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AN INVESTIGATION INTO THE RELATIONSHIP BETWEEN SPEECH PERCEPTION AND SPEECH PRODUCTION IN AN EXPERIMENTAL SPEECH TRAINING PROGRAM FOR CHILDREN WITH HEARING LOSS.

by

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Abstract

AN INVESTIGATION INTO THE RELATIONSHIP BETWEEN SPEECH PERCEPTION AND SPEECH PRODUCTION IN AN EXPERIMENTAL SPEECH TRAINING PROGRAM FOR CHILDREN WITH HEARING LOSS

by

Christine Kosky

Advisor: Professor Arthur Boothroyd

The relationship between speech perception and speech production was examined by measuring six hearing-impaired children's perception and production of the /s/-/sh/ contrast during a two week training program. Recordings were made of a male talker and a female talker for the test of perception. Subjects used broadband amplification during perception tasks, and personal hearing aids during production tasks. At the beginning and end of each no-training period, the tests of perception and production were administered. A general test of contrast production and perception, (IMSPAC), served as a control, and was administered at the beginning and end of the program.

Group mean performance scores for the perception and production of the contrast improved during the training program. The improvements in contrast scores were greater than those seen on the control task, IMSPAC. This finding supports the conclusion that the improvement in perception and production scores for the contrast was the result of training. Improvement in perception scores occurred during training periods only but neither type of training could be tied to the improvement. Improvement in production scores could not be tied to the training or the no-training periods. Contrary to expectation subjects' performance on the perception task was better with the female talker than with the male talker. Also surprising was that performance on the perception task was better with personal hearing aids than with broadband amplification.

These results support systematic training in the perception and production of phonologically significant details of speech. The study did not determine which type of training would produce the best results for comprehension of the /s/-/sh/ contrast and for improved production of the contrast. Unfortunately, the validity of the perception test used is of concern because it may have given information about the perception of intensity differences rather than perception of the contrast. Finally, the addition of previously unavailable acoustic cues through the broadband amplification system did not appear to be beneficial for improved perception of the contrast.

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Chapter 1

Introduction

This study was concerned with speech perception and speech production in children with severe and profound hearing loss. Specifically, it was concerned with the cause-effect relationship between the two-that is, the influence of improved speech perception on speech production and the influence of improved speech production on speech perception. There are numerous studies that show deficits of both speech perception and speech production in hearing-impaired subjects. In general, the incidence and severity of these deficits increase with increasing severity of hearing loss. The correlation is by no means perfect, but pure tone threshold accounts for more of the variance in speech perception and speech production measures than any other single measure. Clearly loss of hearing is the primary cause of the perception and production deficits. Establishing a cause, however, is not the same as establishing a mechanism. And there is not general agreement on the chain of cause-effect relationships that connect hearing loss, speech perception, and speech production.

One position would be that hearing loss causes poor speech perception by a combination of reduced audibility of acoustic speech information and reduced discrimination among those acoustic cues that are audible. The reduced speech perception then causes reduced speech production. If this were the case, one could argue that the primary goal of intervention should be sensory assistance (to make speech information audible) and auditory training (to enhance discrimination). Specific training on production would be unnecessary because improved production would follow spontaneously from improved perception.

It could be argued, however, that production is the key to perception. The thing to be perceived is a motor activity. Only when the child has learned to produce speech does he have the internal representation of the phonemes and the words that are to be perceived. On the basis of this argument one would advocate for an intervention approach that begins with sensory assistance (to make speech information available) and continues with training in production.

A major issue in this work is the relative contribution of audibility and discrimination to speech perception. Children with severe and profound hearing losses are notoriously difficult to fit with hearing aids. It is seldom possible to provide these children with auditory access to the higher frequencies (above 3 or 4 kHz) where much of the information required for identification and discrimination of consonants is to be found. It has been argued, therefore, that the major problem is audibility and that, if this can be addressed, near normal perception will follow. On the other hand, it is well known that sensorineural hearing loss is accompanied by reduced frequency resolution, reduced temporal resolution, and abnormal loudness-intensity functions. It is to be expected, therefore, that problems of speech perception will remain, even if the problem of audibility is resolved. Unfortunately, the research literature provides conflicting evidence on this point.

