Efficacy of fine-grained auditory training in individuals with auditory dys-synchrony

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Project carried out at

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Completed in October 2011

Funded by: AIISH Research Fund, AIISH, Mysore
(SH/CDN/ARF/3.63/2010-11 dated 27-08-2010)

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Abstract

Individuals with auditory dys-synchrony have generally noted to have temporal deficits, and hence have difficulty perceiving short duration signals effectively. They are found to have considerable difficulty in perceiving voice-voiceless contrasts. Behaviourally, fine-grained auditory training has been found to be helpful in improving the perceptual responses in individuals with auditory dys-synchrony (Avilala & Yathiraj, 2011). The present study aimed to further substantiate the effect of fine-grained auditory identification training of voice-voiceless contrasts on speech perceptual abilities in individuals with auditory dys-synchrony. The behavioural and electrophysiological responses of 29 ears of 16 individuals with auditory dys-synchrony following training are reported. Statistically significant improvement in the perception of voice-voiceless was observed for behavioural responses as well as electropysiological responses. The quantum of improvement was found to varied from individual to individual, but was present in all the participants. Besides a reduction in the voicing errors, there was also a decrease in the place errors, though to a lesser extent. The study confirmed the utility of fine grain auditory training in individuals with auditory dys-synchrony.

Introduction

Disruption in the auditory pathway 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). Several disorders are noted to lead to disruption in the perception of sounds. One such condition is auditory neuropathy.

Auditory neuropathy has been 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, Picton, Sininger, Hood, & Berlin, 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, Picton, Sininger, Hood, & Berlin, 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 has been observed to 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, 2003; Rapin & Gravel, 2003). More recently it has been suggested that the term 'auditory neuropathy spectrum disorder' (ANSD) be used by Hayes and Sininger (2008), based on the recommendations proposed at a conference on the condition.

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 the auditory nerve (Berlin, Morlet, & Hood, 2003; Starr et al., 1996; Starr et al., 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 have been reported to be present in individuals having auditory dys-synchrony/auditory neuropathy. These perceptual problems have been reported to be present in quiet as well as in noisy situations.

The speech perception abilities of individuals with auditory dys-synchrony have been found to vary considerably across individuals and also across studies. Some studies report that individuals with auditory dys-synchrony have been found to perform similar to those with cochlear hearing loss of similar degree (Li, Wang, Chen, & Liag, 2005; Kumar & Jayaram, 2006), while others have reported little or no measureable speech identification scores even with near normal hearing (Starr et al., 1996). A discrepancy between sound detection and speech identification has been noted to be one of the most commonly found symptom in individuals with auditory dys-synchrony (Narne & Vanaja, 2008; Sininger & Oba, 2001; Starr et al., 1996). This has been considered to be related to supra-threshold distortion of temporal cues (Zeng, Oba, Grade, Sininger, & Starr, 1999; Rance, McKay, & Grayden, 2004; Zeng, Kong, Michalewski, & Starr, 2005; Kumar & Jayaram, 2006). Starr et al. (1996) reported that the open-set speech identification scores of eight individuals with auditory dys-synchrony ranged from 0 to 92%. In most cases, the speech identification scores were significantly poorer than those obtained with similar degree of cochlear hearing loss.

Rance et al. (2004) found *speech identification abilities* of individuals with ANSD to show good correlation with certain non-speech task such as frequency discrimination abilities. They reported that children with poor frequency discrimination ability typically presented with greater impairment in speech identification. The authors attributed this to the greater degree of hearing loss at low frequency which causes misperception of important speech cues in low frequencies. The poor processing of frequency modulated signals by this population was considered to indicate that the participants had impairment in following changes in frequency over time. This impaired ability to discriminate frequency change was thought to impair perception of fast spectral-temporal changes in speech signal and reduce phoneme perception ability.

Ramirez and Mann (2005) studied the perception of consonants /p/, /t/, /k/, /b/, /d/, /g/, /m/, /n/, /r/, /w/, in the context of /a/ in 4 children with auditory dys-synchrony and 10 children with dyslexia. They reported that glides and nasals were better perceived than stops consonants in this population. They also observed that the error patterns observed in these two groups were similar.

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/, /ṱ/, /ḓ/, /ʃ/) in the context of /a/. They observed that most of their eight participants with auditory dys-synchrony had more difficulty in perceiving voicing and place of articulation when compared to manner cues. The voiced signals were misperceived as voiceless signals. Place of articulation errors were primarily seen among the stop consonants. Further, it was also noticed that the participants had more difficulty in perceiving stops and liquids when compared to fricatives, affricatives and nasals.

Kumar and Jayaram (2011) described the error patters seen for stops in their clients with auditory dys-synchrony, details of whom had been published earlier in 2005. The subjects displayed both voicing and place errors, with the latter being more. They too observed that the voiced stops were more often replaced by voiceless stops than vice versa.

Hassan (2011) reported that individuals with auditory dys-synchrony could perceive /t/, /d/ better than /k/, /g/. The author attributed this to the place of articulation of each consonant. However, the perception of these consonants was studied in different vowel context. While the consonants /k/, /g/ were studied with the vowel /i/, consonants /t/, /d/ were studied in the context of the vowel /o/. Thus, the results could have been influenced by the vowel context and not just due to the place of articulation of the stops.

The speech perception abilities of individuals with auditory dys-synchrony was also studied using speech signals that have been either spectrally or temporally modified. Prabhu, Avilala and Barman (2011) studied the speech perception abilities in 12 individuals diagnosed as having auditory dys-synchrony using spectrally modified speech. The speech stimuli were filtered at two cut-off frequencies (1700 Hz high-pass and 1700 Hz low-pass filtered). The results showed that individuals with auditory dys-synchrony performed better with the high pass filtered speech stimuli when compared to low-pass filtered speech. The scores obtained by them using the high-pass filtered speech was almost equal to their speech identification scores obtained with unaltered speech signal. The authors attributed the poorer performance with the low-pass speech to the physiological coding deficits of low-frequency information which are usually coded by phase locked responses in type I auditory nerve fibres.

Kraus et al. (2000) reported the findings of a subject with auditory dys-synchrony with normal hearing thresholds and no concomitant medical history. The subject obtained 100% scores in quiet, but in the presence of background noise the performance was dropped down to 10 % at +3 dB S/N ratio. Similar results were reported by Shallop (2002) on a subject with mild to moderate loss. The identification scores of the individual 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).

Rance et al. (2007) studied open-set speech identification scores for CNC words in 12 children with AD, 20 children with cochlear hearing loss and 25 children with normal hearing. The evaluation was done using different signal-to-noise ratios (0 dB, 5 dB, 10 dB and in quiet). They reported 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%.

Studies using *electrophysiological measures* have also confirmed the considerable difficult individuals with AN have hearing speech in the presence of noise. Indlamuri and Barman (2009) studied cortical potentials (ALLR) a group of individuals with auditory dys-synchrony, using three speech stimuli varying in place of articulation (/ba/, /da/ and /ga/) both in quiet and in the presence of noise in. It was established that individuals with auditory dys-synchrony had better responses in quiet when compared to their responses in the presence of noise.

Thus, it is evident from literature that a large majority of individuals with auditory dys-synchrony have considerable difficulty in speech perception in quiet as well as in the presence of noise. The magnitude of the perceptual problem has been found to vary considerably among individuals with auditory dys-synchrony. However, the amount of difficulty experienced in the presence of noise is generally noted to be more than that observed in listeners with normal hearing and cochlear hearing loss.

The fact that these individuals have auditory perceptual problems makes it paramount to provide them some remedial measure that will diminish their difficulties. However, not much focus has been given regarding the 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, Peterson, Facer, Fabry, & Driscoll, 2001; Trautwein, Sininger & Nelson, 2000). Other methods recommended include 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.

Hearing aids are generally found to be suitable for individuals with cochlear hearing loss, especially with lesser loss. There has been controversy regarding the recommendation of hearing aids for individuals with auditory dys-synchrony. Some studies have reported that individuals with auditory dys-synchrony performed similar to their cochlear counter parts with the hearing aids (Rance and Barker, 2009; Hood, 1998). In contrary, Rance et al. (1999) reported that only 50% of children with auditory dys-synchrony benefited from amplification. However, Starr et al. (1996) presumed that the presence of OAEs in individuals with auditory dys-synchrony indicated the presence of functional OHCs, therefore making it unnecessary for further amplification of sound. In addition, it was felt that the use of amplification may cause damage to the existing OHCs resulting in hearing loss that was not present in these individuals.

