum they were of pen, cap and shirt. Stimuli were presented in pairs by combining target stimulus with anchor stimulus for both continuums. The anchor stimulus served as the base. Individual target stimulus was discriminated by comparing it with the anchor stimulus. Each presentation of stimuli was followed by a response. The response was in the form of click on the any one of the displayed picture. For both the continuums, individual programs defined the correct and incorrect responses. Each correct response rendered the stimuli to become more similar. Conversely, for each incorrect response stimuli became more readily distinguishable. In this way one up two down procedure was used to determine the minimum value with which each stimulus was discriminated from the anchor stimulus.

3.3.1. /ba/-/pa/ continuum presentation

At the press of the “start” command, a screen appears with picture of “bus”, “pen” and “shirt. At first, a pair of most distinguishable stimuli was presented through the headphone. The most distinguishable stimuli constitute the pair with maximum VOT difference between the anchor and target stimuli. (e.g. ba1 & ba22) The instruction given for each participant is as follows

“You will be hearing two sounds now. The first one will always be /ba/. The second stimuli will keep on changing. If you hear the second stimuli as /pa/, then click on the pen. If you hear it as /ba/, click on the bus and if you hear it as anything else click on the shirt.”

In the program script, correct response was defined as “pen”. So whenever, the child clicked on the pen, the stimuli presented shifted to ones with smaller VOT difference (e.g. ba1 & ba12). If the child did not discriminate the pair then the step goes back to easier ones. That is, if the child clicks on the incorrect answer, that is the “bus” or “shirt”, the trial shifted to pair of stimuli with larger VOT difference. In this way the software used systematic up and down procedure to tackle the minimum VOT value with which the phoneme /ba/ is distinguished from phoneme /pa/. One up and two down procedure was followed by using step sizes of 12 msec, 6 msec and 3 msec. The software automatically ended the procedure with 12 consistent reversals.

3.3.2. /pa-ta/ continuum presentation

The monitor screen displayed pictures of bus, cap (toppi) and shirt on start command. Similar procedures as that of /ba/-/pa/ continuum presentations were followed. The instruction given was as follows

“You will be hearing two sounds now. The first one will always be /pa/. The second stimuli will keep on changing. If you hear the second stimuli as /pa/, then click on the pen. If you hear it as /ta/, click on the cap (topi) and if you hear it as anything else click on the shirt.”

Initially stimuli with maximum difference in F2 transition values were presented. The correct answer was defined as “cap”. The stimuli become more similar in terms perception (lesser F2 transition value difference between anchor and target stimuli), when the child clicked on the cap. If he/she clicked on the incorrect answers that is "pen" or "shirt" the stimuli shifted to easier ones which are by definition, the ones with more F2 value difference. The step size followed were 600Hz, 400Hz and 100Hz. the procedure automatically ends after 12 reversals and trial average will be calculated. Figure 3 and figure 4 shows the laptop monitor display during the presentation of /ba-pa/ continuum and /pa-ta/ continuums respectively.

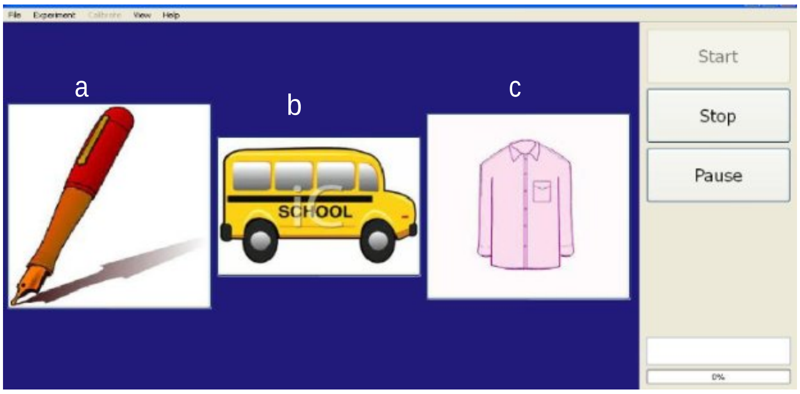


Figure 3: APEX screen while presentation of /ba-pa/ continuum. Screen displays response pictures (a) pen, (b) bus and (c) shirt.

