EFFECT OF LISTENING TRAINING IN PERCEPTION OF VOICING OF STOPS IN INDIVIDUALS WITH AUDITORY DYS-SYNCHRONY

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ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI

MYSORE-570006

May 2010

CERTIFICATE

This is to certify that this master's dissertation entitled ***"Effect of Listening Training in Perception of Voicing of Stops in Individuals with Auditory Dys-Synchrony"*** is a bonafide work submitted in part fulfillment for the degree of Master of Science (Audiology) of the student with registration no: 08AUD030. This has been carried under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this master's dissertation entitled ***"Effect of Listening Training in Perception of Voicing of Stops in Individuals with Auditory Dys-Synchrony"*** is the result of my own study under the guidance of Prof. Asha Yathiraj, professor, Department of Audiology, All India Institute of Speech & Hearing, Mysore, and has not been submitted earlier to any other university for the award of any diploma of degree.

Mysore, **Registration No: 08AUD030**

May, 2010

Dedicated

To

Mom & Dad

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CHAPTER 1

INTRODUCTION

The term auditory neuropathy has been used to describe a form of hearing impairment in which cochlear amplification (outer haircell functioning) is spared but processing of the auditory signal at the eighth nerve and brainstem level is abnormal/impaired (Starr, Picton, Sininger, Hood, & Berlin, 1996). Individuals with auditory dys-synchrony have been noted to have normal oto-acoustic emissions (OAEs) and/or cochlear microphonics (CM), yet exhibit absent or severely abnormal auditory brainstem responses (ABR) and middle ear reflex without any space occupying lesion (Starr et al., 1996). The term 'auditory neuropathy' (AN) or 'auditory dys-synchrony has also been used synonymously to denote the same condition. Advances in accurate measurement of outer haircell function have made it easier to diagnose this hearing disorder, characterized by abnormal temporal processing and neural synchrony (Zeng, Oba, Grade, Sininger, & Starr, 1999).

Hearing sensitivity in individuals with auditory dys-synchrony may range from normal hearing to profound hearing impairment (Sininger & Oba, 2001). The majority of these individuals are found to have low frequency hearing loss with disproportionately poor speech recognition scores for their degree of hearing loss (Starr et al., 1996; Zeng et al., 1999).

Rance et al. (1999) reported that the prevalence of auditory dys-synchrony in at-risk children was 1 in 433 (0.23%) and in children with hearing impairment it was 1 in 9 (11.01%). The prevalence was found to be 2.44% in school aged children with hearing impairment by Tang, McPherson, Yuen, Wong, and Lee (2004). Kumar and Jayaram (2006) reported that in

India, the prevalence of auditory neuropathy was around 1 in 183 in individuals with sensorineural hearing loss.

Typically individuals with auditory dys-synchrony have been noted to have normal frequency resolution and varying degrees of temporal disruption (Rance, Mckay & Grayden, 2004). The severity of this temporal disruption was noted to be strongly correlated to speech perception performance. The temporal disruptions include both temporal resolution/amplitude modulation detection and the temporal aspects of frequency discrimination, such as phase locking.

Zeng et al. (1999) reported that individuals with auditory dys-synchrony had abnormal results of two measures of temporal perception. The two measures included Gap Detection threshold and Temporal Modulation Transfer Function (TMTF). The former reflected a defect in the identification of silence embedded within bursts on noise while the latter indicated poor sensitivity to slow and fast amplitude fluctuations. They also reported a good correlation between temporal modulation transfer function and speech identification scores in their participants. This finding was reiterated by Zeng et al. (2005).

Zeng et al. (1999) inferred from their studies that asynchronous firing of the auditory nerve resulted in distorted temporal coding of speech which in turn resulted in poor speech recognition that was disproportionate to the degree of hearing loss. Rance et al. (2004) attributed these disproportionate speech identification scores to deficits in the processing of temporal information.

It has been reported that perception of intensity related information such as sound localization based on interaural intensity differences and loudness discrimination in individuals with auditory dys-synchrony is similar to those observed in normal hearing individuals. In contrast, the same participants were found to exhibit severe problems in timing related perception like temporal integration, gap detection, temporal modulation detection, backward and forward masking and sound localization using inter aural time difference. It was surmised that individuals with auditory dys-synchrony have difficulty in detecting short duration acoustic signals, rather than longer ones (Zeng et al., 2005).

Fine-grained speech perception abilities of individuals with auditory dys-synchrony have shed further light on their perceptual difficulties. Kraus et al. (2000) presented data on speech perception, electrophysiological, and psychophysical characteristics in a case of auditory dys-synchrony who reported to have normal hearing thresholds. They studied the just noticeable differences for synthesized consonant-vowel continua /ba-wa/ and /da-ga/. The subject showed poor performance on the /da-ga/ continuum. From their findings they concluded that timing information, at stimulus onset, was most vulnerable to disruption. However, representation of long duration steady state timing cues was better preserved.

The rehabilitation of individuals with auditory dys-synchrony has been a challenging task for the hearing professionals, as there is no single rehabilitation method that results in normal or near normal performance. Studies on the ways to reduce the perceptual difficulties in individuals with auditory dys-synchrony are sparse. The studies reported in the literature have concentrated more on evaluating auditory perception following some manipulation of acoustic signals.

Berlin (1999) suggested that hearing aids offer little to no benefit for children with auditory dys-synchrony. However, a few studies report that some children with auditory dys-synchrony may receive considerable benefit from hearing aids (Rance et al., 2007). Another rehabilitation option that had been reported in literature is the use of cochlear implants. There have been reports that children with auditory dys-synchrony, using cochlear implants, perform similarly to those using cochlear implants, but having cochlear hearing loss (Shallop, Peterson, Facer, Fabry, & Driscoll., 2001; Peterson et al., 2003). Gibson and Halit (2007) reported that variable performance is observed when evaluating large groups of paediatric cochlear implant with auditory dys-synchrony. They indicated that some children with auditory dys-synchrony may develop age-appropriate speech and language with hearing aids, while others received limited benefit from hearing aids but perform relatively well with a cochlear implant.

Narne and Vanaja (2008) reported that envelope enhancement using digital techniques improves speech perception of individuals with auditory neuropathy. In the envelope enhancement conditions, cues for manner and place of articulation were perceived better than voicing. Even with the envelope enhancement technique, the voicing cues, which mainly differ in temporal cues, were not enhanced. Further, the technique did not improve the consonant identification to 100% in any of their participants.

Need for the study

Studies regarding the ways to reduce the perceptual difficulties of individuals with auditory dys-synchrony are sparse. The techniques that have been tried have been found to be beneficial for a limited number of individuals or very expensive. While hearing aids and envelop enhancement were found to be beneficial for a few individuals, cochlear implants are known to very expensive. It can be construed that just manipulating an acoustic signal is not adequate in improving all aspects of speech signals. Hence, other techniques need to be utilized to bring about improvement in auditory perception, especially enhancement in the perception of voicing cues.

Converging evidence from animal and human studies indicates that auditory training alters neural activity. Several studies have demonstrated the plastic nature of the brain consequent to auditory training in non-native listeners (Menning, Imaiumi, Zwisterlood & Pantev, 2002). Russo, Nicol, Zecker, Hayes, and Kraus (2005) also demonstrated the existence of plasticity at the level of the human auditory brainstem and that auditory training can improve neural timing in response to sounds in children with central auditory processing disorders. None of the studies done is literature have studied the effect of training, especially fine-grained identification training on the speech perception abilities in individuals with auditory dys-synchrony. Hence, there is a need to determine whether fine-grained identification training, focusing on temporal cues, will bring about an improvement in the perception of voice-voiceless contrasts.

Objectives:

The main objective of the present study was to determine the differences in auditory perception of voiced and voiceless stops before and after fine-grained auditory training in individuals with auditory dys-synchrony. In order to determine this, the following were done:

- Comparison of speech identification scores for bi-syllabic phonemically balanced words before and after fine-grained auditory identification training in individuals with auditory dys-synchrony.
- Comparison of identification scores for non-sense CV plosives with different place of articulation before and after training in individuals with auditory dys-synchrony.

- Comparison of speech identification threshold for voice-voiceless continua by measuring the just noticeable difference before and after fine-grained training.
- Comparison of the speech identification threshold of the voice-voiceless continua obtained by individuals with auditory dys-synchrony after the training with that obtained by a normal hearing control group.
- Determine the phoneme errors before and after training.

Prior to carrying out the study a review of literature was done in order to determine the various variables that are known to affect the perception of acoustical cues in individuals with auditory dys-synchrony. The review was also done to note the various rehabilitation measures that have been tried with individuals with auditory dys-synchrony.

CHAPTER 2

REVIEW OF LITERATURE

Speech perception is a complex chain of events, wherein sensory stimuli are converted into electrical signals at the receptor level, followed by the transmission of the electrical signals through the peripheral nerve. Finally, the processing and interpretation of the electrical signals in the central nervous system occur. Any disruption in this process is known to lead to misperception of speech signals. It has been found that peripheral damage in the inner ear and the auditory nerve leads to elevation of thresholds, impaired loudness, pitch, and temporal processing abilities (Buss, Hall, Grose, & Hatch, 1998; Formby, 1986; Moore, 1996; Moore & Oxenham, 1998; Nienhuys & Clark, 1978; Oxenham & Bacon, 2003; Prosen, Moody, Stebbins, & Hawkins, 1981; Ryan & Dallos, 1975). Central or degeneration disorders are known to produce complex processing deficits in the perception of speech signals (Cacace & McFarland, 1998; Gordon-Salant & Fitzgibbons, 1999; Levine et al., 1993; Wright et al., 1997). There are several disorders that lead to disruption in the perception of sounds. One such condition is auditory neuropathy.