In designing the study to be described, it was important that the focus of intervention should be on sounds to which the subjects had not previously had access. The sound /s/ was considered an ideal candidate because of the high frequency limit of modern hearing aids. It was argued that the provision of access to this sound, using broadband amplification, would provide a ready-made model for testing the effects of production and perception training. There is ample evidence of the problems encountered by hearing-impaired children in the production and perception of /s/. In fact many children fail to contrast /sh/ and /s/ in their production. This phenomenon can be explained on the basis of the acoustic properties of the sounds. Whatever the reason, however, the contrast between /s/ and /sh/ provides a convenient target for examining the effects of providing access to the high frequencies of /s/ and following this with perception and production training.

These then, were the specific goals of the study:

1. To use a broadband amplification system for training perception of the /s/-/sh/ contrast.
2. To train production of the /s/-/sh/ contrast.
3. To measure the effects of both types of training on perception and

production of the contrast before and after training periods, and no-training periods.

4. To determine if similar improvements are seen in perception and production tasks on which the subjects do not have any training?

Two additional goals concerning perception were:

5. To compare /s/-/sh/ perception scores for two talkers, one male, the other female.
6. To compare subjects' perception performance scores for the /s/-/sh/ contrast when using the broadband amplification system, with performance scores obtained when they were using their personal hearing aids.

Chapter 2

Review of the Literature

1. SPEECH PERCEPTION

The different acoustic patterns of speech result from different articulatory configurations. These acoustic patterns are important because they signal differences in meaning. Many studies have tried to determine how the hearing-impaired perceive these acoustic patterns.

a) Consonants

The perception of consonants by the severely-to-profoundly hearing impaired has been found to be poor. However, perception of consonant voicing and manner information is better than perception of place information. Erber (1972) investigated auditory recognition of voicing/nasality and place distinctions within a set of stop and nasal consonants, in a VCV context to normally hearing, severely hearing-impaired, and profoundly deaf children. The normally hearing children recognized all the consonants. The severely hearing-impaired children could categorize the voiced from the voiceless plosives, and the nasal from the nonnasal consonants. The profoundly deaf children confused nasal and plosive consonants. Erber's explanation was that the severely hearing-impaired children were able to discriminate between the voiced/voiceless category and nasal/nonnasal category because the auditory cues were in the lower frequencies. However, the profoundly deaf children could not perceive the cues for voicing and nasality.

Owens, Benedict, and Schubert (1972) agreed with Erber. The authors found that predominant error phonemes were those produced in the same manner as the test phoneme. A multiple choice speech discrimination test was used in which there were 125 items. For each item there were four CVC response alternatives which differed phonemically in only the final or the initial position. An error response was the result of identifying a specific phoneme incorrectly. The authors observed that identification of /s/, initial /t/, and /Θ/ was dependent upon the frequencies above 2000 Hz. Identification of /sh, ch, and j/ was dependent upon the frequencies between 1000 and 2000 Hz. Subjects with no hearing in these frequencies performed badly on the test.

Bilger and Wang (1976) used both CV and VC nonsense syllables as stimuli in a 16 alternative forced choice format with adult normally hearing and hearing-impaired subjects. The hearing-impaired subjects had mild-to-severe hearing impairments. The authors used feature analysis to determine the relationship between audiometric configuration and patterns of consonant confusion. Results indicated that subjects with high frequency hearing losses were unable to perceive the feature of sibilance. The only speech sounds that contain the feature of sibilance are /s/ and /sh/. The authors concluded that factors such as reduced audibility, poor frequency selectivity, and impaired temporal resolution affected the subjects' ability to perceive this feature and made it difficult for them to discriminate between speech sounds.

Harris (1958) used consonant-vowel syllables to investigate the cues normal hearing listeners use to discriminate between fricatives. The author found that when /s/ friction was paired with any vocalic portion, the resulting stimulus was judged as an /s/, and when /sh/ was paired with any vocalic portion the resulting stimulus was judged as an /sh/. The other fricative stimuli were rarely judged as an /s/ or /sh/. Harris suggested that the listener judges whether a syllable belongs to the /s-sh/ group of fricatives on the basis of friction.