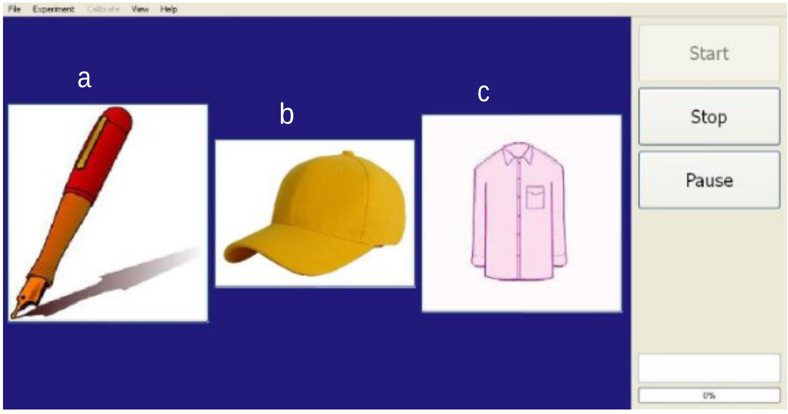


Figure 4: APEX screen while presentation of /pa-ta/ continuum. Screen displays response pictures (a) pen, (b) /toppi/ and (c) shirt.

The software gives the minimum value at which the perception changes from /ba/ to /pa/ and form /pa/ to /ta/ for each subject. This value is termed as *phoneme boundary.* It is calculated by averaging the last 12 reversals for each subject across each continuum.

Logistic psychometric function was fitted for each child using a maximum likelihood algorithm using Matlab software (R2009a, Math work Inc). β value were derived from psychometric curve for each participant by the software. β values for both slope as well as at 50% crossover were derived. The β values at slope were labelled as β1 and at 50 % cross over were labelled as β2. Therefore, each subject had two separate β values for each psychometric fit.

3.4. Statistical analysis

The Phoneme boundary value obtained for /ba/-/pa/ continuum and /pa/-/ta/ continuum for both children who stutter and children who do not stutter were noted. Also, β values obtained following the psychometric fitting for each participant for both the continuums were tabulated. Mann Whitney U-test was done separately for both the groups for each continuum separately, for PB as well as β values.

Chapter 4

Results

The present study compared the auditory perceptual acuity between children who stutter (CWS) and children who do not stutter (CWNS) using fine grained auditory discrimination paradigm. Twenty children who stutter (4 girls and 16 boys) and twenty age and gender matched children who do not stutter participated in the study.

4.1. Comparison of Phoneme Boundary (PB) between CWS and CWNS

Phoneme boundary for each child was derived using "adaptive threshold estimation" procedure. The software APEX was used for this purpose. This software tracked thresholds at which perception changed from /ba/ to /pa/ and from /pa/ to /ta/ for each participant. This threshold was tabulated as the phonemic boundary for the respective child for each continuum. Figure 5 shows an example of the graphical representation of adaptive threshold estimation obtained as output from APEX.

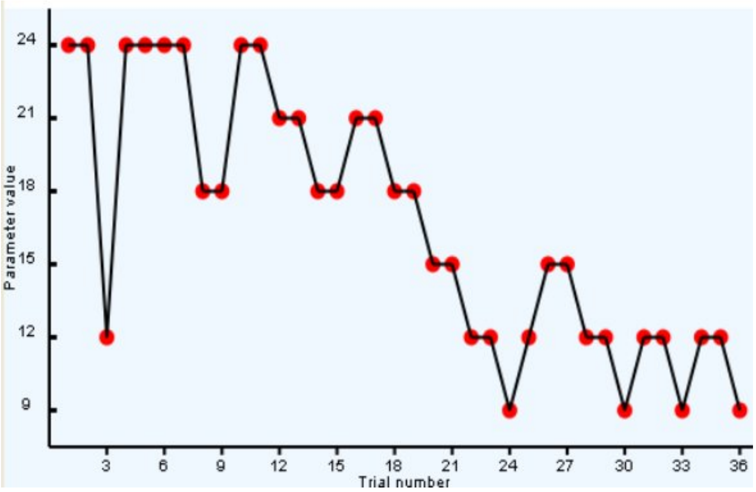


Figure 5: Adaptive threshold graph of CWS for /ba/-/pa/ continuum. VOT value on Y-Axis is plotted against each trial on X-axis. The initial trials show higher difference

in VOT value between the anchor and target stimuli. This difference is reduced with each correct response. The final 12 reversals is averaged to give PB value for each subjects.

