Effect of Listening Training in Perception of Voicing of Stops in Individuals with Auditory Dys-synchrony

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Abstract

The objective of the present study was to determine the effect of fine-grained auditory training on the perception of voiced and voiceless stops in individuals with auditory dys-synchrony. The study also aimed to determine the phoneme errors before and after training. The perception was studied using bi-syllabic phonemically balanced words and a set of non-sense CV stop syllables with different place of articulation. Nine ears of five individuals with auditory dys-synchrony were evaluated. The participants were trained to identify voiced/voiceless pairs of stimuli along three different stop continua (bilabials, velars, & alveolar). Training was provided for each pair till the participants obtained identification thresholds similar to that obtained by 80% of a group of 10 normal hearing individuals. The results of the present study reveal that there was a significant improvement for both words and non-sense CVs following training. The significant improvement in speech identification scores following therapy highlights the utility of systematic fine-grained auditory training in individuals having auditory dys-synchrony. Although the training was given to improve perception of voiced-voiceless stops, the enhancement in performance was not restricted to only voice-voiceless contrasts. Improvement was seen for vowel perception as well as other consonants.

Key words: *Fine-grained auditory training, auditory dys-synchrony, phoneme errors, voice-voiceless contrast.*

Speech perception abilities of individuals with auditory dys-synchrony are not proportional to their hearing sensitivity which usually ranges from normal to profound hearing loss (Sininger & Oba, 2001). The majority of these individuals are found to have low frequency hearing loss (Starr, Picton, Sininger, Hood, & Berlin, 1996; Zeng, Oba, Grade, Sininger, & Starr, 1999). Rance, McKay, and Grayden (2004) attributed these disproportionate speech identification scores to deficits in the processing of temporal information.

Zeng et al. (1999) reported that individuals with auditory dys-synchrony had abnormal results on 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 of 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, Kong, Michalewski, and Starr (2005). From these studies authors inferred 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.

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 had 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.

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

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(Rance et al., 1999; Hood, 1998; Shallop, Peterson, Facer, Fabry, & Driscoll, 2001; Trautwein, Sininger & Nelson, 2000). Other methods recommended are or the use of communication methods like sign language and cued speech (Berlin, 1999; Bantwal & Basavaraj, 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 reported that with envelope enhancement, perception of stops and affricates showed greater improvement than the other consonants. Further, it was also reported that voicing perception did not improve with envelope enhancement. It can be inferred that envelop enhancement may be beneficial to some extent for individuals with auditory dys-synchrony. Hence, there is a need to determine new rehabilitative options for individuals with auditory dys-synchrony. Thus, the current study aimed at developing a training program for rehabilitating these individuals. The 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. The study also aimed to determine the phoneme errors before and after training.

Method

The study was carried out in six phases. In the first phase, material was developed for both evaluation and therapy. In the second phase evaluation was carried twice, one month before the training (Evaluation-I) and again just before the training was given (Evaluation-II). In the third phase, fine-grained identification ability was determined in normal hearing individuals while in the fourth phase, the fine-grained identification ability of individuals with auditory dys-synchrony was determined. In the fifth phase, fine-grained identification training was provided for individuals with auditory dys-synchrony. In the final phase, a post-therapy evaluation (Evaluation-III) was done.

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 are provided in Table-1.

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

Table 1. Demographic 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	10
D	18	Female	14	26.6	Symmetrical	52	44
E	12	Female	11.6	58.6	Symmetrical	40	30

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.

Procedure

Phase I: Development of material

Materials 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 was 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 materials 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. 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.

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. In addition, 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 their responses. 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 and the second evaluation was done just before the therapy.

The written responses for the CV syllables were further subjected to phonemic error analyses, in which vowels and consonants were analyzed separately. Phonemic error analysis was done for each ear by dividing the number of times a particular phoneme was correctly identified by the total number of times the particular stimulus was presented. The values obtained for each ear was summed to compute the mean percentage correct responses for the nine ears.

Phase III: Fine-grained 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-grained 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 stimulus adjacent to the cross-over stimulus which resulted in the participant obtaining 90% accuracy served as the anchor. 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 each 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 was noted for each voiced and voiceless set. Each individual had to correctly identify the stimulus pair presented at least twice 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'.

Phase IV: Fine-grained 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-grained 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-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. 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 break 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 with each session having duration of about 60 minutes. The training continued until the participants were able to identify the stimuli pairs similar to the identification threshold obtained 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-grained auditory training.

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 data obtained for individuals with auditory dys-synchrony was also compared with that of the data obtained for normal hearing individuals using independent t-test.

Results and Discussion

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.

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).

Table 2. 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	22	15	23	23	54
	Lt	19	37	19	39	24	55
2.	Rt	8	11	8	9	16	49
	Lt	6	8	7	8	18	50
3.	Rt	4	6	3	7	12	29
4.	Rt	8	10	7	11	22	57
	Lt	12	8	13	6	23	62
5.	Rt	13	31	12	33	21	50
	Lt	11	36	11	32	22	52

Maximum word score = 25; Maximum CV score = 72

Observation of the individual responses (Table 2) 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.

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 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, Nicol, Zecker, Hayes, and Kraus (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.

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 3 depicts the thresholds obtained just before and after

Table 3. 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				Post-training				Control group			
	/ba-pa/	/da-ta/	/ga-ka/	Combined score	/ba-pa/	/da-ta/	/ga-ka/	Combined score	/ba-pa/	/da-ta/	/ga-ka/	Combined score
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

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.

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)

Comparison of 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 3 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 exists 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 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.

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 4 and Table 5 respectively. Both pre- and posts therapy findings are provided.

From Table 4 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.

Table 4. 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

Table 5. 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.

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.

Conclusions

From the results of the study it is evident that individuals with auditory dys-synchrony obtained, significant better bi-syllabic word identification scores following fine-grained speech identification training. In addition, there was also a significant improvement in the perception of voice-voiceless stops following speech identification training. The comparison of fine-grained speech identification threshold before and after training shows improvement in the threshold which approximated the fine-grained speech identification thresholds of the normal hearing participants. Following training the approximation was more for /da-ta/, and /ga-ka/ but not so for /ba-pa/.

The results show a specific pattern in the phoneme errors for both vowels and consonants. However, the number of errors for vowels and consonants markedly reduced after training. It can be construed that providing training using temporal cues does bring about improvement in the perception of speech in individuals with auditory dys-synchrony. Although the training was given to improve perception of voice-voiceless stops, the enhancement in performance was not restricted to only voice-voiceless contrasts, rather improvement was seen for vowel perception as well as other consonants. The improvement was more for the mid and high frequency vowels and consonants, and less improvement was seen for the speech sounds where the energy concentration is more in the lower frequencies.

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

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