Individuals with auditory dys-synchrony have been found to benefit more from cochlear implants when compared to hearing aids (Shallop et al., 2001; Trautwein et al., 2000). Shallop et al. (2001) observed that children with auditory dys-synchrony showed significant improvement in sound detection and communication skills after implantation. Three of the five children they studied were reported to be able to use a telephone, indicating their ability to use the auditory modality for communication purposes. The post-implant presence of neural response telemetry (NRT) response was considered to reflect the presence of synchronous electrical firing. These neural telemetry responses were similar to those observed in non-auditory dys-synchrony cochlear implant patients.

Trautwein et al. (2000) also compared the acoustically and electrically elicited auditory nerve action potential in a single child who was diagnosed as having auditory dys-synchrony after implanted. In addition to the presence of synchrony of nerve responses after implantation, the authors also reported that the child had consistent word identification abilities one year following the implantation. However, they observed that the speech perception abilities were better after an intensive auditory-oral educational program and recommended the continuance of the listening training with cochlear implant.

Teagle et al. (2010) studied management options in a large group of children diagnosed with auditory dys-synchrony. 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 after 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 than those with absent compound action potential with electric stimulation.

From the studies on the use of hearing aids and cochlear implants in individuals with auditory dys-synchrony, it can be inferred that hearing aids may be of some benefit to individuals with auditory dys-synchrony. However, cochlear implants have been found to be the more viable option for individuals with auditory dys-synchrony when compared to hearing aids.

In addition to the use of hearing aids and cochlear implants, a manual form of communication has also been recommended in the past for individuals with auditory dys-synchrony. Cued speech has been recommended for children with language learning abilities and found helpful to learn language visually (Hood, Berlin, Morlet, Brashers, & Rose, 2002). Earlier, Berlin (1999) had also advocated cued speech as a habilitation method for children with auditory dys-synchrony and suggested that it could be used along with hearing aids or cochlear implants.

Bantwal and Basavaraj (2002) reported that inclusion of signs in an auditory training program for a child diagnosed to have auditory dys-synchrony resulted in significant improvement in communication abilities. They also recommended the use of sign language, MAKATON and signing systems to make communication more effective. Berlin, Hood, Morlet, Rose and Brashers (2003) also recommended the use of sign-language, cued speech or baby sign in such individuals.

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

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 restricts the number of individuals with whom a person with the problem can communicate.

The utility of envelope enhancement of the speech signals was checked by Narne and Vanaja (2008) on 8 individuals with auditory dys-synchrony. The participants were required 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 of unprocessed speech revealed that the participants had more difficulty perceiving voicing and place cues than manner cues. Within the manner cues, stops and liquids were more poorly perceived than fricatives and affricates. With envelope enhancement, perception of stops and affricates showed greater improvement than the other consonants. However, it was noted that voicing perception did not improve with envelope enhancement. Thus, they suggested that applying envelope enhancement strategies in hearing aids might provide some benefit to individuals with auditory dys-synchrony.

Hassan (2011) recommended temporal modifications as a management approach for individuals with auditory dys-synchrony. The speech signals (/ki/-/gi/, /to/-/do/, /si/-/sti/, /so/-/zo/) were modified in two ways which were termed as the 'natural' and 'modified'. In the former, the interstimulus interval (ISI) was expanded without altering the consonants. In the latter method, the formant transitions of the consonants and the pauses between CV pairs were prolonged. It was observed that "modified" speech signals resulted in better perception than the "natural" signal. The findings were attributed to the temporally sharp, distinguishable input that was easy to discriminate by individuals with temporal processing deficits. This was considered to create a more robust phonetic element representation at the cortical level as suggested by Tallal (1984). Further, it was reported that with temporal modification, the articulation (*sic*) cues were perceived better than place cues in individuals with auditory dys-synchrony. The perception of the temporally modified signal was further compared with individuals with sensorineural hearing loss (SNHL). It was found that at slower ISI (1000 ms) the subjects with AN performed as well as those with SNHL, but their performance reduced when the presentation rate increased by decreasing the ISI. The poorer performance at lower ISI was ascribed to forward or backward masking by the neighbouring speech sounds.

Fine-grained discrimination/ identification, a technique that requires an individual to discriminate or identify pairs of stimuli that vary on a particular acoustical cue along a continuum, has been used to check the perceptual difficulties of different target groups. The groups include non-native speakers (Bradlow, Pisoni, Akahane-Yamada & Tohkura, 1997; Tremblay, Kraus & McGee, 1998); those with learning disability or dyslexia (Russo, Nicol, Zecker, Hayes, & Kraus, 2005); auditory dys-synchrony (Kraus et al., 2000); and language learning problems (Cunningham, Nicol, Zecker, Bradlow & Kraus, 2001; Kraus, 2001).

In a case with auditory dys-synchrony, who had normal hearing thresholds, Kraus et al. (2000) found the subject to show poor behavioural responses for a /da-ga/ continuum and not for a /ba-wa/ continuum. Further, the subject obtained robust P1/N1/P2 potentials for /ba/ which were similar to that obtained by normal hearing individuals, but had delayed P1 and N1 latencies for /pa/. Similar to the client's behavioural responses, robust MMNs were obtained for the /ba-wa/ stimuli but not for the /da-ga/ stimuli. From their findings the authors concluded that timing information, at stimulus onset, was most vulnerable to disruption. However, representation of long duration steady state timing cues was better preserved.

Though researchers (Bradlow et al., 1997; Cunningham et al., 2001; Kraus, 2001; Tremblay et al., 1998) have used fine-grained discrimination to study perceptual difficulties, it has not been used much as a training tool. Hence, there is limited evidence to indicate whether it is a useful technique to improve auditory perceptual abilities in individuals with impaired temporal perceptual skills.

Fine-grained discrimination/identification training was tried on a limited number of individuals with auditory dys-synchrony by Avilala and Yathiraj (2010) and was found to be promising. The perceptual abilities of individuals with auditory dys-synchrony before and after fine-grained auditory training using voiced-voiceless stop consonants were studied. It was reported that prior to training the participants had impaired fine-grained identification. However, following training, the fine-grained identification abilities of these individuals improved significantly. In addition to the quantum of improvement seen in fine-grained identification abilities, their perception also improved for words and CV syllables.

From the literature, it can be observed that individuals with auditory dys-synchrony have temporal deficits, and hence have difficulty perceiving short duration signals effectively. They are found to have considerable difficulty in perceiving voice-voiceless contrasts (Narne & Vanaja, 2008; Kumar & Jayaram, 2011). Further, 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 auditory dys-synchrony. There is a need to further substantiate the effect of fine-grained auditory identification training on speech perceptual abilities in a larger group of individuals with auditory dys-synchrony.

Method

In order to determine the effect of fine-grained auditory training on the perception of voice-voiceless contrasts in individuals with auditory dys-synchrony, the study was carried out using the following six phases:

- Phase I: Development of material
- Phase II: Evaluation-I and II (pre-therapy evaluations)
- Phase III: Fine-grained identification in normal hearing individuals.
- Phase IV: Fine-grained identification in individuals with auditory dys-synchrony.
- Phase V: Fine-grained 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 16 participants. All the participants spoke fluent Kannada and had no apparent speech and language problem.

The 16 individuals (12 males and 4 females) with late-onset auditory dys-synchrony had pure-tone thresholds less than 60 dB HL in the frequencies 250 Hz to 8000 Hz. While 11 had symmetrical hearing loss, 5 had asymmetrical hearing loss. They were considered to have asymmetrical hearing loss if the difference between the PTA if the two ears was more than 10 dB. The 5 participants with asymmetrical hearing loss, had similar audiogram configurations. All the participants had TEOAE’s present in both their ears. TEOAEs were considered present if a signal-to-noise ratio of not less than 6 dB SPL was present in at least two consecutive octave frequencies. In addition, they had absent ABR at 90 dB nHL with poor reproducibility. They reported of no other significant neurological symptoms. These participants also exhibited ‘A’ type tympanograms, indicative of normal middle ear functioning. None of the participants received any form of rehabilitation prior to being recruited in the present study. The demographic details of the clinical group are provided in Table-1. All the participants were young adults (age ranging from 17 years to 28 years, mean age being 22.73 years, except one individual who was aged 50 years.