Zeng and Turner (1990) observed that there are two kinds of acoustic information that are most responsible for the perception of voiceless fricatives. One kind of information is the steady-state spectral shape differences existing in the voiceless noise burst: /s/ typically has a spectral peak at 4-8 kHz and /sh/ has one at 2-4 kHz, whereas /f/ and /Θ/ have flat spectra. The second kind of information is the dynamic spectral changes occurring during the voiced formant transition between the fricative and the adjacent vowel. The acoustic cue for duration is not important for the perception of voiceless fricatives whereas the acoustic cue of amplitude does help in the discrimination of /s/ from /f/. The authors investigated the cues necessary for fricative recognition in four fricative-vowel syllables by normal hearing subjects. The speech tokens were presented across a wide range of presentation levels, from as low as 20 dB SPL. The results indicated that the critical frequency region for perception of the fricative portion consists primarily of high frequency components between 1500-2000 Hz. Recognition scores indicated that the frication portion alone, when audible, could serve as a sufficient cue for perception. Subjects obtained only chance performance at 30 dB SPL, when no portion of the frication was audible, but were 62% correct when only a small high frequency portion was audible. In a second experiment the authors compared fricative recognition between normal and hearing-impaired listeners. Zeng and Turner suggested that the hearing-impaired listeners' recognition of fricative-vowel syllables results primarily from the fricative cue. The hearing-impaired listeners achieved essentially normal recognition performance when given equivalent degrees of audibility of the frication cue.

b) vowels

Perception of vowels by the severely to profoundly hearing-impaired is better than that of consonants. Pickett et al (1972) presented a modified Rhyme Test to severely and profoundly deaf adults and found that vowels were perceived better than consonants. Back vowels were perceived better than front vowels. A possible explanation for this is that back vowels have lower second formants, than front vowels.

This finding is in agreement with the work of Hack and Erber (1982) who presented 10 vowels in a bilabial /bVb/ context to deaf children. The first type of error was confusion between vowels having similar first and different second formants. A possible explanation was that subjects were unable to perceive auditory information in the second formant region. A second type of error was that subjects confused vowels having similar first and second formants. A possible explanation was that the subjects could not accurately hear the frequency location of the vowel formants and so confused vowels with neighboring articulatory positions.

c) contrast perception

Boothroyd (1984) demonstrated that specific speech contrasts are available at different levels of auditory perception in children with varying degrees of hearing loss. Context varying, forced choice tests of speech perception were presented to hearing-impaired adolescents with sensorineural hearing losses. The values for hearing loss at which scores fell to 50% (after correction for chance) were 75 dB for consonant place, 85 dB for initial consonant continuance, 90 dB for initial consonant voicing, 100 dB for vowel place, 105 dB for talker's sex, 115 dB for syllabic pattern, and in excess of 115 dB for vowel height. Subjects with the most severe hearing losses tend to perceive those contrasts that are cued by time/intensity patterns. Hearing loss was found to predict speech intelligibility for hearing losses as high as 105-114 dBHL.

Abberton, Hazan, and Fourcin (1991) assessed sixteen severely- to profoundly hearing-impaired children's ability to label speech contrasts in a four-year longitudinal study. The authors suggested that perceptual skills precede productive skills. Some of the children were able to use categorical labeling but these children could not produce the contrast. Those children that produced the contrast usually labeled it. Children who used random labeling were unable to produce a particular contrast. Production and perception for the vowel contrast preceded that for the consonant contrast.

Summary

Perceptual confusions for vowels, and even more so for consonants, result from the hearing-impaired not having access to the necessary acoustic cues. Studies indicated that perception of back vowels by the severely-to-profoundly deaf is higher than for front vowels because the subjects cannot perceive the cues in the second formant region necessary for perception of front vowels. The perception of consonant voicing and manner information is better than that of place information. Subjects with high frequency hearing losses had difficulty perceiving the feature of sibilance but when subjects were given access to the high frequency cues they were able to recognize the fricatives. In order to achieve normal speech recognition performance the hearing-impaired need to be given access to these acoustic cues. The experimental training program used broadband amplification to give access to these acoustic cues.

2. SPEECH PRODUCTION

Speech production requires the ability to coordinate sub laryngeal, laryngeal, and supra laryngeal systems. Effective use of these systems results in the production of acoustic patterns that signal differences in meaning. Many studies have tried to assess the abilities of the hearing-impaired to produce speech.

a) Respiration for speech and suprasegmentals

Two prominent aerodynamic characteristics have been noted in studies of speech production of the hearing impaired. First, during consonant production there is often inappropriate glottal activity causing a blurring of the voiced/voiceless distinction. Secondly, there is an inability to coordinate respiratory patterns with valving at the laryngeal and articulatory levels. Whitehead (1983) described and quantified the respiratory characteristics of hearing-impaired adults, who varied in degree of speech intelligibility, with those of normal hearing adults. The semi-intelligible and unintelligible hearing-impaired speakers undertook speech with reduced lung volumes and expended very high volumes of air per syllable during continuous speech.