Auditory neuropathy is described as a disorder characterized by the presence of normal oto-acoustic emissions or cochlear microphonics with abnormal or absent auditory brainstem responses (ABR) (Starr et al., 1996). It has also been noted that in some instances, auditory dys-synchrony is identified on the basis of the present cochlear microphonics (CM) and abnormal or absent ABRs (Berlin, Hood, Cecola, Jackson, & Szabo, 1993; Starr et al., 1996; Deltenre et al., 1999; Rance et al., 1999) with or without abnormalities of otoacoustic emissions (OAEs). The degree of hearing loss in these individuals may range anywhere from normal hearing sensitivity to profound hearing loss. Speech identification ability is generally found to be affected, especially in the presence of noise, although it may be better in quiet for some patients (Rance et al., 2007). In addition, fluctuant hearing abilities have been reported as some problems are associated with body temperature variations and others with no clear precipitating factors (Starr et al., 1998; Berlin, 1999). Although the term auditory neuropathy has been widely accepted clinically for the purpose of diagnosis, alternative terms such as 'auditory dys-synchrony' have been suggested to reflect the common phenomenon that probably has several underlying pathologies (Berlin, Hood, Morlet, Rose, & Brashears, 2003a; Rapin & Gravel, 2003).

It has been reported that individuals with auditory dys-synchrony exhibit impaired auditory nerve functioning which could be because of the desynchronization at the level of auditory nerve (Berlin, Morlet, & Hood, 2003b; Starr et al., 1996, 2003) or because of the lack of signal transmission to the auditory nerve (Starr et al., 1998; Waxmann, 1977). Reduced input to the auditory nerve has been attributed to loss of inner hair cells (Harrison, 1998; Salvi, Wang, Ding, Stecker, & Arnold, 1999; Sawada, Mori, Mount, & Harrison, 2001) and/or auditory nerve loss (Hallpike, Harriman, & Wells, 1980; Spoendlin, 1974; Starr et al., 2003). As a consequence, a variety of perceptual problems has been reported to be present in individuals having auditory dys-synchrony/auditory neuropathy.

Perceptual problems in individuals with auditory dys-synchrony/auditory neuropathy:

The perceptual abilities in individuals with auditory dys-synchrony/auditory neuropathy have been investigated by a large number of researchers. The perceptual errors have been found to occur for non-speech as well as speech signals. These errors have been studied in terms of different acoustic properties such as frequency, intensity and duration.

Problems in the perception of non-speech frequency cues

Frequency discrimination of non-speech stimuli has been found to be poorer in individuals with auditory dys-synchrony than those with normal hearing (Starr et al., 1991; Starr et al., 1996; Zeng, Oba, Grade, Sininger & Starr, 2001; Rance et al., 2004; Zeng et al., 2005). Starr et al. (1991) studied the frequency discrimination abilities in individuals with auditory dys-synchrony and reported that the just noticeable differences for frequencies were approximately 3 to 15 times higher than normal hearing subjects across different frequencies. Starr et al. (1996) reported that individuals with auditory dys-synchrony required larger frequency differences between the anchor and the variable tone when compared to normal hearing subjects. These studies suggest that frequency discrimination abilities are severely affected in individuals with auditory dys-synchrony.

Similar findings were also reported by Rance et al. (2004) in a group of children with auditory dys-synchrony. They reported that the mean difference limen at 500 Hz was on an average 11 times poorer than that observed in normal hearing children and the difference limen at 4 kHz was on an average of 4.5 times the normal value. Thus, it can be concluded that individuals with auditory dys-synchrony were less able to use frequency cues compared to individuals with normal hearing.

In a later study done by Zeng et al. (2005), frequency discrimination of 12 individuals having auditory dys-synchrony was compared with that obtained by 4 normal hearing individuals. This was done for frequencies from 250 Hz to 8 kHz in octave steps. The authors reported a significant difference in performance between the individuals with auditory dys-synchrony and the normal hearing group. In the normal hearing group, the frequency difference to perceive pitch below 1000 Hz was around 10 Hz. On the other hand, individuals with auditory dys-synchrony had significantly higher difference limen when compared with normal hearing individuals. In addition to this, Zeng et al. (2005) also reported that the difference between the two groups reduced as the frequencies increased and there was no significant difference between the two groups at 8 kHz. This result suggests that the frequency discrimination ability in individuals with auditory dys-synchrony was impaired only at low frequencies (< 4000 Hz). However, at high frequencies (> 4000 Hz) it was not so affected. Similar findings had been reported by Zeng et al. (2001). They too noted that frequency discrimination was more impaired at frequencies below 2000 Hz and the JND values at higher frequencies reached normal value.

In a study of a larger sample, Barman (2008) evaluated the fine-grained discrimination of frequency in 39 individuals with auditory dys-synchrony. This was done at two sensation levels, 10 and 40 dB SL. The results were later compared with that of the normal hearing individuals. The results revealed that individuals with auditory dys-synchrony had significantly poorer discrimination scores for the frequency discrimination scores at both the sensation levels.

Thus, it can be observed from studies given in the literature that individuals with auditory dys-synchrony have impaired frequency discrimination abilities, especially at low frequencies. The impaired frequency discrimination abilities can be explained on the basis of different mechanisms for frequency coding of high and low frequencies. For frequencies above 4 kHz, frequency discrimination was thought to be dependent on place specific excitation pattern along the basilar membrane (Sek & Moore, 1995). In contrast, discrimination of frequencies below 4 kHz was considered to be due to enhanced neural phase locking cues (Goldberg & Brownell, 1973; Blackburn & Sachs, 1989; Winter & Palmer, 1990). This finding suggests that individuals with auditory dys-synchrony may not use the phase locking cues at the lower frequencies like that used by normal hearing individuals. In contrast, they are able to use the place specific excitation cues in a manner similar to normal hearing individuals, making it possible for them to perform better on high frequency discrimination tasks.

Problems in the perceptual of intensity cues

Studies reported in literature have evaluated perception of intensity in individuals with auditory dys-synchrony to a lesser extent when compared to other acoustical parameters. These studies have mainly been done using non-speech stimuli.

Starr et al. (1991) studied the monaural just noticeable difference of intensity in individuals with auditory dys-synchrony using 1000 Hz tone at 20 and 40 dB SL. They compared the data of individuals with auditory dys-synchrony with that of 5 age matched normal hearing children. It was found that individuals with auditory dys-synchrony required intensity increments that were approximately twice (10 dB) that obtained by the normal counterparts (4 dB).

In 1996, Starr et al. studied intensity discrimination using a triad of 1 kHz stimuli at moderate intensity sound levels (60 dB HL). They reported that individuals with auditory dys-synchrony needed more intensity distinction in order to perceive a difference than the normal hearing controls. Zeng et al. (2001) also reported that subjects with auditory dys-synchrony showed slightly larger difference limen at low sensation levels than did the normal controls. In addition, they also reported that intensity difference limens decreased as a function of stimulus intensity, similar to that seen in normal hearing individuals. Later in 2005, Zeng et al. also reported that individuals with auditory dys-synchrony need higher intensity differences till 40 dB SL than their normal hearing counterparts. However, there was statistically no significant difference between the groups.

Recently, Barman (2008) reported that individuals with auditory dys-synchrony exhibited poor fine-grained discrimination performance on an intensity task in the 39 participants studied. Their scores were significantly poorer that the normal hearing individuals who were also evaluated.

From these studies, it can be concluded that the intensity discrimination is impaired in individuals with auditory dys-synchrony. This was more so at lower sensation levels.

Problems in perception of temporal cues

Different aspects of temporal processing have been studied and these include duration discrimination, temporal gap detection, temporal integration, masking level difference, temporal masking and temporal modulation transfer function. These parameters have been studied extensively.

Problems with duration discrimination have been demonstrated by Starr et al. (1991), Starr et al. (1996) and Barman (2008). These studies revealed that the ability to discriminate two short duration stimuli in individuals with auditory dys-synchrony was relatively poor compared to normal controls.

Problems with temporal gap detection have been found to be a major issue in individuals with auditory dys-synchrony (Zeng et al., 2001; Zeng et al., 2005). It has been observed that compared to normal hearing individuals, gap detection was poorer for shorter duration stimuli when compared to longer duration stimuli (Starr et al., 1991). It was also found to be larger at both low and high intensity levels (Zeng et al., 1999).

Perception of temporal integration function in individuals with auditory dys-synchrony has been found to be near normal for tone bursts (Starr et al., 1991) and broad band white noise (Zeng et al., 1999). It has also been reported by Zeng et al. (2005) that the 16 individuals with auditory dys-synchrony studied by them, threshold improved with increase in the duration of the signal, indicting their ability to integrate signals. However, the slope of the integration function was slightly elevated in individuals with auditory dys-synchrony. It is thus evident that the majority of studies find temporal integration in individuals with auditory dys-synchrony to be normal or near normal.

Problems with binaural masking level differences (MLDs) have been studied to a lesser extent. Studies have revealed that thresholds did not improve as is usually observed in normal hearing individuals (Starr et al., 1996; Hood & Berlin, 2001).

Temporal masking problems in individuals with auditory dys-synchrony have been compared with simultaneous masking by Kraus et al. (2000). Their subjects were found to exhibit 60% masking effect even when the signal and the masker were separated by as much as 100 msec. The slope of the masking function was relatively normal in some while others had abnormally steep slopes and yet others had abnormally shallow slopes.

Zeng et al. (2005) reported that individuals with auditory dys-synchrony performed similar to normal hearing individuals on inter aural intensity and monaural beat tasks. In contrast, the performance was poorer for interaural timing and binaural beat tasks. They concluded that individuals with auditory dys-synchrony could perceive slow temporal fluctuations but not fast.