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

Participants	Age (years)	Gender	Age of onset of problem (years)	PTA (dB HL)		Symmetrical/ Asymmetrical hearing loss	SIS	
							Rt	Lt
A	26	Male	24	48.3	56.6	Symmetrical	16%	24%
B	21	Male	16	30	26.6	Symmetrical	92%	92%
C	28	Male	18	30	31.6	Symmetrical	60%	48%
D	21	Male	13	56.6	31.6	Asymmetrical	60%	80%
E	28	Male	21	26.6	28.3	Symmetrical	35%	35%
F	50	Male	20	40	58.3	Asymmetrical	44%	32%
G	16	Female	15	23.3	18.3	Symmetrical	16%	20%
H	18	Male	15	36.6	40	Symmetrical	40%	48%
I	17	Female	14	15	15	Symmetrical	40%	48%
J	27	Female	15	36.6	41.6	Symmetrical	44%	28%
K	28	Female	16	55	36.6	Asymmetrical	0%	0%
L	25	Male	15	18.3	20	Symmetrical	48%	16%
M	18	Male	17	75	40	Asymmetrical	0%	0%
N	22	Male	12	46.6	60	Asymmetrical	56%	44%
O	28	Male	14	30	31.6	Symmetrical	60%	48%
P	18	Male	14	26.6	30	Symmetrical	56%	48%

Ten *individuals with normal hearing* also participated in the present study, whose pure-tone thresholds were 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.

Test environment:

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

Phase I: Preparing the Stimuli

Stimuli were developed for evaluation as well as for training. Details of the procedure utilized for preparing the stimuli are entailed below.

Stimuli for evaluation:

Unaspirated stop consonants (/p/, /b/, /t/, /d/, /k/, /g/) in combination with the vowels (/a/, /I/, /u/ and /e/) forming a Consonant Vowel (CV) syllable were used to form 24 tokens. These syllables recorded using a native Kannada female speaker with clear articulation. All the stimuli were recorded digitally using a Pentium Dual Core laptop loaded with Adobe Audition software (Version 2). A 32-bit D/A converter with a 44,100 Hz sampling rate was used. A unidirectional microphone, kept at a distance of 10 cm from the speaker's mouth, was used for recording the stimuli. The recorded material was scaled so that all the tokens had similar intensity. Each token was presented thrice in a random order resulting in the list having 72 tokens. Prior to the list, a 1 kHz calibration tone was generated using Adobe Audition software for a duration of 500 msec. Three lists (list-1, list-2 & list-3) were prepared, all having the same 72 tokens, but randomised using a random table, so that the order of the tokens differed.

Stimuli for training:

The stimuli for therapy was synthetically altering voiced stop consonants (/ba/, /da/, and /ga/), which were taken from the evaluation stimuli. Analysis-by-synthesis was used to alter the stimuli from voiced to voiceless stops. In order to do this, the voicing pulses of the voiced unaspirated stop consonants were removed or truncated in steps of two pitch pulses, until the prevoicing was completely removed. This point was considered to have 0 ms voice onset time (VOT). Silence was then added after the burst, in steps of 10 msec. From this point, silence was added after the burst in 10 ms 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.

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.

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

Continua /ba/-/pa/		Continua /da/-/ta/		Continua /ga/-/ka/	
Stimuli	VOT (ms)	Stimuli	VOT (ms)	Stimuli	VOT (ms)
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

Phase II: Pre-therapy evaluation I & II

Two baseline evaluations were carried out. The second evaluation was carried out after an interval of one month with no form of intervention having been provided during that period. The two evaluations were done to rule out the possible influence of any unforeseen factors resulting changes in speech perception, in the absence of any intervention being provided.

Procedure for evaluation using behavioural tests:

To estimate the pure-tone thresholds and speech identification scores, a calibrated dual channel diagnostic audiometer GSI-61 with TDH-39 headphones was used. A Radio ear B-71 bone vibrator was used to estimate the bone conduction thresholds. Pure-tone testing was done using the 'Modified Hughson and Westlake procedure' (Carhart & Jerger, 1959). Speech identification scores were determined at the most comfortable level of each participant using the phonemically balanced word list developed by Vandana (1998). A calibrated Middle ear Analyzer (GSI-Tynpstar V 2.0) was used for Immitance evaluation (tympanometry and acoustic reflex testing) which was done using 226 Hz probe tone. Acoustic reflexes were checked at 500, 1000, 2000 and 4000 Hz tone for both ipsilateral and contralateral.

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

Each participant heard all 72 voiced-voiceless tokens in each ear. A participant heard the same list a maximum of two times across the three evaluations that were carried out. At a particular evaluation (Evaluation I / II / III) they did not hear the same list in the two ears.

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 repeat the stimuli heard. These responses were written down by the examiner and later analysed. Every correct response was given a score of one and an incorrect response a score of zero.

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

The responses for the CV syllables were further subjected to phonemic error analyses, in which vowels and consonants are analyzed separately. The phonemic error was calculated for each participant by determining the number of times each phoneme was incorrectly perceived and dividing it by the total number of times the particular phoneme was presented to the individual. The grand total error for each phoneme was then calculated by summing the error for the particular phoneme obtained by all the participants and its average was obtained by dividing it with the total number of participants. The values thus obtained were tabulated. Further, the responses obtained for the incorrect phonemes were noted by the experimenter.

Procedure for evaluation using electrophysiological tests:

The electrophysiological tests to assess the auditory functioning at the sub-cortical level [auditory brainstem response, (ABR)] and at the cortical level [(Late Latency Responses, (LLR)] were used. These responses were recorded from a single channel auditory evoked potential instrument (IHS V3.22) using ER-3A insert receivers. Initially, ABR responses were obtained, followed by the LLR responses. All electrophysiological evaluations were carried out with the participants seated comfortably in a reclining armchair. The participants were requested to be calm and relaxed during the testing. The protocol used to record the ABR is described in Table 3. The presence or absence of wave V was considered for analysis in both the groups.

Table 3: Parameters for recording Auditory Brainstem Responses

Stimulus parameter	Stimulus	Click stimulus
	Duration	100 µsec
	Intensity	90 dB nHL
	Repetition rate	11.1 / sec
	No. of sweeps	1600 to 2000
	Polarity	Rarefaction and/or Condensation
Acquisition parameters	Transducer	Insert ER-3A ear phones
	Analysis time	12.5 msec
	Filter setting	100-3000 Hz
	Amplifier gain	1,00,000
	Artifact rejection	40 µV
	Electrode montage	Fz: Non-Inverting Test ear mastoid: Inverting Non-test ear mastoid: ground
	Electrode Impedance	< 5 kohms
	Inter-electrode Impedance	< 2 kohms

Following the ABR recording, LLR recording was done with the same electrode placement in the same position except that the patient is asked to watch a mute video during the recording of the LLR. The parameters that were used for recording LLR are given in Table 4.

For analyzing the late latency responses, N1-P2 response amplitude was determined for all three stimuli used in this study. The N1-P2 amplitude was measured for all the waveforms for both the normal hearing as well as the individuals with auditory dys-synchrony before and after therapy.

Table 4: Parameters for recording Auditory Late Latency Responses

Stimulus parameter	Stimuli	/ba/, /da/, and /ga/
	Intensity	90 dB nHL
	Repetition rate	1.1 / sec
	No. of sweeps	150
	Mode of presentation	Ipsilateral
Acquisition parameters	Transducer	Insert ER-3A ear phones
	Analysis time	-100 – 500 ms
	Filter setting	0.1-30 Hz
	Amplifier gain	50,000
	Artifact rejection	40 µV
	Electrode montage	Fz: Non-Inverting Test ear mastoid: Inverting Non-test ear mastoid: ground
	Electrode Impedance	< 5 kohms
	Inter-electrode Impedance	< 2 kohms

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

Fine-grained auditory identification task on the normal hearing group was determined from the developed material. This done to obtain the smallest difference that can be identified by normal hearing individuals, for each of the CV continua that were developed. This was determined separately for all the three continua /ba/-/pa/, /da/-/ta/, and /ga/-/ka/. The participants, who were seated comfortably in a quiet room, free from distractions, 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. The smallest difference along each continuum was determined. One end-point served as the anchor stimulus and the other served as the variable stimulus. The variable stimulus was gradually changed along the continuum until 90% of time the normal hearing individual was able to correctly identify the stimuli. Following this, the activity was carried out with the anchor and the variable stimuli being reversed. Half the participants were tested in the right ear and the other half 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 randomised using random table to avoid any order effect.