Other researchers such as Nickerson (1975), Monsen (1979), John and Howarth (1965), and Levitt, Smith, and Stromberg (1974), investigated timing errors. They found that a reduced rate of speaking was related to a number of different errors. These errors included increased duration of phonemes, prolonged pauses within utterances, and poor rhythm. McGarr and Osberger (1978) found that deaf children were most successful at producing the intended feature of pause.

Changes in phoneme duration are important for the listeners' recognition of phonemes, particularly for differentiation between some of the vowels. Vowels preceding voiced stops and continuants have longer duration. It appears that the deaf lengthen many vowels and consonants. Angelocci (1962) observed that the deaf took four to five times as long to produce fricatives as compared to a normally hearing speaker. The durations of unstressed vowels by the deaf were four to five times as long as those of the average normal speaker. McGarr and Lofqvist (1982) confirmed this finding. The authors found that the absolute duration of articulatory events was longer in the speech of the deaf than that of normally hearing speakers.

Speech sounds that require precise coordination of the timing of different articulatory movements or the rapid transition from one articulatory position to another have often been identified as a problem for deaf speakers. McGarr and Loqvist (1982) observed glottal and supra glottal events during obstruent and obstruent-cluster production in a comparison of hearing-impaired and normally hearing speakers. The data revealed the closure duration to be considerably larger for the stops in the deaf speakers' utterances and there was evidence of inappropriate glottal gestures. An example of this was a deaf speaker making a glottal abduction/adduction gesture immediately preceding the test word, before the onset of lip closure for an initial stop consonant. An abduction/adduction gesture between words was never observed for the hearing subject.

For the deaf speakers whose speech was difficult to understand, or whose speech was almost unintelligible, the glottal gesture and the interarticulatory timing were abnormal. All deaf speakers were more successful in producing fricatives than stops. The authors found that in general deaf subjects correctly produced the laryngeal gesture for the voiceless fricative /s/. McGarr and Loqvist suggested that voiceless fricatives require less precise interarticulatory timing than voiceless stops because deaf speakers need only open the glottis and then direct the airstream in an outward direction.

Some have suggested that the visible articulator(s) are used appropriately by deaf speakers but appropriate use of the less visible articulator(s) is variable. This suggestion is supported by the work of Harris, McGarr, and Rubin-Spitz (1985) who noted that front-back movement of the tongue is difficult to see. They found that the EMG pattern for peak genioglossus activity in a /pVpVp/ sequence by deaf speakers was quite variable.

Some investigators have noted that deaf speakers are apt to have a relatively high pitched voice. Angelocci, Kopp, and Holbrook (1964) in a study concerning vowel production found the mean fundamental frequency for all vowels produced by deaf subjects was considerably higher than for normally hearing subjects. However, Monsen (1979) found that only a few speakers had clearly deviant fundamental frequencies. Some have suggested that the problems with pitch are the result of the proprioceptive feedback that the deaf speaker receives while speaking. Martony (1968) suggested that the extra effort used by the deaf speakers helped make them aware of the onset and progress of voicing. He observed that some deaf speakers begin a breath group with an abnormally high pitch and then lower the pitch to a normal level.

b) Production of consonants

Deaf speakers have difficulty with the production of fricatives, and affricates, as well as differentiating between voiced and voiceless consonants. Smith (1975) obtained speech samples from children with severe to profound hearing losses using sentences, which incorporated all of the most frequently used phonemes in English. Bilabial place of articulation was at the head of the list for correct production, followed by glides. Stops in the alveolar and velar region as well as /h/ and lingua dental consonants followed. Near the bottom of the list were the alveolar and palatal fricatives. Affricates had the greatest portion of errors. There was no difference in the mean proportion of errors in the initial and medial position, but there was a marked increase for errors in the final position, and a major proportion of these errors was the error of omission.

It is not surprising that deaf children have difficulty producing fricatives in the palatal region. For /s/ the tongue body is low with the tongue tip raised and only the sides of the tongue in contact with the palate. This results in minimal visibility of the articulatory positions necessary for the production of

/s/, minimal proprioceptive information, and because acoustic cues for /s/ are usually above 4 kHz this information is also unavailable.