Problems with the perception of temporal modulation transfer function have been noted in individuals with auditory dys-synchrony (Zeng et al., 1999; Kumar & Jayaram, 2005). Kumar and Jayaram (2005) observed that the average modulation detection threshold in individuals with auditory dys-synchrony was three times higher than their normal hearing listeners. The difference between the normal listeners and individuals with auditory dys-synchrony was more pronounced for higher modulation frequencies. The authors attributed this to the differential processing of higher and lower modulation frequencies in the auditory system.

From the review of literature, it can be surmised that individuals with auditory dys-synchrony have considerable difficulty in the perception of temporal cues. This in addition to the difficulty in perception of intensity and frequency cues.

Perceptual problems of speech stimuli in quiet environments

Speech perception abilities in individuals with auditory dys-synchrony have been studied extensively. While a few studies have evaluated speech discrimination abilities, most of the studies have evaluated speech identification abilities. Kraus et al. (2000) systematically examined fine-grained speech perception abilities in an adult having auditory dys-synchrony. They reported that the subject had good discrimination for speech sounds along a /ba-wa/ continuum where the speech sounds differ in their manner of articulation. However, the subject displayed very poor discrimination for the speech sounds /da-ga/, that varied in place of articulation.

A symptom commonly noted in individuals with auditory dys-synchrony is the lack of correlation between speech identification abilities and pure-tone hearing sensitivity (Narne & Vanaja, 2008; Sininger & Oba, 2001; Starr et al., 1996). It was noted by Starr et al. (1996) that in most individuals with auditory dys-synchrony the speech identification scores were significantly poorer than those expected for a similar degree of cochlear hearing loss. In their study, they determined open-set word recognition scores for eight subjects with auditory dys-synchrony. They reported that the speech identification scores of individuals with auditory dys-synchrony ranged from 0 to 92% and in most cases the speech identification scores were significantly poorer than those obtained with similar degree of cochlear hearing loss.

The speech perception abilities of individuals with auditory dys-synchrony have been found to vary considerably across individuals and also across studies. Some individuals with auditory dys-synchrony have been found to perform similar to those with cochlear hearing loss of similar degree (Li, Wang, Chen, & Liang, 2005; Kumar & Jayaram, 2006) while some individuals are noted to have little or no measurable speech identification scores even with near normal hearing (Starr et al., 1996). This discrepancy between sound detection and speech identification was observed to be related to supra-threshold distortion of temporal cues (Zeng et al., 1999; Rance et al., 2004; Zeng et al., 2005; Kumar & Jayaram, 2006).

Speech identification scores have also shown good correlation with frequency discrimination abilities in individuals with auditory dys-synchrony. Rance et al. (2004) reported a strong correlation between open-set speech identification scores and difference limen for frequency at all the frequencies assessed by them. Children with poor frequency discrimination ability typically presented with greater impairment in speech identification. This can be attributed to the greater degree of hearing loss at low frequency which causes misperception of important speech cues in low frequencies. In addition, poor processing of frequency modulated signals indicates that participants with auditory dys-synchrony have impairment in following changes in frequency over time. This impaired ability to discriminate frequency change could impair perception of fast spectral-temporal changes in speech signal and reduces phoneme perception ability.

Sininger and Oba (2001) assessed speech identification scores of 36 subjects with auditory dys-synchrony. They found that the scores for 25 participants were below the normative range reported by Yellin, Jerger and Fifer (1989). Word identification of one participant with auditory dys-synchrony was assessed by Starr et al. (1991) who found that the high frequency consonants (/s/, /sh/, /ch/) were perceived better than other consonants.

Ramirez and Mann (2005) who evaluated the consonants /p/, /t/, /k/, /b/, /d/, /g/, /m/, /n/, /r/, /w/, in the context of /a/, found that glides and nasals were better perceived than stops consonants in individuals with auditory dys-synchrony and dyslexia. Their participants included four participants with auditory dys-synchrony, ten with dyslexia and fourteen normal hearing listeners. The error patterns observed in individuals with auditory dys-synchrony were similar to that seen in children with dyslexia.

Similar to the study carried out by Ramirez and Mann (2005), Narne and Vanaja (2008) examined the perception of consonants (/p/, /b/, /t/, /d/, /k/, /g/, /s/, /l/, /r/, /m/, /n/, /tʃ/, /ʃ/, /ṱ/, /ḓ/) in the context of /a/. They observed that most of their eight participants with auditory dys-synchrony had considerable difficulty in perceiving place of articulation when compared to manner and voicing cues. Further, it was also noticed that the participants had more difficulty in perceiving stops and liquids when compared to fricatives, affricatives and nasals.

Speech perception difficulties experienced by participants with auditory dys-synchrony resemble those experienced by participants with learning disability and the elderly. Research has indicated a good correlation between speech perception abilities and temporal resolution in elderly listeners (Gordon-Salant, & Fitzgibbons, 1999) and individuals with learning disability (Tallal & Stark, 1981). Hence, attempts have been made to correlate modulation detection threshold and speech perception in individuals with auditory dys-synchrony and the results of these investigations have indicated that the severity of abnormality is significantly correlated with speech understanding difficulties.

From these studies it can be concluded that in adults with auditory dys-synchrony, speech signal disruption is more severe than that observed in individuals with sensorineural hearing loss. However, not all adults with auditory dys-synchrony were reported to have poor speech understanding in quiet listening conditions.

Perceptual problems of speech stimuli in presence of noise

Poor speech perception abilities in the presence of background noise are not unique to subjects with auditory dys-synchrony. Individuals with sensorineural loss also have difficulty in understanding speech in the presence competing signals (Moore, 2003). However, the effects are more severe in individuals with auditory dys-synchrony.

Rance et al. (2007) studied open-set word recognition scores for CNC words in twelve children with AD, twenty children with cochlear hearing loss and twenty-five children with normal hearing at three different S/N ratio conditions (0 dB, 5 dB, 10 dB and quiet). The results showed that children with normal hearing and those with cochlear hearing loss were able to maintain a score of 70% till +5 dB S/N ratio. However, in individuals with auditory dys-synchrony the performance dropped down to 30% at +5 dB S/N ratio. They further demonstrated that the reduction in scores observed depended on the speech identification scores in quiet. The performance dropped down to 40% at 0 dB S/N ratio for individuals having identification scores greater than 60% in a quiet condition. For those with scores less than 60% in quiet, the performance dropped further down to 20%.

Kraus et al. (2000) reported the findings of a 24 years old subject, who was diagnosed as having auditory dys-synchrony, with normal hearing thresholds and no concomitant medical history. On the CUNY sentence assessment, the subject obtained 100% scores in quiet, but in the presence of background noise at +3 dB S/N ratio, the identification scores were 10%. Similarly, Shallop (2002) also reported the findings of a subject auditory dys-synchrony along with a mild to moderate hearing loss. The identification scores on the Hearing in Noise Test (HINT) sentences was 100% in quiet, 25% at +15 dB S/N ratio and 0% at +12 dB S/N ratio. The mechanism underlying these extreme perceptual difficulties in noise have not been explained by the authors. However, their findings were consistent with the results of psychophysical studies that showed the presence of excessive masking of pure-tones by simultaneous noise, as well as by noise bursts presented before and after the test signal (Kraus et al., 2000; Zeng et al., 2001; Zeng et al., 2005).

Ramirez and Mann (2005) compared the speech perception abilities of 10 children diagnosed as having learning disorders and four individuals with auditory dys-synchrony. These responses were compared with that of 15 normal hearing individuals. The 10 CV syllables /ba/, /da/, /ga/, /ma/, /na/, /ka/, /pa/, /ra/, /ta/, and /wa/ were presented to all the participants in 4 audio only conditions, 1 visual only condition and 4 audio-visual conditions. For all conditions the stimuli were presented twice. In some of the audio only conditions, the CV syllables were either masked by noise at one of three signal-to-noise ratios (+7, -2, -7 S/N ratios) or was presented in quiet. They reported that individuals with auditory dys-synchrony performed better in the visual modality that those with learning problems. They attributed this to be more involvement at the level of sub-cortical for individuals with auditory dys-synchrony and the lesion to be more central for individuals with learning problems. However, the performance with visualarticulatory mode was similar among a few individuals with auditory dys-synchrony and children with dyslexia at maximum noise levels. They concluded that the performance varied across the modality; however both the groups made similar errors in perceiving speech signals especially in the presence of noise.

In summary, a majority of individuals with auditory dys-synchrony have shown severely impaired speech perception ability. The magnitude of the perceptual problem has been found to vary considerably among individuals with auditory dys-synchrony. The factors that determine the extent of perceptual difficulties experienced by these individuals has not been determined completely. Speech understanding has been found to be impaired in quiet conditions and in the presence of noise. However, the amount of difficulty experienced in the presence of noise is more than that observed in listeners with normal hearing and cochlear hearing loss.

Management of Individuals with Auditory Dys-synchrony:

Not much focus has been given regarding management of individuals with auditory dys-synchrony. This is despite considerable number of individuals having the problem. The management options that have been reported in literature include the use of hearing aids, cochlear implants, frequency modulation transmitter and other assistive devices (Rance et al., 1999; Hood, 1998; Shallop et al., 2001; Trautwein, Sininger & Nelson, 2000). Other methods recommended are or the use of communication methods like sign language and cued speech (Berlin, 1999). Thus, the management strategies for individuals with auditory dys-synchrony can be classified into those that use devices and those that do not.

Management approaches with devices

Hearing aids are generally given to individuals with any form of peripheral hearing loss. These devices usually provide amplification to restore the audibility of sounds that are inaudible to the listener. There has been controversy regarding the recommendation of hearing aids for individuals with auditory dys-synchrony. Strarr et al., (1996) reported that the presence of OAEs in individuals with auditory dys-synchrony indicates the presence of functional OHCs, therefore making it unnecessary for further amplification of sound. In addition, it was felt the use of amplification may cause damage to the existing OHCs. This could cause hearing loss that was not present in these individuals (Starr et al., 1996).