Scoring for fine-grained speech identification threshold:

Scoring was done separately for the different CV to determine the fine-grained speech identification threshold. This was done by determining the number of times the individuals were able to identify the correct stimulus presented across each continua.. The smallest identifiable difference between the anchor stimulus and the variable stimulus in the continua was 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 which was considered to be the behavioural ‘fine-grained speech identification threshold’. For the /ba-pa/ and /da-ta/ continua, the speech identification threshold ranged from 8 to 10 with mean being 9. Likewise, for the /ga-ka/ continuum it ranged from 11 to 13 with the mean being 12.

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

All participants 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. 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-grained identification threshold.

Phase V: Fine-grained 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. The identification training commenced with the end-point stimuli and gradually progressed towards the 'fine-grained speech identification threshold' that was obtained by the normal hearing individuals. For each pair, the training was provided until they were able to obtain 80% accuracy.

A rest of 5 minutes was given to the participants between the training of each continuum. In addition, 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.

Analysis:

The data thus obtained was subjected to statistical analyses using SPSS software Version 16. The pre- and post- training electrophysiological test data were also compared using Wilcoxon Signed Rank test. Further, the speech identification scores for words and CVs were also compared across the three evaluations using repeated measures ANOVA. The significance of difference between the crossover points for the voiced-voiceless continuum obtained by individuals with auditory dys-synchrony prior to and after training was determined using paired t-test. Phonemic error analysis was also done for CVs obtained after fine-grained auditory training to determine the effect of the training.

Results and Discussion

The data of the thirty ears of sixteen subjects were analyzed to compare the following: The electrophysiological responses (ABR & LLR) before and after training; The pre- and post-therapy speech identification scores for words and CVs in individuals with auditory dys-synchrony; the pre- and post-therapy fine-grained speech identification threshold for three different stimulus pair (/ba-pa/, /da-ta/, and /ga-ka/) in individuals with auditory dys-synchrony; the speech identification thresholds of the clinical and the normal hearing individuals. In addition, the pre and post-therapy phoneme error analysis was also carried out.

I. Comparison of Electro-Physiological responses before and after training in individuals with auditory dys-synchrony.

Auditory Brainstem Responses

The pre- and post-training *ABR responses* to clicks were similar, with no ABR responses being present during both evaluations in all the participants. Wave V could not be identified in any of the participants. This highlighted that fine grained speech identification training had no impact in the areas that are responsible for the generation of ABR responses in individuals with auditory dys-synchrony. It is generally believed the generators lie between the VIII nerve and Inferior Colliculus, with the latter being responsible for the generation of wave V.

The lack of improvement may not be on account of the difference in the type of stimuli used for evaluation and training in the present study. While the evaluation had been carried out using click stimuli, the training had been provided using speech stimuli. Similar responses were reported by Hayes, Warrier, Nicol, Zecker and Kraus (2003) who also reported that none of their 15 participants with learning problems with delayed wave V latency for a /da/ stimulus showed an improvement in latency following Earobics training. This was seen despite the training being given primarily through the use of speech stimuli and the evaluation also being done with the a speech stimulus. This study also supports the finding that auditory training does not have a positive effect on brainstem responses.

The findings of the present study and that of Hayes et al. (2003) do not concur with that of Russo, Hornickel, Nicol, Zecker and Kraus (2010) on a group of 5 children with autism spectrum disorders. Russo et al. observed faster brainstem responses to a ‘da’ stimulus in 3 of the 5 children studied by them following Fast ForWord training. Such responses were not observed in the 6 control children with autism spectrum disorder who were not provided the training. However, considering the small sample studied and the responses being present in just 60% of the participants studied, the results cannot be considered as gold standard.

Song, Skoe, Banai and Kraus (2011) also found no improvement in brainstem responses to a /da/ stimulus presented in quiet in a group of non-musicians, following LACE training. This was despite the training involving only speech perception in degraded conditions.

However, studies have found a change in the region of brainstem to speech stimuli presented in quiet following music training (Wong, Skoe, Russo, Dees & Kraus, 2007; Musacchia, Strait & Kraus, 2008). Though most of the studies report of no improvement in the afferent pathway at the brainstem level, reports have been provided indicating improvement in the efferent pathway at the brainstem level through the use of contralateral suppression (DeBoer & Thornton, 2008) confirming the plasticity at the level of brainstem.

Auditory Late Latency Responses

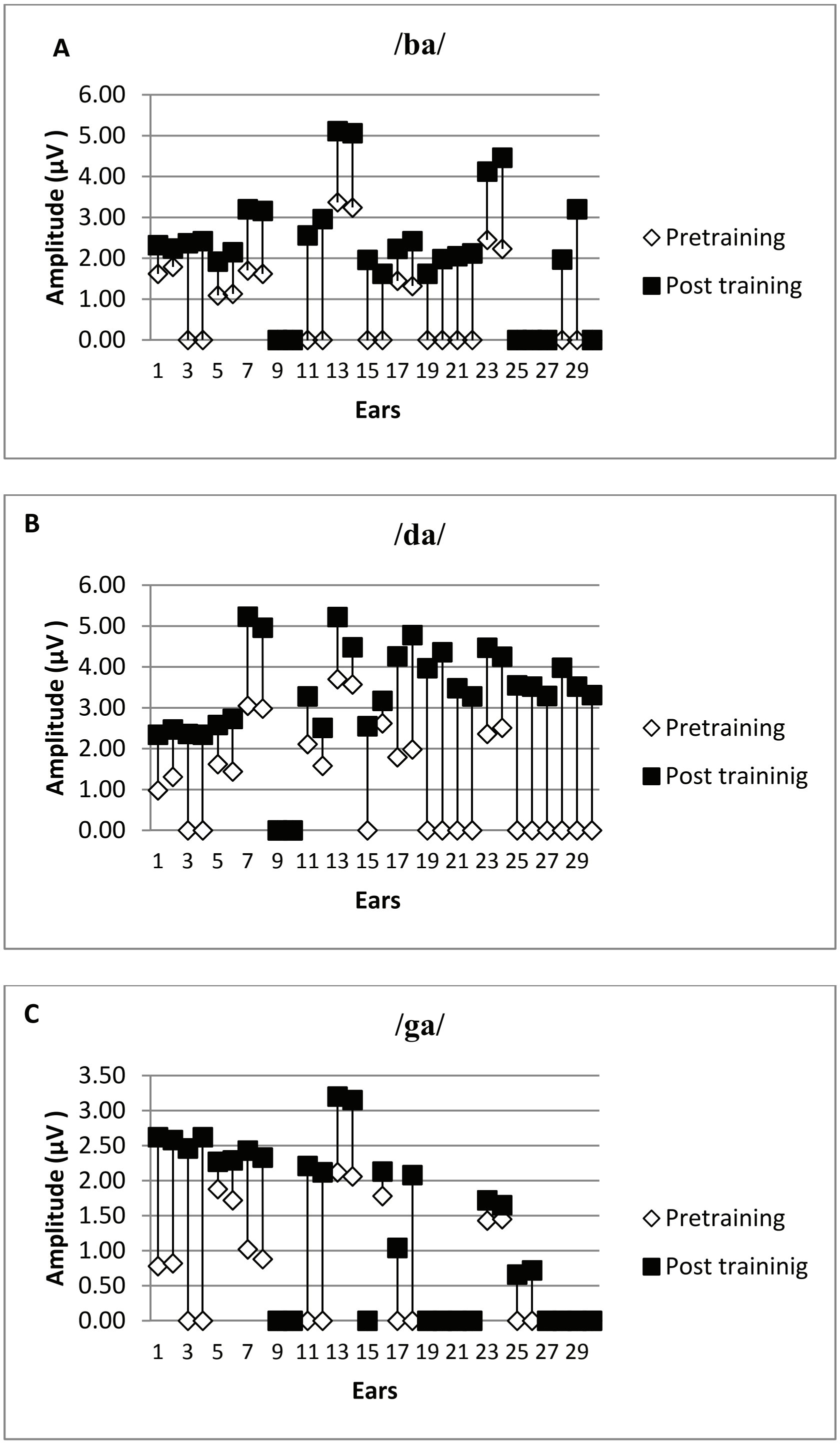
In addition, the impact of training on the *late latency responses* was obtained by determining the number of individuals who had responses present before and after training; and comparing the N1-P2 amplitude responses obtained from the individuals with auditory dys-synchrony before and after training. The comparison was done for the responses to the three voiced stop consonants (/ba/, /da/ and /ga/) before and after training. Further, the comparison was also done between the responses obtained from the normal hearing individuals and the individuals with auditory dys-synchrony.