The articulatory positions necessary for /sh/ are also not fully visible. The variations in the configuration of the tongue appear to be less critical than for the production of /s/ and lip protrusion is visible. The acoustic cues for /sh/ are as low as 2 kHz. For these reasons the deaf child can produce /sh/ and may indeed substitute /sh/ for /s/.

c) Production of vowels

Hudgins and Numbers (1942) classified vowel and diphthong errors in the speech of the hearing-impaired into five categories: substitution, distortion of diphthongs, neutralization, diphthongization, and nasalization of vowels. The literature has noted that vowel production is better than consonant production. Smith (1975) found 53% of all speech errors were consonant errors while only 39% were vowel and diphthong errors.

It is difficult to compare the absolute value of the vowel error rates reported in studies because of the differences in text stimuli and elicitation procedures. Studies have also differed in their criteria for a correct response, in their experience of their listeners, and in the training methods the deaf children have been exposed to.

Many studies have investigated the relationship between F1 and F2 in the vowel production of the deaf. Angelocci, Kopp, and Holbrook (1964) found that the means of F1 for the deaf was 325 Hz lower than for hearing children.

The means of F2 was also lower for the deaf than for hearing subjects. The degree of overlap among the areas representing different vowels on plots F2 against F1, was greater in the speech of the deaf. Monsen (1976) also found a reduced range for F2 in the speech of the deaf. He assessed the general speech intelligibility of the deaf and normally hearing children using simple sentences containing spondees or monosyllables, such as 'I like ice cream.' He found that vowel targets were based primarily upon the movement of F1 and that in some subjects the extent of movement for both formants was collapsed. The lack of movement of F2 precluded the transmission of important consonantal as well as vocalic information. Monsen (1976) collected data on vowel production, by hearing and deaf adolescents, using sentences composed of monosyllables. He found that the deaf subjects' poor vowel intelligibility was the result of a restricted range of the second formant. He suggested that F1 is perceptually more prominent to the deaf child than F2 because the deaf have better residual hearing in the frequency range of the first formant and perceive the F1 frequency as the primary distinctive feature of the various vowel sounds.

Harris, Mcgarr, and Rubin-Spitz (1985) assessed the vowel production of deaf and normally hearing speakers using a monosyllable /bVb/ within a carrier phrase. On average deaf speakers showed a reduced range of F1 and F2 values relative to normals. Analysis of the mean plots and variability plots of individual talkers showed that some of the talkers had small variability for the point vowels, while some showed great overlap between the front and back vowels, and some showed a great variability for all vowels. They suggested that the placement of the average values in the F1 by F2 space did not predict the relative variability of the talkers around average values. They found that there was more intra subject variability on every acoustic dimension for the deaf talkers in the study than for the normally hearing subjects.

f) Summary of speech production

Hearing-impaired speakers' speech production difficulties include making the distinction between voice/voiceless consonants, coordinating respiratory activity with laryngeal and articulatory activities, and using a relatively high voice pitch. Speech production errors include a reduced rate of speaking and errors in the production of consonants. One of the reasons deaf children have difficulty producing palatal fricatives is because there is minimal visibility of the different tongue positions necessary for production of palatal fricatives. In vowel production the hearing-impaired are able to produce the articulatory movements necessary for F1 because the acoustic cues are in the low frequencies. However they have difficulty producing the movements necessary for the production of F2 because those acoustic cues are in the higher frequencies.

3. IMPLICATIONS FOR SPEECH TRAINING

The inability to perceive the necessary auditory cues combined with the poor visibility of the necessary articulatory movements make it critical to give deaf children access to the necessary acoustic cues. Ling and Milne (1981) evaluated the speech intelligibility of seven profoundly hearing-impaired children who had received treatment for three or more years. Treatment included the provision and maintenance of appropriate binaural hearing aid as well as speech therapy. Results indicated that the speech intelligibility of the profoundly hearing-impaired children was not significantly poorer than that of their normally hearing peers. The levels of intelligibility ranged from 56 to 98% and contrasted with those reported in previous studies, such as Smith (1972) where average intelligibility levels ranged from 18 to 31%. The authors suggested the results indicated that clear fluent speech is a realistic goal for hearing-impaired children and that the generally poor standards of speech largely reflected inadequate speech training.