In support of the use of hearing aids, Rance et al. (1999) showed that approximately 50% of children with auditory dys-synchrony benefited from amplification. This was similar to that expected in children with a comparable degree of sensorineural hearing loss. Based on this finding it was felt that the use of hearing aids was a viable option for individuals with auditory dys-synchrony.

It has been reported that if hearing aids are to be used, there are some precautions to be considered. Hood (1998) suggested that individuals with auditory dys-synchrony performed better with the hearing aids that had high quality, low gain, and wide dynamic range compression (WDRC). Hood (1998) also suggested that hearing aids should be worn for limited periods or in only one ear, in order to prevent damage to the outer hair cells of the ear from being exposed to loud amplified sounds. It was recommended that an audiologist should monitor cochlear function using OAEs while using a client used hearing aids.

Rance and Barker (2009) compared the findings of individuals with auditory dys-synchrony, provided with amplification, with age matched children having sensorineural hearing loss. They reported that individuals with auditory dys-synchrony performed similar to their cochlear counter parts. They opined that providing amplification may be useful to almost 50% of those individuals.

Zeng et al. (1999) studied 8 subjects with auditory dys-synchrony and reported that a special type of speech processing hearing aid was needed for them. In addition to amplifying and making sounds audible, they propose that a hearing aid should compensate for the impaired temporal processing at supra-threshold levels. They recommended that until speech processing devices suggested by them became available, infants or children with auditory dys-synchrony who had abnormal hearing threshold should be provided with amplification in the context of a comprehensive habilitation program and should be constantly monitored.

Several studies have noted that individuals with auditory dys-synchrony experience poorer speech perception in the presence of background noise (Kraus et al., 2000; Rance et al., 2007; Shallop, 2002). Therefore, it was assumed that the use of directional microphones or *personal FM systems* may be beneficial since they would improve the signal-to-noise ratio (Stredler-Brown, 2002).

Besides the use of conventional listening devices, the use of a device which could enhance the *envelope of the speech signal* has also been recommended. Narne and Vanaja (2008) reported that digital techniques like envelop enhancement resulted in improving the speech perception ability in individuals with auditory dys-synchrony. They suggested that applying envelope enhancement strategies in hearing aids might provide some benefit to individuals with auditory dys-synchrony. They studied 8 individuals with auditory dys-synchrony who were asked to identify consonants when the envelope of the speech signal was enhanced by 15 dB for different modulation bandwidth (3 to 10 Hz; 3 to 20 Hz; 3 to 30 Hz; 3 to 60 Hz). The results revealed that consonant identification improved in six individuals and only two individuals showed no improvement. The amount of improvement was greater for the 3-30 Hz bandwidth condition when compared to the others. An error analysis revealed that manner cues were better perceived than voicing and place cues. Within the manner cues, fricatives and affricates were better perceived than stops and liquids. With envelope enhancement, perception of stops and affricates showed greater improvement that the other consonants. Further, it was noted that voicing perception did not improve with envelope enhancement. It can be inferred that envelop enhancement may be beneficial to some extent to individuals with auditory dys-synchrony.

Cochlear implantation is another option that has been recommended for those individuals with auditory dys-synchrony. The results of studies regarding the use of cochlear implants in these individuals have been relatively more positive than those regarding the use of hearing aids (Shallopet al., 2001; Trautweinet al., 2000).

Shallop et al. (2001) studied the usefulness of cochlear implantation in five children with auditory dys-synchrony and reported that they had significant improvements in sound detection and communication skills after implantation. Three of the five children were reported as being able to use a telephone, which suggests good speech perception abilities without the use of visual cues. They also demonstrated the presence of synchronous electrical auditory brainstem responses (EABR) in individuals with auditory dys-synchrony after implantation using neural response telemetry (NRT) using intracochlear electrode. They reported that the post-implant individuals with auditory dys-synchrony show synchronous neural response telemetry similar to that observed in non-auditory dys-synchrony cochlear implant patients.

Trautwein et al., (2000) compared the acoustically elicited ABR with that of electrically evoked auditory nerve action potential in a single child who was diagnosed as having auditory dys-synchrony and was fitted with a cochlear implant. They reported the evidence of neural synchrony with electrical stimulus one year post implantation. The authors reported that the child was consistent in word identification at one year post implantation. They concluded that the speech perception abilities were better after intensive auditory-oral educational program and they asked the parents to continue using cochlear implant along with listening training.

The management protocol in children diagnosed with auditory dys-synchrony was studied by Teagle et al. (2010). Of the 140 children studied, 57 (37%) received cochlear implants in their affected ears. It was reported that children with cochlear nerve deficiency evident on the preoperative magnetic resonance imaging, performed poorly on open-set speech identification scores even with the six months experiences with the cochlear implants. They concluded that individuals with robust response on electrical evoked intra-cochlear compound action potential performed better on open-set speech identification scores that those with absent compound action potential with electric stimulation.

It can be inferred from the studies mentioned in the literature that the use of hearing aids may bring about some benefit to individuals with auditory dys-synchrony. The use of envelop enhancement in a listening device would probably make speech more understandable. Cochlear implants have also been found as a viable option for individuals with auditory dys-synchrony. However, as a part of the pre recommendation of cochlear implants there is a need to establish the presence of electrical evoked intra-cochlear compound action potentials.

Management approaches without devices

Speech reading has been recommended for individuals who do not have useful residual hearing (Breeuwer, & Plomp, 1984; Boothroyd, Hnath-Chisoim, Hanin, & Kishon-Rabin, 1988; Bantwal & Basavaraj, 2002). It has also been considered as a method of communication to be used with individuals with auditory dys-synchrony.

A *manual form of communication* has also been recommended in the past for individuals with auditory dys-synchrony. Cued speech has been advocated as a habilitation method for children with auditory dys-synchrony (Berlin, 1999). Cued speech has been recommended as a tool to help children learn language visually (Hood et al., 2002). It has been suggested that it should be used along with the hearing aid or cochlear implant. In addition, Berlin, Hood, Morlet, Rose and Brashers (2003a) recommended the use of sign-language, cued speech or baby sign in such individuals. Bantwal and Basavaraj (2002) reported that inclusion of signs in an auditory training program for a child diagnosed as auditory dys-synchrony showed significant improvement in his communication abilities. They also recommended the use of sign language, MAKATON and signing systems to make communication more effective.

These techniques result in individuals with auditory dys-synchrony using communication methods that are not conventionally utilised by individuals with good auditory abilities. As these methods are not known to the general population, it would restrict the number of individuals the person with the problem can communicate with.

Fine-grained discrimination/identification which refers to the perception of minute acoustic differences between phonemes is more known as an evaluation tool than as a remedial method. This technique has been used more as a tool to investigate the perceptual difficulties in individuals with different conditions. This includes those with learning disability; children with dyslexia (Russo et al, 2005); language learning problems (Kraus, 2001); non-native speakers (Bradlow, Pisoni, Akahane-Yamada & Tohkura, 1997; Tremblay, Kraus & McGee, 1998). The technique involves the perception of small variations in a single segmental cue (Elliott, Hammer, & Scholl, 1989). In simple terms, fine-grained discrimination/identification is a technique that requires an individual to discriminate or identify pairs of stimuli that vary on a particular acoustical cue along a continuum.

Elliott, Hammer and Scholl (1989) compared fine-grained auditory discrimination in normal and language impaired children. The participants were divided into a younger and an older group. The stimuli presented were /ba/-/pa/ for voice-voiceless distinction and /ba/-/ga/for place of articulation discrimination. The stimuli were presented at 80 dB SPL. For each trail, the stimuli were presented sequentially with an inter-syllabic interval of 500 msec. The just noticeable difference for these continuum were then determined using a discrimination task. It was reported that in the younger group containing 15 children with language learning problems, one child could not achieve the discrimination threshold even for the end-point stimulus pair. In the older children with language learning problems, poor performance on the just noticeable difference task for voice-onset time continuum was noted. The authors also reported that these children had the concept of same and different.

Cunningham, Nicol, Zecker, Bradlow and Kraus (2001) studied nine normal and nine children with language learning problems. The stimulus pair used was a /da/-/ga/ continua generated synthetically by changing the formant frequencies, especially the third formant onset frequency using the Klatt synthetic analyzer. Following the initial testing, clear speech enhancement was made by lengthening the gap duration for stop consonants and increasing the burst release intensity. These were considered as important cues for the perception of speech in presence on noise. Speech-evoked ABR was also done for the synthetically generated 40 msec /da/ stimulus. The results revealed that in the initial testing, children with learning problems had poor performance for both perceptual and neurophysiological responses. However, with the stimuli having cues that were enhanced, both the perceptual and neurophysiological responses improved.

Abnormal perceptual and neural responses for a fine-grained auditory discrimination task were reported by Kraus (2001) in children with language learning-problems. The poor encoding of speech sound representation in children with learning problems was evident even at the sub-cortical level. Thus, Kraus (2001) assumed that the speech sound representation in children with language learning-problems was independent of cognition and attention which were presumed to affect most of the language and reading disorders. However, these perceptual and neurophysiological responses were found to improve by enhancing the segmental component of the speech signal and/or with the perceptual training.

Though fine-grained discrimination/identification has been used as an assessment tool, it has not been used much as a remedial tool. Hence, there is limited evidence to indicate whether it is a useful technique to improve auditory perceptual skills in individuals having problems in that area.