Table 5: Mean, Standard deviation, and Range of amplitude of N1-P2 responses in µV obtained before and after training for different speech stimuli in individuals with auditory dys-synchrony

Stimuli	**Pre-training** N1-P2 **amplitude (** µV)			**Post-training** N1-P2 **amplitude (** µV)		
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**
/ba/	1.92 (N = 12 ears)	0.76	1.09 - 3.37	2.71 (N = 24 ears)	1.01	0.92 - 5.11
/da/	2.24 (N = 15 ears)	0.82	0.98 - 3.70	3.58 (N = 28 ears)	0.91	2.34 - 5.23
/ga/	1.45 (N = 11 ears)	0.5	0.78 - 2.12	2.12 (N = 19 ears)	0.7	0.66 - 3.20

The *presence of ALLRs* was not observed in all the participants who had auditory dys-synchrony. There were many individuals in whom the ALLR were absent for all the three stimuli studied or for one or two of the stimuli. As evident from Table 5 and Figure 1, prior to the training, the responses were present for /ba/in 12 ears and present in 15 and 11 ears for /da/ and /ga/ respectively. This number increased following training, but there continued to be a difference in the number of ears the response was seen depending on the stimulus. Following training, measureable N1-P2 amplitudes were observed in 24, 28 and 19 ears for the stimuli /ba/, /da/ and /ga/ respectively. Thus, subsequent to the training, the stimulus that resulted in the maximum ALLRs was /da/ followed by /ba/. The stimulus /ga/ yielded the least number of responses.

Figure 1: Pre and post training N1-P2 amplitude (µV) of 30 ears of 16 individuals with auditory dys-synchrony for the stimuli /ba/ (panel A), /da/ (panel B) and /g/ (panel C)



Not only was there an increase in the number of individuals in whom ALLR was present, there was also an increase in the *amplitude of the mean N1-P2 complex following training* obtained from individuals with auditory dys-synchrony for the three different speech stimuli (Table 5). To determine if the increase in the amplitude of N1-P2 responses obtained after the training was statistically significant, Wilcoxon Signed Rank test was done by comparing the three evaluations that were carried out, two before the training and one after training. The N1-P2 complex obtained during the two pre-training sessions, with stimuli grouped, did not show any significant difference ($z = -1.001$; $p > 0.05$). In contrast, the pre-training evaluation responses differed significantly from the responses obtained in the evaluation following therapy ($z = -3.561$; $p < 0.05$), when stimuli were grouped. This trend was seen for all three voiced stop consonants used in the study when Wilcoxon Signed Rank test was administered separately for each stimulus. The N1-P2 responses obtained from the pre-training (Evaluation-II) and the post-training responses (Evaluation-III) differed significantly with the z-scores being 3.059, 3.408 and 2.934 for the syllables /ba/, /da/ and /ga/, respectively.

To check if the *N1-P2 amplitude across the three stimuli* varied significantly, Wilcoxon Signed Rank test was done. Both prior to and after the training, a statistically significant difference was observed between all the stimuli at the 0.001 level of significance (z ranged from -4.268 to -3.172; $p < 0.01$) except between the post training between /ba/ and /ga/ ($z = -2.107$; $p > 0.05$).

Rance et al. (2002) and Michaelewski et al. (2005) considered the *absence of ALLR* responses in individuals with auditory dys-synchrony to be an indication of the severity of the problem. Further, McMahon et al. (2008) and Santrelli et al. (2008), using ECohG/ABR, reported that the site of lesion varied in individuals with auditory dys-synchrony. The site of lesion was found to have an influence in the cortical responses. The findings of the present study lend support to both the notions that ALLR is an indication of the severity of the problem and that it is influenced by the site of lesion. In the current study, in several of the ears that had ALLRs absent prior to the training, measureable responses could be obtained following training (12, 13, & 8 for /ba/, /da/ & /ga/ respectively). The initial absence of ALLR in these ears probably could be on account of the severity of the problem which decreased following the training.

The *increase in amplitude* of the waveform is another yardstick that probably indicates the decrease in severity of the problem following the fine-grained auditory training. In all the participants who had measurable ALLRs prior to the training, the amplitude of the N1-P2 increased following the training, though to different extents. In the few ears (6, 2, & 11 for /ba/, /da/ & /ga/ respectively) that continued not to have ALLRs present following training, it is possible that it was a combined effect of the severity of the problem and the site of lesion.

The significant difference in the *N1-P2 amplitude of across the three stimuli* prior to and after training probably was on account of the frequency composition of the stimuli. The bilabial and velar stops which are known to have relatively lower burst frequencies than alveolar stops (Liberman, Delattre, & Cooper, 1952) were probably poorly represented in the auditory pathway as the majority of the participants had a predominant low frequency hearing loss. Though /ga/ has a mid frequency burst, its falling second format transition (Liberman, Delattre, Cooper, & Gerstman, 1954) could have led to it being poorly represented in the auditory pathway compared to /ba/ which has a rising second format transition. In contrast, the relatively higher burst frequency of /da/ in comparison to /ba/ and /ga/ could have led to it being better represented. This better representation is evident from the higher mean N1-P2 amplitude present for /da/ when compared to /ba/ and /ga/ (Table 5). It is possible that prior to the training, the participants primarily dependent on the burst cues for the perception of the stops, resulting in their perception of the three speech sounds being significantly different from each other. Following training, the participants probably utilised a combination of the burst cues and the formant transition cues, and were able to perceive /ba/ and /ga/ equally well.

II. Comparison of Pre- and Post-therapy Speech Identification Scores in Individuals with Auditory Dys-synchrony

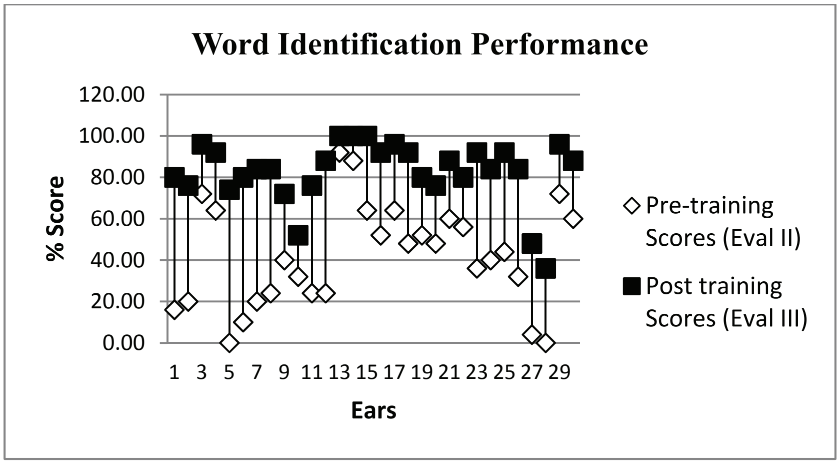
The *word identification scores* of the individuals with auditory dys-synchrony were compared across the three evaluations which were obtained one month prior to training (evaluation-I), just before the start of training (evaluation-II) and soon after the training (evaluation-III).

From the average responses obtained (Table 6, Figure 3) it is evident that the scores obtained during the two pre-training evaluations differed only marginally. However, the responses obtained during evaluation-I and evaluation-II differed considerably from the responses of the post training evaluation (evaluation-III). Such an improvement was present in all the participants, though the extent of improvement varied (Figure 2).