Mean, median and standard deviation values for both the groups, independently for each continuum, were calculated using SPSS software (version17). Table 6 shows the mean, median, and standard deviation values of PB for /ba/-pa/ as well as /pa/-/ta/ continuum for both CWS and CWNS groups.

Table 6

Comparison of Mean, median, and standard deviation values of PB for /ba/-/pa/ and /pa/-/ta/ continuum in CWS and CWNS

	/ba/-/pa/			**/pa/-/ta/**		
Group	Mean	Median	SD	Mean	Median	SD
CWS	3.61	3.375	7.60	2031.20	2033.50	252.44
CWNS	-21.07	-22.5	10.39	1814.87	1858	189.70

Note: CWS=children who stutter, CWNS=children who do not stutter, SD=standard deviation

Mann-Whitney U test was done to compare PB values of CWS and the CWNS for /ba/-/pa/ continuum and /pa/-/ta/ continuums. The results for /ba/-/pa/ continuum indicated a statistically significant difference [(Z = -5.033, p<.001)] between PB values of CWS and CWNS groups.

Likewise, the results of Mann-Whitney U test for PB values of /pa/-/ta/ continuum also indicated statistically significant difference [(Z = -2.801, p=.004)] between CWS and CWNS groups.

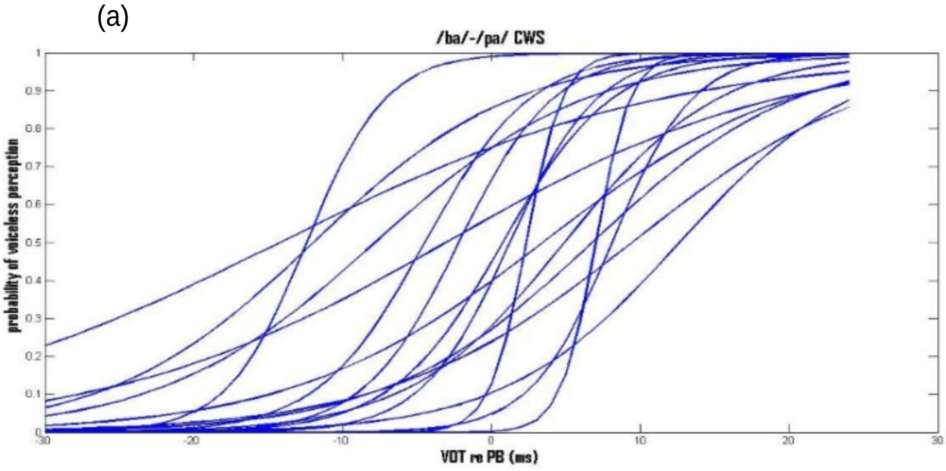
4.2. Logistic regression curves for /ba/-/pa/ and /pa/-/ta/ continuums

Figures 6 shows the psychometric curves obtained for each child for both the continuums. Curves were plotted using Matlab software. Each trial was plotted against the correctness of responses using complex algorithms. VOT values are plotted on X-axis against the probability of voiceless/place of articulation perception on Y-Axis. The scale“1” on Y-Axis signifies maximum probability of correct response and the scale “0” signifies highest probability of wrong response. Hence, for each child the VOT values for individual trials were plotted against its probability of correctness to give a sigmoid curve.