From the reported in the literature, it can be observed that individuals with auditory dys-synchrony have temporal deficits, and hence have difficulty perceiving short duration signals effectively. It is evident from the sparse literature on fine-grained auditory training that the technique is helpful in improving the perceptual and neurophysiological responses in individuals with learning problems. The errors made by the individuals with auditory dys-synchrony were noted to be similar to those of children with dyslexia (Ramirez & Mann, 2005). Hence, there is a possibility that fine-grained auditory discrimination might be helpful in providing rehabilitation to individuals with auditory dys-synchrony. Therefore, there is a need to study the effect of fine-grained auditory identification training on speech perceptual abilities especially for the stops in individuals with auditory dys-synchrony.

CHAPTER 3

METHOD

The present study was aimed to determine the effect of fine-grain auditory training on the perception of voice-voiceless contrasts in individuals with auditory dys-synchrony. This was done in the following six phases:

- Phase I: Development of material
- Phase II: Evaluation-I & II (pre-therapy evaluations)
- Phase III: Fine-grain identification in normal hearing individuals.
- Phase IV: Fine-grain identification in individuals with auditory dys-synchrony.
- Phase V: Fine-grain identification therapy
- Phase VI: Evaluation-III (Post therapy evaluation).

Participants:

Two groups of participant were studied, one consisting of normal hearing individuals and the other consisting of individuals with acquired auditory dys-synchrony. While the former group had 10 participants, the latter group had five participants. All the participants spoke fluent Kannada and have no apparent speech and language problem.

The *individuals with auditory dys-synchrony,* who were included in the study had pure-tone thresholds less than 60 dB HL in the frequencies 250 Hz to 8000 Hz with speech identification scores that were less than 60% in the better ear. Further, they had 'A' type tympanograms with ipsilateral and contralateral reflexes absent; presence of TEOAE's with robust amplitude having a signal-to-noise ratio of not less than 6 dB SPL at least in two consecutive octave frequencies; absent ABR at 90 dB nHL with poor reproducibility; and no history of other neurological symptoms. The demographic details of the clinical group is provided in Table-1.

Table 1: Demographic and audiological details of the participants with auditory dys-synchrony

Participants	**Age in years**	**Gender**	**Age of onset of problem in years**	**PTA (dB HL)**	**Symmetrical /Asymmetrical hearing loss**	**Speech identification scores**	
						Rt ear	**Lt ear**
A	17	Male	12	25	Symmetrical	64	76
B	21	Female	13	16.6	Symmetrical	32	24
C	28	Male	12	46.6	Asymmetrical	5	-
D	18	Female	14	26.6	Symmetrical	52	44
E	12	Female	11; 6	58.6	Symmetrical	40	30

The *individuals with normal hearing* had pure-tone thresholds less than 15 dB HL in both the ears in the octave frequencies ranging from 250 Hz to 8000 Hz. Their speech identification scores were greater than 90%. The presence of normal middle ear functioning was confirmed based on the existence of 'A' type tympanograms with ipsilateral and contralateral reflexes being present. In addition, they had normal TEOAEs and auditory brainstem responses (ABR) that had waveforms with good morphology and reproducibility at 90 dB nHL. None of the participants had any history of otologic or neurologic problems.

Equipment: A calibrated dual channel diagnostic clinical audiometer GSI-61 with TDH-39 headphones housed in MX-41/AR ear cushions with audio cups was used for estimating the pure-tone air-conduction thresholds and speech identification scores in both the groups. The audiometric output from a Radio ear B-71 bone vibrator was used to estimate the bone conduction thresholds. A calibrated immittance meter, GSI-TYMPSTAR was utilized to assess middle ear function. Using ILO V6 DP Echoport, oto-acoustic emissions were measured. ABR was measured with Intelligent Hearing System (IHS) fitted with an ER-3A insert receiver. An Intel Core 2 Duo computer with Adobe Audition software was employed to record and play the speech test/therapy material.

Test environment:

All the audiological tests were carried out in an acoustically sound treated room. The ambient noise levels were within permissible limits (ANSI 1991; S3.1). The therapy was carried out in a quiet room free from distraction.

Phase I: Development of material

Material were developed for the purpose of evaluation as well as for training. Details of the procedure utilised for developing the material are entailed below.

Material for evaluation:

Consonant-vowel (CV) syllables were used as test stimuli. Unaspirated initial stop consonants (/p/, /b/, /t/, /d/, /k/, /g/) in combination with the vowels /a/, /I/, /u/ and /e/ were used to form 24 tokens. The test material were recorded by a native Kannada female speaker having clear speech. The recording was done on a Pentium Dual Core laptop using Adobe Audition software (Version 2) with a sampling rate of 44.1 kHz and a 32-bit analogue-to-digital converter. A unidirectional microphone, kept at a distance of 10 cm from the speaker's mouth, was used. The recorded material was scaled so that all the tokens had a similar intensity. Each token was repeated thrice in a random order resulting in the list having 72 tokens. Prior to the list a 1 kHz calibration tone was recorded. Three lists (list-1, list-2 & list-3) were prepared, all having the same 72 tokens, but randomised so that the order of the tokens differed.

Material for training:

The therapy material were developed by synthetically altering the stimuli /ba/, /da/, and /ga/ that were recorded for the test material. This was done using the Adobe Audition software. The voicing pulses of the voiced unaspirated stop consonants were removed in steps of 2 pitch pulses. This was continued until the VOT was completely removed. This point was considered to have 0 msec VOT. Once the prevoicing was removed, silence was added after the burst in 10 msec steps. This was done until the total duration of the silence was equal to that of the lag VOT of the natural syllabi /pa/, /ta/ and /ka/ produced by the same speaker. These served as the voiceless stops.

Three VOT continua, /ba/-/pa/, /da/-/ta/, and /ga/-/ka/ were prepared having lead to lag VOT. Between the end-points of /ba/-/pa/, /da/-/ta/, and /ga/-/ka/ there existed 16, 18 and 20 stimuli respectively. Details of these stimuli are given in Table 2. These continua served as material for training the individuals with auditory dys-synchrony. In addition to the therapy material, three pairs of practice items were selected. The practice items consisted of the end-points of the three stimuli pairs /ba/-/pa/, /da/-/ta/, and /ga/-/ka/. These practice items were presented before the initial session to demonstrate the identification task.

Table 2: VOT values in msec for the continua /ba/-/pa/, /da/-/ta/, and /ga/-/ka/

Continua /ba/-/pa/		**Continua /da/-/ta/**		**Continua /ga/-/ka/**	
Stimuli	**VOT**	**Stimuli**	**VOT**	**Stimuli**	**VOT**
1	-100	1	-110	1	-120
2	-90	2	-100	2	-110
3	-80	3	-90	3	-100
4	-70	4	-80	4	-90
5	-60	5	-70	5	-80
6	-50	6	-60	6	-70
7	-40	7	-50	7	-60
8	-50	8	-40	8	-50
9	-40	9	-50	9	-40
10	-30	10	-40	10	-50
11	-20	11	-30	11	-40
12	-10	12	-20	12	-30
13	0	13	-10	13	-20
14	+10	14	0	14	-10
15	+20	15	+10	15	0
16	+30	16	+20	16	+10
-	-	17	+30	17	+20
-	-	18	+40	18	+30
-	-	-	-	19	+40
-	-	-	-	20	+50

The clarity of both sets of material, i.e., the material for evaluation and the material for therapy were subjected to a goodness test. The recorded material was heard by 10 normal hearing adults, who had to identify the stimuli. For the therapy material, only the stimuli in the end-points were subjected to the goodness test. The stimuli were considered as acceptable only if 90% of these participants could identify the material.

Phase II: Pre-therapy evaluation I & II

Procedure for evaluation:

The developed evaluation material was played using the Adobe audition software. The output of a Core 2 Duo computer was routed to the audiometer, the output of which was sent to headphones. A 1 kHz calibration tone was played to adjust the VU meter deflection of the audiometer to '0' before the presentation of the stimuli.

The speech identifications scores for bi-syllabic phonemically balanced words developed by Vandana (1998) were determined for both the evaluations (evaluation I and evaluation II) and was further subjected to statistical analyses. The differences in speech identification scores for words were determined for both the evaluations.

Each participant heard all 72 voiced-voiceless tokens in each ear. Half of participants heard list-1 in the right ear and list-2 in the left ear while the other half heard list-1 in the left ear and list-2 in the right ear. Further, half the participants were tested in the right ear first and the other half in the left ear first. These were done to avoid any familiarity and ear effect, respectively.

The tokens were presented at 40 dB SL (reference to average of pure-tone thresholds at 500 Hz, 1000 Hz and 2000 Hz). The participants had to listen and write down the response. The responses thus obtained were tabulated and scored. Ever correct response was given a score of one and an incorrect response was given a score of zero.

Each individual was tested twice prior to the commencement of therapy. The first evaluation was one month before the commencement of the therapy the second evaluation was done just before the therapy.

The written responses for the CV syllables was further subjected to phonemic error analyses, in which vowels and consonants are analyzed separately. Phonemic error analyses was done by adding the total number of correct responses for all the ears tested and then divided by the total number of times the particular stimulus was presented. The score obtained was considered as the mean percentage correct responses and was tabulated.

Phase III: Fine-grain identification by the normal hearing participants

A fine-grained auditory identification task was carried out on a normal hearing group using the developed material. This was used to determine the smallest difference that could be identified for each of the CV continua. This task was carried out separately for the continua /ba/-/pa/, /da/-/ta/, and /ga/-/ka/.

The participants, who were comfortably seated in a quiet room free from distraction, heard the stimuli played from a computer via headphones. The output level of the computer was adjusted for each participant so that the signal was at his/her most comfortable level.

Initially *a pilot study* was carried out to determine the voice/voiceless crossover for four participants. The pilot study was done to choose the crossover point from a choice of two different procedures. The two procedures differed in terms of the choice of the anchor stimulus.