Table 6: Mean, Standard deviation, and Range of the pre- and post-therapy speech identification percentage scores for words and CVs in individuals with auditory dys-synchrony

	Pre-training evaluation-I			**Pre-training evaluation-II**			**Post-training evaluation**		
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**
Words	41.5	25.49	0 - 92	41.93	24.8	0 – 92	82.6	15.12	36 - 100
CVs	35.79	24.52	1.39 - 90.28	35.98	24.52	2.78 - 88.89	70.42	20.18	23.61 - 97.22

Figure 2: Pre and post training word identification scores of 30 ears of 15 individuals with auditory dys-synchrony

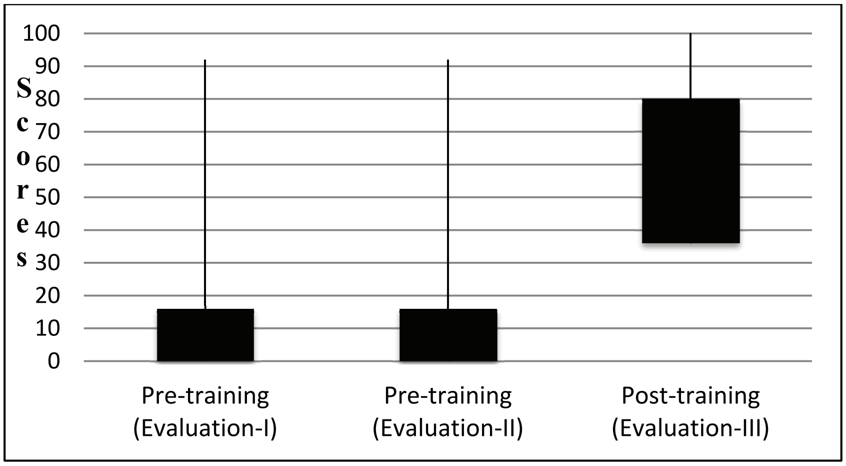


Further, to see if the scores differed significantly, repeated measures ANOVA was done. For the *word identification responses*, a significant main effect was observed when the three evaluations served as the independent variables and the scores obtained in each of the three evaluations served as the dependent variables [F (2, 58) = 149.812, $p < 0.05$]. Further, Bonferroni's 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 ($p > 0.05$). In contrast, there was a statistically significant difference between the evaluation-I and evaluation-III ($p < 0.001$) as well as evaluation-II and evaluation-III ($p < 0.001$).

The s*peech identification scores for voiced-voiceless stop CVs* were also compared across the three evaluations. From the mean values given in Table 6 and Figure 4, it can be observed that the identification scores for the CVs obtained on evaluations-I (35.79 %) and II (35.98 %) were similar but considerably lower than that obtained in evaluation-III (70.42 %). Also, the variations in scores were relatively more for evaluations I and II when compared to evaluation III.

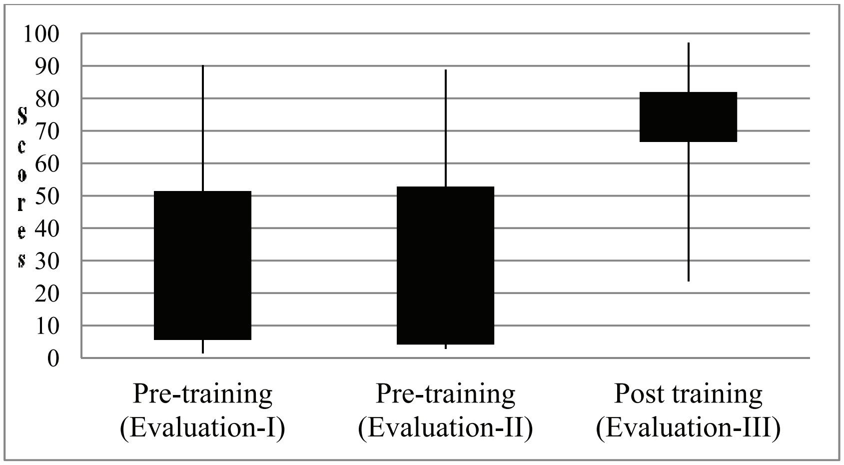
Repeated measures ANOVA revealed that there was a significant main effect [F (2, 58) = 105.26, $p < 0.001$] for CV identification scores across the three evaluations. As seen with the word scores, the Bonferroni's pair-wise comparison test indicated that there was no significant difference between evaluation-I and evaluation-II ($p > 0.05$). However, there was a statistically significant difference between the evaluation-I and III ($p < 0.001$) and between the evaluation-II and III ($p < 0.001$).

Figure 3: Speech Identification scores for phonemically balanced words obtained from 30 ears diagnosed with auditory dys-synchrony before and after-training.



Evaluations

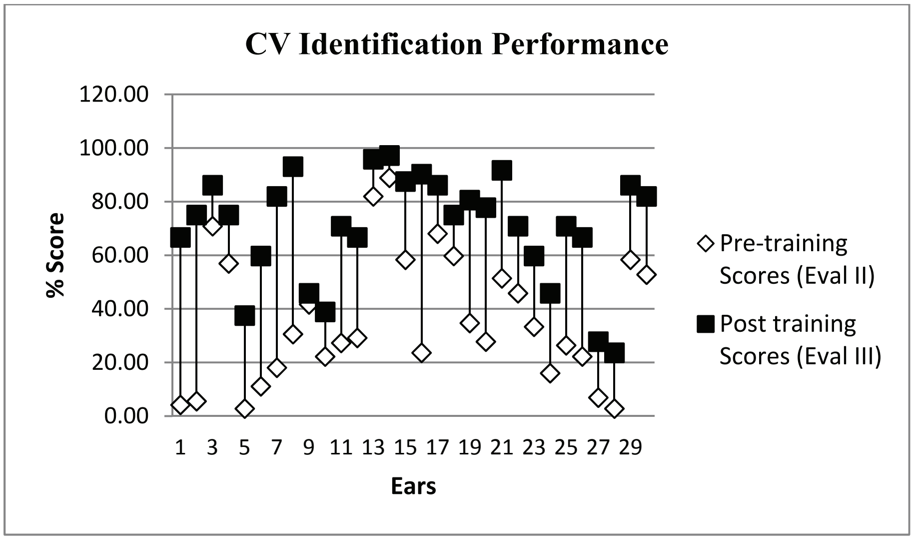
Figure 4: Percentage CV Identification scores obtained from 30 ears diagnosed with auditory dys-synchrony before and after-training.



Evaluations

The average improvement for words and CVs were 40.67% and 34.44% respectively while the range of improvement seen were 8 to 36% and 8.33 to 20.83% respectively. Though the quantum of improvement varied from individual to individual, there was no participant who did not show a positive change. Thus, the group data reflected the information observed for individual participants (Figure 5).

Figure 5: Pre and post training CV identification scores of 30 ears of 15 individuals with auditory dys-synchrony



The findings of the present study are in consonance with earlier carried out research that utilized fine-grained auditory training. Avilala and Yathiraj (2010) reported a significant improvement in the speech identification scores for words and CVs using a similar training task on a group of 5 individuals (9 ears) having auditory dys-synchrony. Their findings and that of the present study highlights the positive impact of fine-grained auditory training on speech identification of individuals with auditory dys-synchrony. It can be construed that trained individuals to 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. Likewise, the usefulness of fine-grained auditory training has also been demonstrated to be useful in children with learning disability by Kraus (2001).

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 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.

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 is recommended that the technique be suggested as a line of management for individuals with auditory dys-synchrony.

III. Comparison of Fine-grained Speech Identification Threshold before and after-therapy in individuals with auditory dys-synchrony

The fine-grained speech identification thresholds obtained before and after training were compared for each stimulus continuum (/ba-pa/, /da-ta/, and /ga-ka/). The combined scores obtained from all three continuum were also compared. To calculate the combined scores, the sum of the thresholds obtained for the three stimuli was computed for each ear. Table 7 depicts the mean, standard deviation and range of the thresholds obtained. From the table it can be seen that prior to the training, the ears with auditory dys-synchrony had very high threshold values. Only one individual was able to identify the end-point stimulus (Figure 6). However, the speech identification threshold of this particular individual was considerably lesser than the speech identification threshold of the normal hearing individuals (Table 7). None of the other participants were able to perceive even the end-points for all three continua and hence were assigned a score that was higher than the poorest scores that were permissible (i.e. 17 for /ba-pa/, 19 for /da-ta/, and 21 for /ga-ka/). In contrast, following therapy, their thresholds reduced markedly. This was evident for all the ears that were evaluated (Figure 6).