Boothroyd (1994) reported IMSPAC data for 97 severely and profoundly deaf children in various educational settings around the United States. Multiple regression analysis showed that the only significant predictor of performance, under the auditory-only condition was degree of hearing loss. Hearing loss accounted for 50% of the variance in the score. Under the auditory-visual condition, hearing loss was still the primary predictor of performance but it accounted for only 30% of the variance. Analysis of the auditory-visual scores for the subjects, from traditional oral programs, showed them to be 35-40 percentage points higher than the auditory-alone scores, whereas the difference for subjects, from the total communication programs, was only about 15 percentage points. The better auditory-visual scores for the orally trained subjects were present only in those with hearing losses of 90 dB or more. These data support the notion that the development of phonetic level speech production skills for the profoundly deaf child is strongly influenced by learning opportunity.

4. THE RELATIONSHIP OF SPEECH PERCEPTION TO HEARING-IMPAIRMENT.

A hearing-impaired person's speech perception is closely related to the configuration of the hearing loss. Owens, Benedict, and Schubert (1972) found that fricatives were easily identified by patients with pure tone flat configurations. As stated previously in this chapter identification of /s/, initial /t/, and /Θ/ was dependent upon frequencies above 2000 Hz and identification of /sh, ch, and j/ was dependent frequencies between 1000 and 2000 Hz. Subjects with sharply falling configurations presumably have difficulty perceiving fricatives because the information necessary for identification is in these higher frequencies.

Bilger and Wang (1976) investigated the perception of features in hearing-impaired subjects with mild to severe hearing impairments. Subjects with high frequency hearing losses were unable to perceive the feature of sibilance, while those with flat or rising configurations were able to identify it.

5. THE RELATIONSHIP OF SPEECH PRODUCTION TO HEARING-IMPAIRMENT

The configuration and degree of the hearing-impairment, as seen on the audiogram, give some indication to the phonemes that might be produced by a subject. Smith (1975) found that hearing threshold at 125 Hz, 500 Hz, and 1000 Hz, and the extent of hearing in the higher frequencies, was related to speech intelligibility. Monsen (1978) compared the correlations obtained between speech intelligibility and the subject's hearing levels at 0.5 kHz, 1 kHz, 2 kHz, and 4 kHz. He averaged the subject's responses at the different groupings of frequencies. The highest correlation was obtained between overall intelligibility and the average responses at 1 kHz, 2 kHz, and 4 kHz. Boothroyd (1984) found that hearing loss predicted speech intelligibility for hearing losses as high as 105-114 dBHL, but not perfectly.

Further evidence of an association between degree of hearing loss and phonemic intelligibility is given by Boothroyd and Gorzycki (1977). Adequacy of /sh/ articulation was significantly correlated with pure tone thresholds, especially at 2KHz. Boothroyd (1986) assessed the probability that /sh/, produced by 16 deaf talkers, would be correctly identified by normally hearing listeners in a two alternative forced choice task, using the comparison phoneme /s/. Scores did not drop to chance level until a threshold value of 115 dB was reached.

6. THE RELATIONSHIP BETWEEN SPEECH INTELLIGIBILITY AND HEARING-IMPAIRMENT

Studies that have investigated the relationship between speech intelligibility and the degree of hearing impairment have found that low intelligibility is usually associated with the poorest hearing thresholds. Smith (1975) found that the proportion of correct responses was well correlated with hearing thresholds at 1 kHz. However, the correlation between the intelligibility of the child's speech with the child's speech discrimination skills was better, than either of them, with hearing threshold. Much of the information on manner of articulation, voicing, and vowel differences was significantly related to speech intelligibility. Levitt, McGarr, and Geffner (1987) in a longitudinal study concerning the development of language and communication skills in hearing impaired children, found a strong association between hearing level and speech communication skills. Their work confirmed Smith's findings, in that speech intelligibility was highly correlated with speech perception measures.