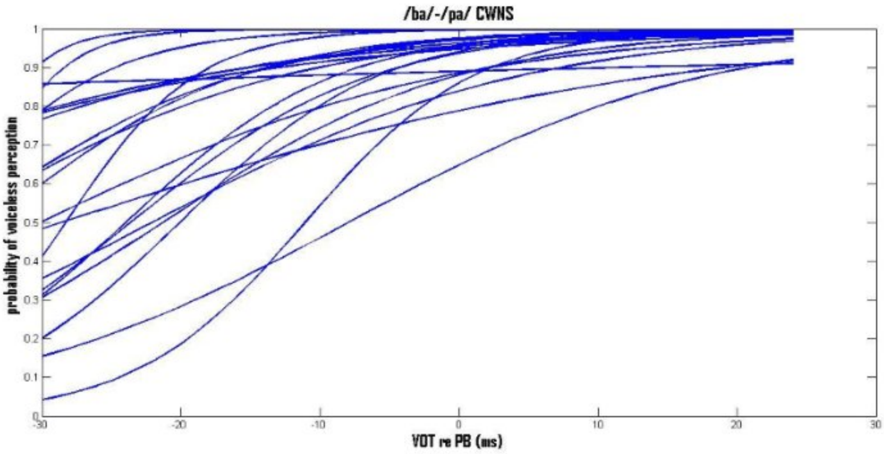
Children whose values failed to attain the sigmoid morphology were eliminated. The data of CWS 1, CWS 8 and CWS 9 were eliminated for /ba/-/ta/ continuum and CWS 12 and CWS 15 were eliminated for /pa/- /ta/ continuum.

The psychometric curves obtained for CWS are found to be nearer to the central region in case of /ba/-/pa/ continuum where as for the CWNS, the responses were evident more in the negative regions for the same continuum. This trend was not observed in case of /pa/-/ta/ continuum.

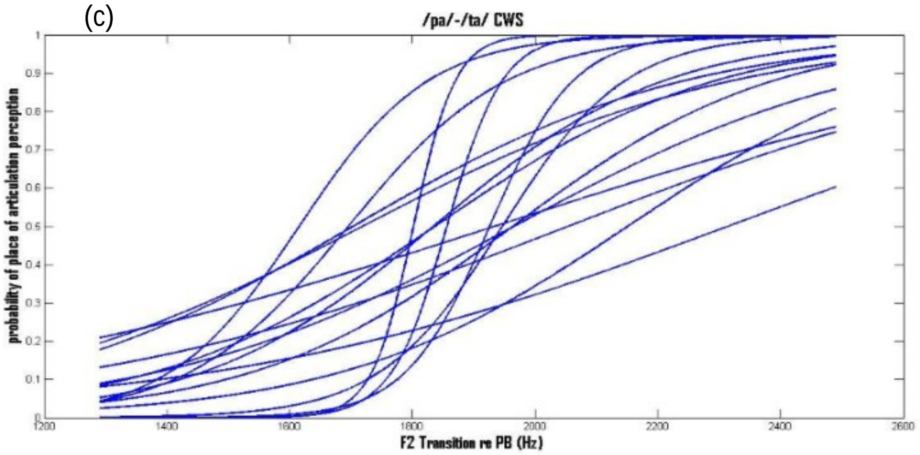
(a)



(b)


/ba/-/pa/ CWNS
probability of voiceless perception
VOT re PB (ms)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
-30
-20
-10
0
10
20
30

(c)


/pa/-/ta/ CWS
probability of place of articulation perception
F2 Transition re PB (Hz)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1200
1400
1600
1800
2000
2200
2400
2600

(d)