Table 7: 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

	Pre-training			**Post-training**			**Normal hearing group**		
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**
/ba-pa/	16.60	3.42	12 - 17	9.03	1.22	8 - 14	8.67	0.71	8 - 10
/da-ta/	18.80	4.31	16 - 19	9.77	2.08	8 - 16	9	0.87	8 – 10
/ga-ka/	20.90	3.47	18 - 21	12.27	1.05	11 - 14	12	0.87	11 – 13

Note. For /ba/-/pa/, the highest possible score was 1 and the lowest possible score was 17.

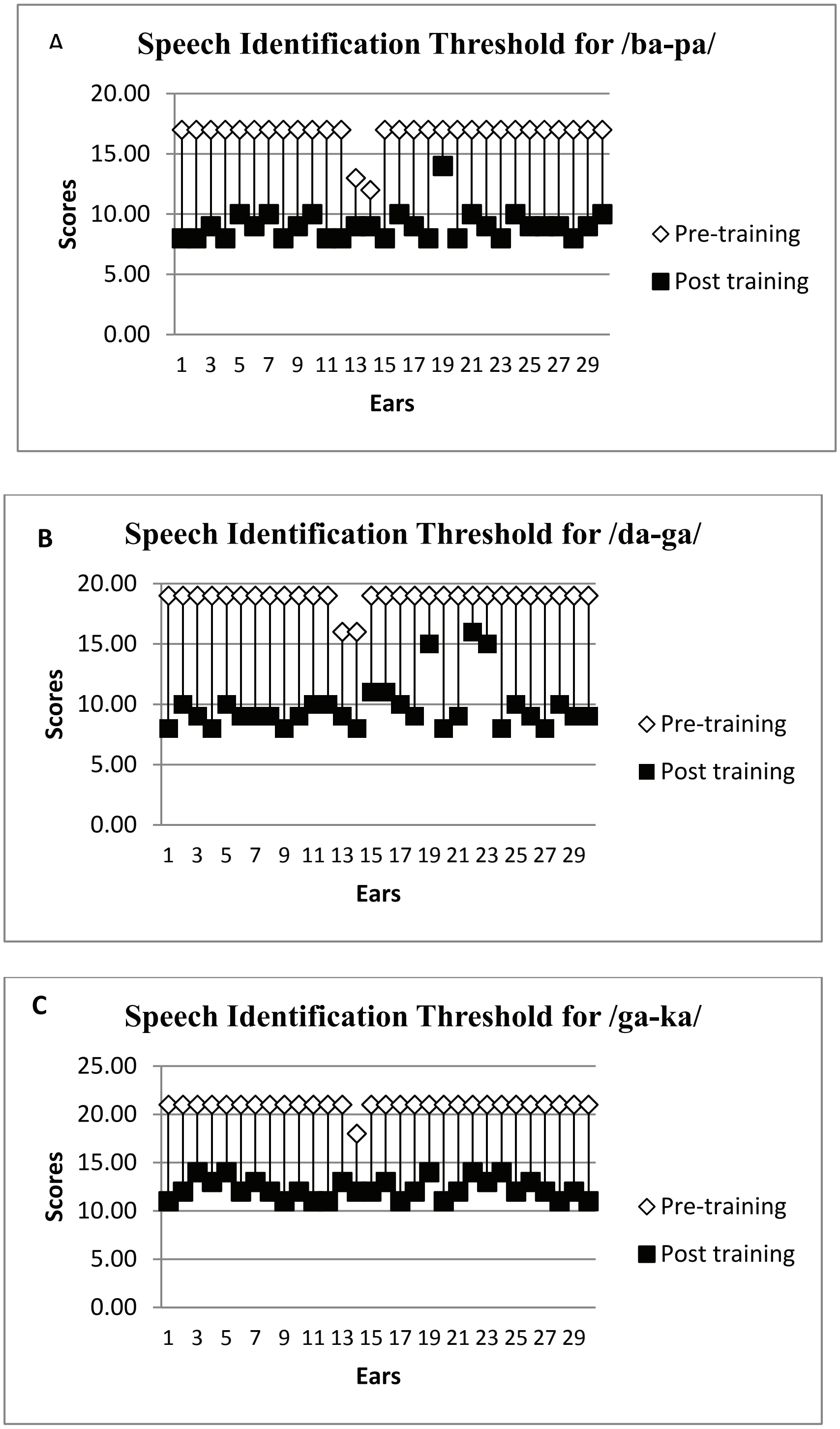
For /da/-/ta/, the highest possible score was 1 and the lowest possible score was 19.

For /ga/-/ka/, the highest possible score was 1 and the lowest possible score was 21.

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

The paired t-test revealed that there was a statistically significant difference between the threshold obtained across evaluation-II and evaluation-III for all three continua {/ba-pa/ [$t = 10.67$; $p < 0.001$], /da-ta/ [$t = 9.93$; $p < 0.001$], and /ga-ka/ [$t = 12.41$; $p < 0.001$]}. Likewise, the repeated measures ANOVA also revealed that there was a statistically significant difference [$F(1, 29) = 143.86$, $p < 0.001$] between the combined speech identification thresholds in individuals with auditory dys-synchrony before and after training.

Figure 6: Speech identification threshold for /ba-pa/ (Panel A), /da-ta/ (Panel B) and /ga-ka/ (Panel C) for 30 ears of 15 individuals with auditory dys-synchrony



Though many of the participants were not able to identify even the end-points initially, they were able to achieve much lower threshold values following therapy, indicating their improvement in perception (Figure 6). 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 identify prior to the training. Drawing their attention to perceive specific temporal based cues present in the 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.

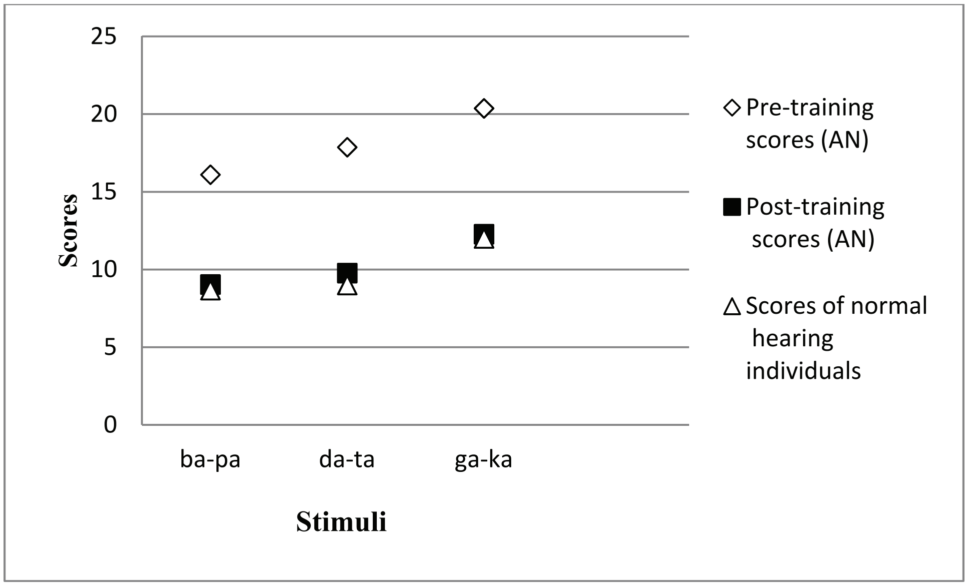
From the results of the present study, it is evident that individuals with auditory dys-synchrony are able to get benefit from systematic fine-grained auditory training, highlights that learning is possible not just in younger individuals, but is also possible in adults. As mentioned earlier, the improvement could be due to the plastic nature of the brain which has been demonstrated in studies reported in literature (Avilala & Yathiraj, 2010; Kraus, et al., 1995; Russo et al., 2004).