McGarr and Osberger (1978) examine the effects of pitch deviancy on intelligibility and found that children with better hearing (<90dB in the better ear) achieved higher intelligibility ratings. They used rating scales to measure the prosodic feature of speech and overall speech intelligibility. The rating scale for pitch described a rating of 1, as being unable to sustain phonation, and a rating of 5, as being appropriate for age and sex. The rating scale for intelligibility described a rating of 1, as speech that could not be understood, and a rating of 5, as speech that was completely intelligible. The subjects read sentences developed for a prosodic feature production test and experienced listeners evaluated the recordings. An articulation test was used to measure the children's production of vowel and consonant sounds in isolated words. No child with hearing loss of greater than 90dB achieved a rating of 5 (i.e. speech is completely intelligible). However, several children with poor hearing achieved a rating of 4 (i.e. speech is intelligible with the exception of a few words or phrases). These children had pure tone averages that were greater than 90 dB, but they had some measurable hearing through at least 1000 Hz. The authors observed that several children with relatively good hearing received poor intelligibility ratings.

Levitt (1987), in a longitudinal study, observed that intelligibility of a child's spontaneous speech production correlated moderately well with his/her hearing level but showed a higher correlation with measures of speech.

It is difficult for the hearing-impaired to recognize all the phonemes through their personal hearing aids even if they have the necessary spectral resolution. High-powered hearing aids are limited in their output above 3.5 kHz. Killion (1993) noted, that at one time, hearing aid transducers were intentionally designed with a bandwidth restricted to the frequencies between 500 and 3-4000 Hz. The belief was that such a restriction would allow nearly all of the important speech information to pass while rejecting noise in those regions where residual speech cues were of less importance. French and Steinberg's (1947) articulation index experiments revealed that the frequency bands below 400 Hz contained only 5% of the speech information, and those above 4000 Hz contained only 15% of the information. It should be noted, however, that normal hearing subjects were used to obtain the data. These subjects already had knowledge of language whereas deaf children do not. A consequence of the limited bandwidth of hearing aids is that severe-to-profoundly deaf children do not have access to all the acoustic cues that differentiate the sibilant /s/ from the contrast /sh/.

7. INTERVENTION STUDIES

The aim of auditory training is to enable hearing-impaired persons to make maximal use of the sound cues audible to them so that they may comprehend speech and monitor their own speech production. The aim of speech production training is for the hearing-impaired child to develop speech that is intelligible. In order to achieve these objectives it is necessary to develop appropriate remediation procedures within training programs for hearing-impaired children. Some research studies have attempted to evaluate the effectiveness of different speech training procedures. Osberger, Johnstone, Swarts, and Levitt (1978) developed and evaluated a speech program that was based on Ling's hierarchical speech skills (1976) training program. A group of twenty hearing-impaired children ranging in age from 7 to 10 years were taught the suprasegmental patterns of English. The children's performance on the speech training hierarchy was monitored on a daily basis using a checklist system. Speech production training was effective for two-thirds of the children but one-third of the children had severe difficulties at one or more levels of the program. These difficulties included not progressing beyond a certain level, an inability to maintain previously learned skills, or a very slow rate of progress. The data revealed that many of these subjects had very limited residual hearing, and additional problems other than a hearing loss. This study did not evaluate the possible impact of speech production on speech perception.

There is one study that has successfully trained production of the phoneme /s/ with the contrast phoneme /sh/ with hearing-impaired children. Boothroyd and Gorzycki (1977) completed a short articulation training program for the sibilant /s/ with 8 children, with severe to profound hearing losses. The experimental subjects were given 2 weeks of training for ten minutes daily, using both descriptive techniques, and an ‘s’ indicator. An ‘s’ indicator is a small rectangular instrument with a light and a microphone. The light is activated when a subject says /s/ but not /sh/, (a more complete description of the ‘s’ indicator appears in chapter 4). The subjects were reevaluated and 6 of the 8 experimental subjects were found to have changed their performance in the direction of more acceptable sibilants. This study was not however, followed up with one assessing speech perception skills.

Ling (1976) stated that speech production training should be the basis for auditory training. He suggested that speech training improved speech perception because speech production and perception are interdependent. Empirical support comes from Lieberth and Subtelny (1978) who examined the effect of speech training on auditory speech perception skills of hearing-impaired young adults. Auditory perception tests were administered to two groups of subjects matched on the basis of hearing characteristics. In the experimental program, auditory phoneme identification tests were administered before and after a twenty-week period of speech training. A control group received the same tests but did not receive any speech training. Significant improvement in phoneme recognition was achieved in the experimental group but not in the control group. Assessment of speech production skills was, unfortunately, not included in the study.