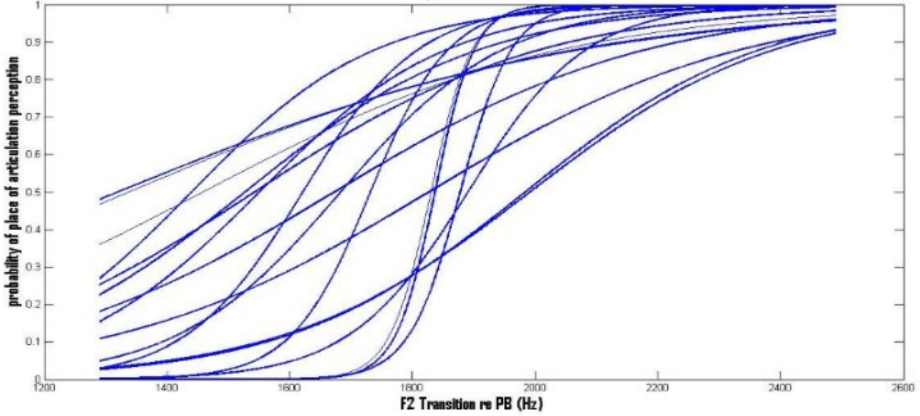

/pa/-/ta/ CWNS
probability of place of articulation perception
F2 Transition re PB (Hz)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1200
1400
1600
1800
2000
2200
2400
2600

Figure 6: Individual Psychometric functions for /ba/-/pa/ continuum and /pa/-/ta/ continuum for (a) /ba/-/pa/ CWS, (b) /ba/-/pa/ CWNS, (c) /pa/-/ta/ CWS, and (d) /pa/-/ta/ CWNS. Individual data for each trial was pooled to generate the sigmoid curve using logistic regression. The plot is obtained by scaling VOT values on X-axis and probability of perception on Y-axis. Outliers whose values did not show the sigmoid curve were eliminated. CWNS=children who do not stutter; CWS=children who stutter.

4.3. Comparison of β values between CWS and CWNS

β1 and β2 values derived from the psychometric fit were subjected to statistical analyses. Table 7 & table 8 show the mean, median, and standard deviation values for β1 and β2 respectively, separately for both /ba/-/pa/ and /pa/-/ta/ continuums.

Table 7

Mean, median, and standard deviation of β1 for /ba/-/pa/ and /pa/-/ta/ continuum

	/ba/-/pa/			/pa/-/ta/		
Group	Mean	Median	SD	Mean	Median	SD
CWS	-.1470	0.0363	2.168	-12.40	-8.61	13.77
CWNS	3.838	2.9826	3.211	-15.69	-10.03	17.12

Note: CWS=children who stutter, CNWS=control subjects, SD=standard deviation

Table 8

Mean, median, and standard deviation of β2 for /ba/-/pa/ and /pa/-/ta/ continuum

Group	/ba/-/pa/ Mean	/ba/-/pa/ Median	/ba/-/pa/ SD	/pa/-/ta/ Mean	/pa/-/ta/ Median	/pa/-/ta/ SD
CWS	.243	0.1593	.234	.0321	0.0043	.115
CWNS	.122	0.0962	.088	.036	0.0058	.121

Note: CWS=children who stutter, CWNS=children who do not stutter, SD=standard deviation

Mann-Whitney U test was done to evaluate the significant difference between both the groups for both β1 and β2 values. For /ba/- /pa/ continuum, β1 values for CWS were statistically significant from that of CWNS [(Z=-4.68, p<.001)]. β2 for CWS and CWNS also presented with a similar results showing significant difference between both the groups [(Z= -2.083, p = 0.037)].

For /pa/-/ta/ continuum, both β1 and β2 values failed to show any significant difference for both the groups [Z= -1.163, p = 0.245)]; [(Z = -1.298, p = 0.194)].

Chapter 5

Discussion

The current study explores the possibility of impaired auditory processing in CWS as a cause for their breakdown in fluency. If there exist a faulty processing of auditory signal in these children, then their discrimination ability at a finer level would be affected. The present study attempted at assessing the finer discrimination ability in CWS for voiced-voiceless phoneme continuum (/ba/-/pa/) and place of articulation continuum (/pa/-ta/)/. Phoneme boundary measures the minimum level at which the perception shifts from /ba/ to /pa/ and/or from /pa/ to /ta/. If the children who stutter did have deficit at the level of auditory processing, then they would indeed require more difference in the VOTs/ F2 transitions between two stimuli to perceive them as different.

The result of the current study presents evidence to support this hypothesis. There exists a significant difference in perceptual ability of CWS in comparison with CWNS when the phoneme boundary data of both of these groups were compared. In case of /ba/ -/pa/ continuum, the CWNS perceive the voiceless phoneme /pa/ with minimum cues. That is, these children start perceiving the voiceless phoneme well ahead in the continuum. Whereas, CWS discriminate the voiceless phoneme /pa/ from that of the voiced phoneme /ba/ at a later point in the continuum, which means that these children require much more cues to shift their perception to a voiceless phoneme from a voiced phoneme.