In the first procedure, the smallest difference along each continuum where 90% of the time two participants could identify the stimulus-pair of a continuum was determined. Initially, each participant was given practice by presenting the tokens using live voice and then with recorded items. This was done so that the participants understood what they were expected to do. Following this, the recorded end-point stimuli of a continuum were presented and the participants had to identify them. One end-point served as the anchor stimulus and the other severed as the variable stimulus. The variable stimulus was gradually change along the continuum until 90% of time the individual was able to correctly identify the stimuli. Following this, the activity was carried out with the anchor and the variable stimuli being reversed. Once again, this was continued until the smallest difference in the continua was identified with 90% accuracy. This was considered as the threshold of the fine-grain identification task.

In the other two participants, the procedure was same as the above except that when the stimuli in the continuum were reversed the anchor was the stimulus adjacent to the cross-over stimulus which resulted in the participant obtaining 90% accuracy. The other end-point was gradually changed along the continuum until 90% of the time the participants could identify the stimulus-pair accurately.

From the pilot study, it was determined that the first procedure was found to be easier and less time consuming. Hence, the remaining participants were evaluated using this procedure where one end-point served as the anchor stimulus and the other severed as the variable stimulus. Half the participants (5 males and 5 females) were tested in the right ear and the other half (5 males and 5 females) in the left ear to avoid any ear effect. The order of presentation of the three continua (/ba/-/pa/, /da/-/ta/, and /ga/-/ka/) was also randomized to avoid any order effect.

Scoring for fine-grained speech identification threshold:

Scoring was done separately for different CV to determine the fine grained speech identification threshold in the following way. The number of times the individuals were able to correctly identify the stimulus presented across each continua was determined. The smallest identifiable difference between the anchor stimulus and the variable stimulus in the continua were noted for each voiced and voiceless set. Each individual had to correctly identify the stimulus pair presented at least two out of three trails for it to be considered correct. The smallest perceptible difference was determined. The smallest difference was considered to be the behavioural 'fine grained speech identification threshold'.

Phase IV: Fine grain identification by individuals with auditory dys-synchrony

Based on the findings of the pilot study, as mentioned earlier, the first procedure was selected to carry out the fine-grain identification task on participants having auditory dys-synchrony. All but one participant were tested in both ears with half of them being tested in the right ear first and the other half in the left ear first. One participant was evaluated only in the right ear since he had asymmetrical hearing loss. The order of the three continua was also randomised. Further, each participant was evaluated twice on the task, once just prior to the commencement of training and once just following training. For each continuum, the stimulus-pair that resulted in 90% accuracy was noted. This was considered as the fine-grain identification threshold.

Phase V: Fine-grain identification therapy

A procedure similar to that used to determine fine-grained identification was utilised for therapy. However, during the initial training sessions for those clients who could not identify the end-point stimuli, a discrimination task was carried out. For the discrimination task, the participants were required to indicate whether the stimuli were same or different. Each stimulus was presented at least 10 times and feedback was provided to the participants as to whether they discriminated the pair correctly. Once the participants obtained 80% accuracy, the training continued as an identification task. For each pair, the training was provided until they were able to obtain 80% accuracy. The order of presentation within the each continuum was randomized.

A rest of 5 minutes was given to the participants between the training of each continuum. Also, adequate social reinforcements were given to encourage, maintain their attention and to elicit reliable responses. If the participant showed any signs of fatigue or restlessness, further breaks were given within each test session. The oral responses of the participants were recorded by the tester on a forced-choice binary response sheet, immediately after each response.

The training was given for a minimum of 10 sessions each having a duration of about 60 minutes. The training continued until the participants were able to identify the stimuli similar to that done by the normal hearing participants.

Phase VI: Post-therapy evaluation (evaluation-III)

Following the training, the individuals with auditory dys-synchrony were tested again (evaluation-3). The procedure for evaluation was similar to that used in evaluation-2. Speech identification scores for bi-syllabic phonemically balanced words (Vandana, 1998) and identification of voice-voiceless CVs was obtained. This was done to verify the effect of training on speech perception ability of participants with auditory dys-synchrony.

Phonemic error analysis was also done for CVs obtained after fine grain auditory training. This scores was later compared with that obtained on pre training evaluation (evaluation II)

Analysis:

The data thus obtained was subjected to statistical analyses using SPSS software Version 16. The speech identification scores for words and CVs were compared across the three evaluations using repeated measures ANOVA. The significance of difference between the crossover points of individuals with auditory dys-synchrony before and after therapy was determined using an independent t-test. The post therapy date obtained for individuals with auditory dys-synchrony was also compared with that of the data obtained for normal hearing individuals using independent t-test.

CHAPTER 4

RESULTS AND DISCUSSION

The present study aimed at determining the effect of fine-grained auditory training in individuals with auditory dys-synchrony. The data of nine ears of five subjects were analyzed. As one of the participants had asymmetrical hearing loss, only his right ear scores were included. The responses of both the ears of the other participants, who had symmetrical hearing loss, were analysed. The collected data were compared in the following four ways: Comparisons of pre and post-therapy word and CV identification scores in individuals with auditory dys-synchrony; Comparison of pre and post-therapy fine-grained speech identification threshold for each stimulus pair in individuals with auditory dys-synchrony; Comparison of pre and post-therapy fine-grained speech identification threshold across the three stimuli-pairs in individuals with auditory dys-synchrony; and comparison of fine-grained speech identification threshold of individuals with auditory dys-synchrony with that obtained by normal hearing individuals. In addition, the pre and post-therapy phoneme error analysis is also provided.

I. Comparisons of pre- and post-therapy identification scores in individuals with auditory dys-synchrony

A comparison was made between the identification scores obtained by individuals with auditory dys-synchrony across three evaluations. The evaluations included evaluation-I done one month prior to initiating training, evaluation-II carried out just before the initiating training session and evaluation-III done following training. The comparison was done for the scores got for words as well CVs (voiced and voiceless stops).

Observation of the individual responses obtained (Table 3) revealed that the scores obtained during the two pre-training evaluations differed marginally. In contrast, both these evaluation scores differed considerably from that obtained in the evaluation following therapy. This trend was seen for all the nine ears that were evaluated for both word and CV scores.

Table 3: Pre and post-therapy speech identification raw scores of words and CVs (with scores in percentage in brackets) in individuals with auditory dys-synchrony

Participant	Ear	Pre-training evaluation-I		Pre-training evaluation-II		Post-training evaluation	
		Words	CVs	Words	CVs	Words	CVs
1.	Rt	16 (64%)	22 (30.56%)	15 (60%)	23 (31.94%)	23 (92%)	54 (75%)
	Lt	19 (76%)	37 (51.39%)	19 (76%)	39 (54.17%)	24 (96%)	55 (76.38%)
2.	Rt	8 (32%)	11 (15.28%)	8 (32%)	9 (12.5%)	16 (64%)	49 (68.06%)
	Lt	6 (24%)	8 (11.11%)	7 (28%)	8 (11.11%)	18 (72%)	50 (69.44%)
3.	Rt	4 (16%)	6 (8.33%)	3 (12%)	7 (9.72%)	12 (48%)	29 (40.28%)
4.	Rt	8 (32%)	10 (13.89%)	7 (28%)	11 (15.28%)	22 (88%)	57 (79.17%)
	Lt	12 (48%)	8 (11.11%)	13 (52%)	6 (8.33%)	23 (92%)	62 (86.11%)
5.	Rt	13 (52%)	31 (43.06%)	12 (48%)	33 (45.83%)	21 (84%)	50 (69.44%)
	Lt	11 (44%)	36 (50%)	11 (44%)	32 (44.4%)	22 (88%)	52 (72.22%)

Maximum word score = 25; Maximum CV score = 72

Further, to see if the scores differed significantly, repeated measures ANOVA was done. Both non-parametric and parametric ANOVA was carried out. Both forms of statistics yielded similar results. Hence, the findings of the parametric statistics are provided which is more valid compared to non-parametric statistics. For the *word identification responses*, a significant main effect was observed when the three evaluations served as independent variables and the scores obtained in each of the three evaluations served as the dependent variable [$F (2, 16) = 99.014$, $p < 0.05$]. Further, Bonferroni pair-wise comparison was done to determine which of the three evaluation scores were significantly different. The results revealed that there was no significant difference between evaluation-I and evaluation-II ($p > 0.05$). However, there was a statistically significant difference between the evaluation-II and evaluation-III ($p < 0.001$).

Similar statistical analysis of the *CV identification scores* across the three evaluation session was also done. Repeated measures ANOVA revealed that there was a significant main effect [$F (2, 16) = 46.572$, $p < 0.001$] for speech identification scores of CVs, across the three evaluations. As seen with the word scores, the Bonferroni pair-wise comparison test indicated that there was no significant difference between evaluation-I and evaluation-II ($p > 0.05$). However, there was a statistically significant difference between the evaluation-II and evaluation-III ($p < 0.001$).

The above findings highlight the impact of fine-grained auditory training on speech perception of individuals with auditory dys-synchrony. The significant improvement in speech identification abilities following therapy highlights the importance of systematic auditory training. It can be construed that trained individuals to distinguish and identify voice-voiceless stops, using a fine-grained training paradigm is a useful technique in improving the auditory perceptual skills of individuals with auditory dys-synchrony.

In the present study, the average improvement for words was 38% while it was 44.75% for CVs. Though the quantum of improvement varied from individual to individual, there was no participant who did not show a positive change. These improvements substantiate the positive outcome of providing fine-grained auditory training

The influence of fine-grained auditory training seen in the present study is in consensus with the findings of Kraus (2001) on a group of children with language learning problems. The fine-grained auditory discrimination training task in children with learning disability resulted in improved perceptual and neurophysiological responses. Ramirez and Mann (2005) reported that the errors made by individuals with auditory dys-synchrony are similar to those of children with dyslexia. Hence, it can be construed from the findings of the study by Kraus and that of the present study that those who exhibit perceptual problems on fine-grained tasks, could be helped by fine-grained perceptual training. While Kraus proved that such training is useful in children with learning disability, the present study shows that it can be useful even in adults who have auditory dys-synchrony.