IV. Comparison of Fine-grained Speech Identification threshold of individuals with auditory-dys-synchrony with normal hearing individuals.

The fine-grained speech identification thresholds obtained by individuals with auditory dys-synchrony before and after training were further compared with that of their normal hearing counterparts. From Table 7 and Figure 7, 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, following training the difference between the two groups was considerably less. The post-therapy values obtained by those with auditory dys-synchrony were within the normal range in all but a few ears. The number of ears that attained scores within the normal range, varied depending on the stimulus. For the /ba-pa/ continuum 29 ears obtained scores within the normal range, while for the /da-ta/ and /ga-ka/ continua it was 25 and 26 ears respectively.

In order to determine whether the scores obtained by the clinical group before and after training were statistically different from the normal hearing group, paired t-test was done. This comparison was done for each stimulus continuum. The results revealed that prior to training, the individuals with auditory dys-synchrony had significantly higher speech identification thresholds compared to that of the normal hearing individuals. 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/ [$t = 31.18$; $p < 0.001$].

Figure 7: Mean speech identification threshold of individuals with auditory dys-synchrony before and after training (unfilled diamond and filled square) and normal hearing individuals (unfilled triangles) for three voiced-voiceless stop consonants continua.



Following training, no statistically significant difference between the scores of the normal hearing individuals and individuals with auditory dys-synchrony existed for all three stimuli {/ba-pa/ [$t = 0.36$; $p > 0.05$], /da-ta/ [$t = 2.45$; $p > 0.05$] and /ga-ka/ [$t = 2.92$; $p > 0.05$]}. Thus, the speech identification thresholds improved to almost a near normal value for the bilabials, velar and alveolar speech sounds.

The results of the present study are in contrast with that of the earlier study by Avilala and Yathiraj (2010), where the improvement was more for velars and alveolar stop consonants and significant improvement was not observed for bilabials. This difference occurred despite the procedure adopted and the stimuli used in the two studies being the same. The difference between the two studies can be ascribed to the small sample size studied in the previous study. In the earlier study, 9 ears of 5 individuals were studied, while in the present study 30 ears of 15 individuals were studies. Of the 9 ears studied earlier, only 3 ears showed relatively less improvement for the /ba-pa/ continuum. However, due to the small sample size this probably resulted in a significant difference.

Thus, from the findings of the present study, it can be construed that fine-grained auditory training does bring about an improvement not just in mid and high frequency voice-voiceless contrasts, but also in low frequency contrasts.

V. Phonemic error analysis

An error analysis was carried out for the CV identification responses that was obtained from the clinical group. The vowels and consonants errors that occurred prior to and after therapy were analyzed separately. 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 percentage of vowel errors present prior to and after therapy are shown in Table 8.

Table 8: Mean percentage error scores for vowels for 30 ears with auditory dys-synchrony before and after training

Stimuli → **% Error Pattern** ↓	/a/	/i/	/u/	/e/
Pre-training errors (%)	1.75 0.00^{*}	45.14	63.89	75.69
Post-training errors (%)	1.67 0.00^{*}	15.97	12.5	34.03
Improvement	0.08	29.17	51.39	41.66

Note. * Data from 28 ears

From Table 8 it can be observed that prior to therapy, the mean percentage of errors across the four vowels /a/, /i/, /u/ and /e/, varied considerably. The errors were minimal for the vowel /a/, with only two ears of one participant having misperceived it. The maximum pre-training errors occurred for the vowel /e/ (75.69 %), followed by /u/ (63.89 %). Following fine-grained auditory training, the vowel errors reduced markedly for all the vowels. No improvement in the perception of the vowel /a/ was observed due to the ceiling effect obtained prior to the training (Tables 8 & 9). The individuals with auditory dys-synchrony had limited difficulty in perceiving this speech sound before and after the training.

Table 9: Confusion matrix for vowels obtained before and after training from individuals with auditory dys-synchrony

Stimuli → **Response** ↓	**Pre-training Scores**				**Post-training Scores**			
	/a/	/i/	/u/	/e/	/a/	/i/	/u/	/e/
/a/	98.25	30.09	15.24	50.46	98.33	3.54	10.3	27.24
/i/	-	54.86	5.03	21.299	-	84.03	-	6.79
/u/	-	3.79	36.11	3.94	-	1.78	87.5	-
/e/	1.75	11.26	5.2	24.31	1.67	10.65	2.2	65.97
NR			38.42					

Note. NR = No response

From the confusion matrix of the vowels (Table 9) it is evident that the vowel with higher second formants (/i/ & /e/) were most often replaced with vowels having a relatively lower second formants (/a/). However, the vowel /u/, which has low formant frequencies, most often elicited no response.

From the mean percentage error scores for different stop consonants (Table 10) it was evident that bilabials and the velars were marginally more affected than the alveolar stop consonants. Similar to the performance for vowels, following the fine-grained auditory training there was a noticeable improvement in the perception across all the stop consonants. This improvement was seen irrespective of the place of articulation or whether the stop was voiced or voiceless. The improvement was greatest for the velars, followed by the bilabials and least for the alveolar stops.

Table 10: Mean pre- and post-training percentage error scores for stop consonants for 30 ears with auditory dys-synchrony and the percentage improvement

Stimuli → **% Error Pattern** ↓	/p/	/b/	/t/	/d/	/k/	/g/
Pre-training errors (%)	73.19	73.96	66.67	62.5	73.96	68.75
Post-training errors (%)	35.42	29.17	42.71	41.67	17.35	21.88
Improvement (%)	37.77	44.79	23.96	20.83	56.61	46.87

Table 11: The confusion matrix for the consonants in individuals with auditory dys-synchrony before and after training

Stimuli → **Response** ↓	**Pre-training**						**Post-training**					
	/p/	/b/	/t/	/d/	/k/	/g/	/p/	/b/	/t/	/d/	/k/	/g/
/p/	26.81	8.34	30.24	5.21	6.89	2.85	64.58	9.38	13.89	3.12	4.16	3.12
/b/	7.29	26.04	2.78	15.83	3.12	5.21	9.62	70.83	3.12	12.29	-	6.25
/t/	13.54	4.17	33.33	26.25	22.34	-	13.8	-	57.29	9.38	6.25	-
/d/	3.12	3.12	14.19	37.5	-	21.27	-	5.42	2.78	58.33	-	3.12
/k/	4.17	1.04	-	-	26.04	39.42	8.3	-	16.67	-	82.65	9.39
/g/	4.17	9.12	-	5.01	41.61	31.25	-	2.08	-	14.8	6.94	78.12
O	40.9	48.17	9.46	10.2	-	-	3.7	12.29	6.25	2.08	-	-

O: Other consonants such as nasals, liquids, laterals, affricatives or No Response.

The phoneme error analysis (Table 11) revealed that prior to the training the stops were substituted by other classes of speech sounds or elicited no responses. This occurred primarily for the low frequency bilabials. Following training, such errors reduced considerably. Besides a reduction in the voicing errors, there was also a decrease in the place errors, though to a lesser extent. The reduction in pure voicing errors was more evident in the velar and alveolar stops than in the bilabial stops. The pure place errors reduced mainly for the mid frequency velar stops and not so much for the bilabial and alveolar stops.

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.

Conclusion

The finding of the study highlights the impact of fine-grained auditory training on N1-P2 amplitude in individuals with auditory dys-synchrony and their perceptual abilities of speech signals. The significant improvement in speech identification abilities following therapy highlights the importance of systematic fine-grained 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 both behaviorally and physiologically. Though the quantum of improvement varied from individual to individual, all participants showed 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 Avilala and Yathiraj (2010) on a small group of individuals with auditory dys-synchrony. Kraus (2001) also reported improved perceptual and neurophysiological responses in a group of children with learning disability following fine-grained discrimination training.

In the present study the fine-grained training was given for the voice-voiceless stop consonants, which 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.

Acknowledgement

This project was supported by the All India Institute of Speech and Hearing research fund (SH/CDN/ARF/3.63/2010-11 dated 27-08-2010). The authors are thankful to the Institute for having sanctioned this project. Several individuals made it possible for this project to be completed on schedule and the authors are thankful to them.

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