In case of the /pa/-/ta/ continuum too, the results indicate that the CWS require more phonemic cues to discriminate the place of articulation feature. The CWNS perceive the shift in phoneme /pa/ to that of phoneme /ta/ at an early point in the continuum whereas children who stutter attain this discrimination ability only after the supply of more cues in terms of changes in F2 transition. These findings are in support with other studies done by different authors using various other procedures (Sommers, Brady & Moore, 1975; Riley & Riley, 1980; Howell, Rosen, Hannigan, Rustin, 2000), thus signifying the presence of perceptual deficits in children who stutter.

The psychometric curves obtained in case of /ba/-/pa/ continuum for CWNS is evidently different from that of CWS (figure 8). The shift in the curve could be attributed to the fact that CWNS perceived the voiceless phoneme at a VOT value much earlier in the continuum in comparison to CWS. Therefore, the curves are clustered around the negative region of the X-axis where as in case of CWS these responses are near the mid-region suggesting that their perception of the voiceless phoneme occur in this region,

However in case of /pa/-/ta/ continuum the curves for both the groups are clustered around the same region suggesting no much difference in perception of place of articulation difference between the groups.

According to neural model of speech perception (Civier, Tusko & Guenther, 2010; Kalveram & Jancke, 1989; Max, Guenther, Gracco, Ghosh & Wallace, 2004), individuals with stuttering possess faulty feed-forward control systems. Hence, their sensory representation of phonemes would be blurred. The β value obtained using psychometric function gives a direct measurement of phoneme perception in the individuals. If the β values are smaller, the psychometric curve obtained would be steeper. This corresponds to a lesser VOT range in which stimuli are not identified with consistency. On the contrary, a larger β value corresponds to a wider slope and large range of VOT in which stimuli are perceived ambiguous.

For the /ba/-/pa/ continuum, the data analyses in β1 and β2 in the current study presents conflicting results. The β1 value which is the β calculated for slope is higher for CWNS in comparison to CWS where as the β2 value calculated at 50% cross over showed an opposing result. The 50% cross over region is the region where in an individual's perception shifts from voiceless phoneme to voiced phoneme. That is, these values correspond to the ambiguous range of VOT perception. Therefore according to the obtained results, CWS have more ambiguous responses than normal subjects at 50% cross over region. This finding is in support of the results obtained by Neef, Sommer, Neef, and Paulus (2012) who found similar results with adults who stutter. The results for β1 obtained by Neef et.al (2012) however were not replicated in the current study. The β1 values were calculated for the slope of the psychometric curve. So when these values were pooled, both groups showed wider range of responses in comparison to adults. When the mean for these values were taken the CWNS group showed more variable responses than CWS group. This may be the reason for discrepancy in results between the current study and the study done by Neef et.al (2012).

β1 & β2 values of /pa/-/ta/ continuum did not show any significant difference suggestive of equivalent ambiguous range of F2 perception for both CWS and CWNS groups.

These findings can be interpreted in terms of the meta-linguistic processes involved during the discrimination of voiced-voiceless phoneme. The discrimination of speech sounds is viewed as a meta-linguistic process involving active phonetic and acoustic process of incoming acoustic signal through comparison between articulatory plan and phonological feature (Rauschechker & Scott, 2009; Turkeltaub & Coslett, 2010). The identification of the voiced or voiceless phoneme requires the activation of the articulatory plan of that particular model (Meister, Wilson, Deblieck, Wu & Iacoboni, 2007; Turkeltaub & Coslett, 2010). This articulatory plan is located at the level of ventral premotor cortex and posterior inferior frontal gyrus (Golfinopoulos, Tourville & Guenther, 2010) together with the involvement of primary motor cortex (Mottonen & Watkins, 2009). This inter neuron connection are mainly in form of intact left perisylvian fibers connecting the cortical sensory and motor areas. The process of discrimination requires coordinated neural activity and synchrony of these connections. Weakening of any of these neural connections leads to reduced discrimination abilities in an individual. The PB values obtained in the current study gives a direct support for this theory. It is evident from the PB values that CWS group require more cues to discriminate two stimuli than their age and gender matched CWNS group. This suggests a weaker neural connection in this group. Henceforth, present study strengthen the view of impaired perisylvian connections in CWS (Cykowski, Fox, Ingham, Ingham, & Robin, 2010; Sommer, Koch, Paulus, Weiller & Buchel, 2002; Watkins, Smith, Davis, & Howell, 2008) which results in reduced discrimination ability in them.