The improved speech identification scores after fine grained auditory training can be attributed to plasticity of the brain. In literature, proof of such plasticity has been provided by researchers recording changes in brain activity following training. Russo et al., (2004), reported that the neural encoding of the complex signals improved neural synchrony in the auditory brainstem following training. They noted that this in turn resulted in improvement in perceptual, academic and cognitive measures.

Learning associated plasticity changes has also been demonstrated in individuals with actively performing a task associated with a particular stimulus that reflect the auditory system's responses. This has also been seen in individuals passively even when the subject was not responding behaviourally to that stimulus or is attending to another unrelated task (Kraus, McGee, Carrell, King, Tremblay & Nicol, 1995).

In the present study the fine grained training was given for the voice-voiceless stop consonants, which was aimed at improving the perception of voicing in individuals with auditory dys-synchrony. However, it was observed from the improvement seen in the word scores that the impact was not restricted to just voice-voiceless contrasts. The improvement was also seen for other vowels and consonants. Thus, it can be inferred that the temporal based training that was provided did help in overall perception of temporal cues. It can be concluded that fine-grained auditory training is of considerable help to individuals with auditory dys-synchrony. It is recommended that the technique be suggested as a line of management for individuals with auditory dys-synchrony.

II. Comparison of pre- and post-therapy fine-grained speech identification threshold in individuals with auditory dys-synchrony

The pre- and post-therapy fine-grained speech identification thresholds were compared for each stimulus continuum (/ba-pa/, /da-ta/, and /ga-ka/) and with the combined scores. Table 4 depicts the thresholds obtained just before and after therapy for each stimulus-pair as well as the combined thresholds. To calculate the combined scores, the sum of the thresholds for the three stimuli was computed for each ear. From the table it can be seen that prior to the training, the ears with auditory dys-synchrony had very high threshold values. None of the participants were able to perceive even the end points for all three continua and hence were assigned the poorest scores that were permissible. In contrast, following therapy, their thresholds reduced markedly. This was evident for all 9 ears that were evaluated.

To check if the pre- and post-therapy data were statistically different, independent paired-t test and two-way repeated measure ANOVA were done. The former statistical test was done for the three continua and the latter for the combined threshold values.

Table 4: Pre- and post training fine-grained speech identification thresholds in individuals with auditory dys-synchrony and normal hearing individuals for the three continua and combined scores

Participants' ears	**Pre-training**			**Combined score**	**Post-training**			**Combined score**	**Control group**			**Combined score**
	/ba-pa/	**/da-ta/**	**/ga-ka/**		**/ba-pa/**	**/da-ta/**	**/ga-ka/**		**/ba-pa/**	**/da-ta/**	**/ga-ka/**	
1.	17	19	21	57	8	11	11	30	8	10	11	29
2.	17	19	21	57	9	11	12	32	9	8	12	29
3.	17	19	21	57	8	10	14	32	9	8	11	28
4.	17	19	21	57	9	9	13	31	8	10	13	31
5.	17	19	21	57	14	15	14	43	8	9	11	28
6.	17	19	21	57	13	8	12	33	9	9	13	31
7.	17	19	21	57	12	9	13	34	10	9	12	31
8.	17	19	21	57	9	16	12	37	9	10	12	31
9.	17	19	21	57	10	15	11	36	8	8	13	29

Maximum possible threshold for /ba-pa/, /da-ta/ and /ga-ka/ is 17, 19, and 21 respectively.

The independent paired-t test revealed that there was a statistically significant difference was present for all three continua, /ba-pa/ [t = 9.14; p < 0.001], /da-ta/ [t = 7.43; p < 0.001], and /ga-ka/ [t = 22.71; p < 0.001]. Likewise the repeated measures ANOVA also revealed that there was a statistically significant difference [F (1, 8) = 292.87, p < 0.001] in combined speech identification threshold in individuals with auditory dys-synchrony before and after training. Though the participants were not able to identify even the end-points initially, they were able to achieve much lower threshold values following therapy.

The significant improvement in the fine-grained speech identification proves that individuals with auditory dys-synchrony can be taught to perceive voice-voiceless contrasts that they were unable to do. Drawing their attention to perceive specific temporal based cues such as VOT helped them respond to the cues. It is speculated that it is possible that these individuals did have some abilities to perceive the temporal cues which were dormant. However, with stimulation which required active participation of the individuals, these dormant perceptual abilities were stimulated into activation.

The fact that adults with auditory dys-synchrony are able to get benefit from systematic fine-grained auditory training, highlights that learning is possible not just in younger individuals, but is also possible in adults. It is possible that, if training is given for a longer duration than what was given in this study, that the improvement could be more, especially for those who did not achieve large improvements.

As mentioned earlier, the improvement could be due to the plastic nature of the brain which has been demonstrated in studies reported in literature (Kraus, et al., 1995; Russo et al., 2004)

III. Comparison the fine-grained speech identification threshold of normal hearing individuals with that of the individuals with auditory dys-synchrony

Comparisons were made between the fine-grained speech identification thresholds obtained by individuals with auditory dys-synchrony before and after therapy with that of the threshold obtained by normal hearing individuals. From Table 4, it can be observed that the fine-grained speech identification thresholds obtained during the pre-training evaluations by the individuals with auditory dys-synchrony were considerable higher than that obtained by the normal hearing group. In contrast, the difference between the two groups was considerably less after the clinical group underwent therapy. However, in general the normal hearing group continued to have lower thresholds when compared to the clinical group. Depending on the stimulus, the post-therapy values at times were almost equal to that obtained by the normal hearing individuals.

Paired-t test was done to check if the difference between the thresholds obtained by normal hearing group and the clinical group. This comparison was done using the pre-therapy thresholds as well as with the post-therapy threshold of the individuals with auditory dys-synchrony for each stimulus continuum.

The results revealed that prior to training, there existed a significant difference between the individuals with auditory dys-synchrony and the normal hearing group. This was observed for the three continua, /ba-pa/ [$t = 35.36$; $p < 0.001$], /da-ta/ [$t = 34.64$; $p < 0.001$], and /ga-ka/ [$t = 31.18$; $p < 0.001$].

Following training, no statistically significant difference between the scores of normal hearing individuals and individuals with auditory dys-synchrony existed for the continua /da-ta/ [$t = 2.45$; $p < 0.05$] and /ga-ka/ [$t = 2.92$; $p < 0.05$]. However, there continued to be a statistically significant [$t = 2.00$; $p > 0.05$) difference between the groups for the continuum /ba-ta/. Thus, the speech identification thresholds improved to almost a near normal value for the velar and alveolar speech sounds unlike that for the bilabials.

A possible reason for the near normal improvement seen for alveolar and velar stops and not for bilabials stop consonants probably had to do with the frequency composition of these signals. While bilabials have a predominant low frequency composition, the other two have more high to mid frequency composition, respectively. It has been reported that individuals with auditory dys-synchrony have more hearing problems in low frequencies when compared to the high frequencies and mid frequencies (Barman, 2008; Zeng et al., 2005). This similar problem in perceiving low frequency signals is reflected in their perception of speech signals also in the present study. Zeng et al. (2005) have reported that the difficulty in processing low frequency information is on account of lack of temporal synchrony in the low frequencies.

The fine-grained speech identification thresholds for individuals with auditory dys-synchrony continued to be significantly different from the normal hearing control group for bilabial voice-voiceless contrast, despite training being given. As it is known that the clinical group have more difficulty in perceiving low frequency signals, it is recommended that additional training be given for low frequency contrasts such as bilabials. This might enable the clinical group to get more normal like responses on such contrasts also.

IV. Phonemic error analysis

An error analysis was carried out for CV identification test that was administered on the clinical group. The vowels and consonants errors were analyzed separately for the pre-therapy and the post-therapy performance. Since the two pre-therapy evaluations were not statistically significant, the error analysis was done only for the evaluation done just prior to the commencement of therapy. The vowel and consonant confusion matrix are shown in Table 5 and Table 6 respectively. Both pre- and posts therapy findings are provided.

Table 5: Mean percentage error scores of vowels in individuals with auditory dys-synchrony before and after training

Vowel	**Pre-training**				**Post-training**			
	/a/	/I/	/u/	/e/	/a/	/I/	/u/	/e/
/a/	74.07	38.27	47.5	51.2	96.91	3.7	7.4	14.19
/I/	-	32.09	8.6	15.43	-	88.27	-	9.26
/u/	-	7.3	27.16	4.9	-	3.08	86.42	-
/e/	24.69	22.2	4.3	28.39	3.08	4.93	6.17	76.54
NR			12.3 (47.2)*					

NR = No response, *mean percentage error score of two ears with auditory dys-synchrony

From Table 5 it can be observed that individuals with auditory dys-synchrony had poor performance with vowels which have predominant low frequency cues. The performance on the vowel /u/ was poorer when compared with that of the vowels /I/ and /e/. The best performance in individuals with auditory dys-synchrony was observed with the vowel /a/. It can also be observed that there was a large difference between the percentage correct response for the vowel /a/ and other vowels.

Further, from Table 5 it can be observed that the mean percentage correct scores after training improved significantly. The number of vowel errors made was far less after training when compared to that obtained prior to the training. This improvement was observed across all the vowels. The improvement was more for the vowels that had poorer performance prior to training. The scores for the vowel /a/ was already fairly prior to the training , hence did not improve to the same extent.

Table 6 brings to light that prior to the training the individuals with auditory dys-synchrony had considerable difficulty in the perception of stop consonants. The place errors were more common than the voicing errors. This was especially seen for the bilabials. The bilabial and alveolar stop consonants were often perceived as nasals, where as the velar stop consonants were misperceived as laterals and liquids. The scores improved drastically following training. The maximum improvement was obtained for the velar stop consonants followed by alveolar and bilabial stop consonants.

Table 6: The mean percentage scores of consonants in individuals with auditory dys-synchrony before and after training.

Cons.	Pre-training						Post-training					
	/p/	/b/	/t/	/d/	/k/	/g/	/p/	/b/	/t/	/d/	/k/	/g/
/p/	31.5	13.8	18.5	0.92	1.85	0.92	69.4	1.85	4.16	-	-	-
/b/	-	26.8	2.78	15.7	0.92	5.5	4.61	67.6	13.8	12.0		4.16
/t/	25.9	-	47.2	20.3	11.1	-	12.0		75%	2.69	1.85	
/d/	-	12.0	8.3	27.3	-	12.0		15.7		76.5		2.78
/k/	13.9	-	-	0.92	53.7	36.1	12.0			1.85	94.4	3.7
/g/	-	-	-	15.7	16.6	38.8				3.7		87.9
US	15.7	47.3	9.25	19.4	16.6	12.0	1.85	14.8		3.24	3.7	1.85

US = Un specified consonants such as nasals, liquids, laterals, affricatives.

Thus, the results revealed that the there was a significant improvement after providing fine-grained auditory training in identification of voice-voiceless stops of individuals with auditory dys-synchrony. It can be confirmed that the improvement seen was on account of the training provided since there was no significant difference in scores obtained in the first two evaluations, with no intervention having been provided between them. In contrast, the pre- and post-therapy evaluations were significantly different. This can be established on account of the

Table 6: The mean percentage scores of consonants in individuals with auditory dys-synchrony before and after training.

Cons.	Pre-training						Post-training					
	/p/	/b/	/t/	/d/	/k/	/g/	/p/	/b/	/t/	/d/	/k/	/g/
/p/	31.5	13.8	18.5	0.92	1.85	0.92	69.4	1.85	4.16	-	-	-
/b/	-	26.8	2.78	15.7	0.92	5.5	4.61	67.6	13.8	12.0		4.16
/t/	25.9	-	47.2	20.3	11.1	-	12.0		75%	2.69	1.85	
/d/	-	12.0	8.3	27.3	-	12.0		15.7		76.5		2.78
/k/	13.9	-	-	0.92	53.7	36.1	12.0			1.85	94.4	3.7
/g/	-	-	-	15.7	16.6	38.8				3.7		87.9
US	15.7	47.3	9.25	19.4	16.6	12.0	1.85	14.8		3.24	3.7	1.85

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Thus, the results revealed that the there was a significant improvement after providing fine-grained auditory training in identification of voice-voiceless stops of individuals with auditory dys-synchrony. It can be confirmed that the improvement seen was on account of the training provided since there was no significant difference in scores obtained in the first two evaluations, with no intervention having been provided between them. In contrast, the pre- and post-therapy evaluations were significantly different. This can be established on account of the marked improvement in word identification scores, voice-voiceless stop identification scores as well as fine-grained voice-voiceless identification thresholds. Thus, the results substantiate the positive impact of fine-grained auditory identification training on individuals with auditory dys-synchrony.

From the results of the study it is evident that individuals with auditory dys-synchrony obtained:

- Significantly better bi-syllabic word identification scores following fine-grained speech identification training,
- Significantly better voiced-voiceless stop identification scores following fine-grained speech identification training,
- A significant difference between their pre- and post-therapy fine-grained speech identification thresholds. The thresholds were lower following fine-grained speech identification training.
- Significantly higher pre-therapy fine-grained speech identification thresholds when compared to normal hearing individuals. This was seen for all the three continua that were evaluated (/ba-pa/, /da-ta/, and /ga-ka/).
- No significant difference between the post-therapy fine-grained speech identification thresholds when compared to normal hearing individuals for the continua /da-ta/, and /ga-ka/, but significant difference for /ba-pa/.

- A specific pattern in the phoneme errors for both vowels and consonants. Following therapy, the number of errors for vowels and consonants markedly reduced.
- It can be construed providing fine-grained auditory training using temporal cues does bring about improvement in the perception of speech.
- Though the training was given to improve perception of voice-voiceless stops, the enhancement in performance was not restricted to only voice-voiceless contrasts. Improvement was seen for vowel perception as other consonants.
- The improvement was more for the mid and high frequency vowels and consonants. Lesser improvement was seen for the low frequency consonants.
- All the ears that were provided training showed an improvement in speech identification for words, CVs as well as fine-grained speech identification thresholds.
- The quantum of improvement varied from individual to individual. It is recommended that more training be given to those individuals who did not show large improvements following training.
- The study substantiates the utility of providing fine-grained auditory training in individuals with auditory dys-synchrony.
- The results indicate that auditory training is beneficial for adults and not just for children, as was earlier reported in the literature.

SUMMARY AND CONCLUSIONS

Individuals with auditory dys-synchrony are known to have low frequency hearing loss and speech identification scores disproportionate to their pure-tone hearing loss (Starr et al, 1996; Li et al., 2005; Kumar & Jayaram, 2006). This discrepancy between the pure-tone hearing thresholds and speech identification scores has been assumed to be on account abnormal temporal coding.

The management options available for individuals with auditory dys-synchrony are limited. These options include providing hearing aids (Rance et al., 1999; Hood, 1998), cochlear implants (Teagle et al., 2010; Trautwein et al., 2000), envelope enhancement techniques (Narne & Vanaja, 2008, 2009) and manual form of communication. Most of the techniques have not been found to be full proof.

Another management technique that has been used for other conditions is fine-grained auditory training. It is the ability of a listener to discriminate or identify pairs of stimuli that vary on a particular acoustical cue along a continuum. This technique has been advocated by researchers in treating perceptual problems in children with language learning problems such as dyslexia (Cunningham et al., 2001). However, the technique has not been done on individuals with auditory dys-synchrony. Hence, the present study was undertaken to determine the effect of fine-grained auditory training using temporal cues (VOT) in individuals with auditory dys-synchrony. The study aimed at comparing the following:

- Speech identification scores for bi-syllabic phonemically balanced words before and after fine-grained auditory identification training in individuals with auditory dys-synchrony.

- Speech identification scores for non-sense CV plosives with different place of articulation before and after training in individuals with auditory dys-synchrony.
- Fine-grained speech identification threshold for voice-voiceless continua by measuring the just noticeable difference before and after fine-grained training.
- Fine-grained speech identification threshold of the voice-voiceless continua obtained by individuals with auditory dys-synchrony after the training with that obtained by a normal hearing control group.

In addition, the phoneme errors before and after training were noted.

Five individuals with auditory dys-synchrony participated in the study. The participants were evaluated thrice to determine their speech identification abilities, twice before therapy and once soon after therapy. Nine ears of five participants were evaluated as one of the participants had asymmetrical hearing loss. Soon after the second evaluation, fine-grained auditory training was given using the continua, /ba-pa/, /da-ta/ and /ga-ka/. This training material, which tapped temporal perception, was developed as a part of the the study.

The collected data were analysed in the following ways:

- Comparison of pre- and post-therapy speech identification scores in individuals with auditory dys-synchrony for words and CVs. Repeated measure ANOVA was done to determine the significant effect of training in these individuals before and after training.
- Comparison of pre- and post-therapy fine-grained speech identification threshold for the three continua used for trained purpose. Independent paired t-test was done for determining the effect of training in individuals with auditory dys-synchrony.

- Comparison of fine-grained speech identification threshold of individuals with auditory dys-synchrony after therapy with that obtained by normal hearing individuals. This was done using independent paired t-test.
- Pre- and post-therapy phoneme error analysis is also provided.

From the results of the study it is evident that individuals with auditory dys-synchrony obtained:

- Significantly better bisyllabic word identification scores following fine-grained speech identification training,
- Significantly better voiced-voiceless stop identification scores following fine-grained speech identification training,
- A significant difference between their pre- and post-therapy fine-grained speech identification thresholds. The thresholds were lower following fine-grained speech identification training.
- Significantly higher pre-therapy fine-grained speech identification thresholds when compared to normal hearing individuals. This was seen for all the three continua that were evaluated (/ba-pa/, /da-ta/, and /ga-ka/).
- No significant difference between the post-therapy fine-grained speech identification thresholds when compared to normal hearing individuals for the continua /da-ta/, and /ga-ka/, but significant difference for /ba-pa/.

- A specific pattern in the phoneme errors for both vowels and consonants. Following therapy, the number of errors for vowels and consonants markedly reduced.

- It can be construed providing fine-grained auditory training using temporal cues does bring about improvement in the perception of speech.

- Though the training was given to improve perception of voice-voiceless stops, the enhancement in performance was not restricted to only voice-voiceless contrasts. Improvement was seen for vowel perception as other consonants.

- The improvement was more for the mid and high frequency vowels and consonants. Lesser improvement was seen for the low frequency consonants.

- All the ears that were provided training showed an improvement in speech identification for words, CVs as well as fine-grained speech identification thresholds.

- The quantum of improvement varied from individual to individual. It is recommended that more training be given to those individuals who did not show large improvements following training.

- The study substantiates the utility of providing fine-grained auditory training in individuals with auditory dys-synchrony.

Implications of the study:

- From the study, it is evident that the speech perception abilities in individuals with auditory dys-synchrony can improve with fine-grained auditory training. As all the 9 ears that were evaluated showed improvement, it can be recommended for any client with auditory dys-synchrony, as long as they have residual hearing.

- This study paves the way for further research in providing variations of auditory training for individuals with auditory dys-synchrony.
- This study also adds to the corpus of information regarding rehabilitative options for individuals with auditory dys-synchrony.

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