According to motor theory of speech perception (Libermann & Mattingly, 1985), the speech is produced in the same way as it is perceived. That is, there is an intrinsic link between the speech perception and production. So when the perception abilities are compromised, the production also gets affected. The current study shows a broadened VOT range for CWS for perception of bilabial plosives, which implies that the production of the same will be affected. This inefficient production of plosives may be the reason for the dysfluencies in these children (Max & Gracco, 2005). Thus, it can be said that the stuttering events may be caused due to reduced perceptual acuity in the children who stutter.

Chapter 6

Summary and conclusion

The aim of the current study was to compare the auditory perceptual acuity in children who stutter with age and matched children who do not stutter using fine grained auditory discrimination paradigm. Two continuums, /pa/-/ta/ (place of articulation), /ba/-/pa/ (voicing) were presented to twenty Malayalam speaking school going children who stutter and twenty age and gender matched children who do not stutter. The APEX software was used for this purpose. The adaptive threshold estimation was used for determining the minimum value at which each child discriminated the stimulus at one end of the continuum from the stimulus at the other end. This value was termed as phoneme boundary (PB). The PB values obtained for each participant were tabulated individually for both /ba/-/pa/ continuum and /pa/-/ta/ continuums. Psychometric fit was done for each participant for each of the continuum using Matlab software. The fitting generated psychometric curve and β values. Mann Whitney U-test was done to compare two groups separately for each continuum and separately for PB and β values.

Summary of Results

- Mean PB values were significantly different in children who stutter compared to children who do not stutter for both /pa/-/ta/ and /ba/-pa/ continuums.
- The β2 (β calculated at 50% cross over) were significantly higher in case of children who stutter in comparison to children who do not stutter for /ba/-/pa/ continuum.
- β1 and β2 for /pa/-/ta/ continuum did not show any significant difference between the groups.

Limitations of the study

- The task was somewhat difficult for children, especially for younger ones, as it demanded a lot of cognitive processes including divided attention, organization, problem solving etc.
- The tokens of /pa/-/ta/ continuum were reported as "confusing" by almost all the participants.
- The experimental group consisted of mostly children with lesser severity of stuttering. The discrimination ability in children with more severe stuttering needs to be done.
- Contrary to the case of adults who stutter and adults who do not stutter (Neef, Sommer, Neef, Paulus,Gudenberg, Jung, & Wüstenberg, 2012), the psychometric curves obtained in case of children were broad. This may be due to the relatively wider range responses in this population.

To conclude, the results from the PB values obtained for the present study indicate that children who stutter require more cues for discriminating the phonemes /pa/ from /ba/ and the phoneme /pa/ from /ta/, than their age and gender matched children who do not stutter. This finding indicates the presence of subtle auditory processing deficit in these children, which is evidenced by poorer discriminating abilities in them. The inferior performance in auditory discrimination tasks provides support for the hypothesis of poor temporal and spectral processing in these children which can be attributed to the weak neuronal connections in left perisylvian areas of their brains. By applying the motor theory of speech perception (Libermann & Mattingly, 1985) to the current results, the relationship between the dysfluencies and auditory processing can be understood. According to this theory, the production of a phoneme is according to its perception. So, the reduced perceptual acuity of phonemes in these children may be the cause for their inaccurate production, which is perceived by the listener as dysfluencies (Max & Gracco, 2005). Thus, it can be said that reduced perceptual acuity in children may be one of the cause which can lead to stuttering.

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