Only one study has investigated the training of speech production and speech perception skills in hearing-impaired children. Novelli-Olmstead and Ling (1984) investigated the effects of training auditory speech discrimination together with speech production as compared to the effects of training auditory discrimination alone. The subjects were 14 hearing-impaired children, aged 5-7 years, who were matched with 14 other hearing-impaired children. The members of each group were randomly assigned to one of two groups. The task of the first group was to listen to, and to produce speech. The task of the second group was to listen to speech, and to discriminate speech. Both subjects in each pair attended each of the training sessions. During training the speaking member of each pair listened to and then produced, or was taught to produce, phonetic-phonological targets, while the listening member of the pair only made discriminations.

Both speaking and listening subjects scored significantly better on the posttraining test than on the pretraining test. All subjects made gains in phonetic skills over the training period and those who were required to speak made significantly more progress than those subjects whose task was only to listen. The authors suggested that active participation in speech production was more effective than passive listening, and concluded that improved speech production results in improved speech perception.

A serious flaw in the study was that members of each pair were not well matched for thresholds of hearing. From the information given concerning the members of the pairs, it appears that many of those with lower thresholds had the speaking role. Another difficulty was that the training materials used were different for each subject. Each subject was assigned material related to his/her performance needs within the phonetic-level subskills, targets, and training strategies described by Ling (1976).

The Novelli-Olmstead and Ling study is the only study that has investigated the training of speech production skills and its impact on the development of speech perception skills. This study was limited in scope and the issue of the relationship between speech production and perception remains essentially unresolved.

Summary

The training studies of Osberger, Johnstone, Swarts, and Levitt (1978), Boothroyd and Gorzcki (1977), Novelli-Olmstead and Ling (1984), suggest that speech production training can improve speech production skills. The training study of Liebeth and Subtelny (1978) suggests that speech production training improved speech perception skills. The Novelli-Olmstead and Ling training program suggests that perceptual training alone does not result in improved speech production.

Problems with these studies include non-standardization of materials used, and the attempt to compare perception and production performance in subjects with different amounts of residual hearing.

8. SPEECH TRAINING AIDS

Speech training aids do not teach the child how to produce a sound but they are helpful in giving a child additional feedback on correct production of a speech sound while practicing speech.

Risberg (1968) used a visual /s/ indicator to help two severely hearing-impaired children learn the correct phoneme-to-motor pattern for /s/. The subjects were given two types of training for words containing /s/. Both subjects showed some improvement in production of /s/, but only one subject was able to generalize production of /s/ from trained to non trained material.

In the study by Boothroyd and Gorzycki (1977), described earlier in this chapter, the authors used a visual /s/ indicator with hearing-impaired children, in a training program for improved articulation of /s/. The subjects' production of /s/ improved but no evaluation concerning the role of the visual training aid in the improved production was given.

Guttman, Levitt, and Bellefleur (1970) investigated the use of a real time acoustic display of the low frequency surrogate fricatives /s/ and /sh/ in articulatory training of the deaf. There was an experimental group of six children and a control group. Both groups received the same training except that only the experimental group used the real time acoustic display instrumentation. Subjects received individual training sessions. Improved production of /s/ and /sh/ could not be tied to the use of the instrumentation. Two concealed-identity evaluations of pre- and post training performances revealed nearly equal performance by the experimental and control groups. There was greater improvement in the production of /sh/ than /s/ for both groups in the study.

9. STUDIES RELATED TO /S/ AND /SH/

A consequence of the limited bandwidth of hearing aids is that severe-to-profoundly hearing-impaired children do not have access to all the acoustic properties that differentiate the sibilant /s/ from the contrast /sh/. Both phonemes are the result of turbulent airflow being produced between the tongue and the hard palate. For /sh/ the body of the tongue is raised. The space in front of the tongue is larger and is coupled to the space behind the tongue. Because there are differences in the articulation of the sounds there are also differences in the acoustics. The phoneme /sh/ includes energy at frequencies as low as 2 kHz whereas /s/ has frequencies above 4 kHz. The hearing-impaired may perceive these spectral cues as similar to the spectral cues for /sh/. Hearing-impaired children, with sensorineural hearing losses, do not have access to the high frequency cues for /s/ through their personal hearing aids. Boothroyd and Gorzycki (1977) noted that many hearing-impaired children produce a quasi /sh/ sound for both /s/ and /sh/.

The spectrum of /s/ depends upon the adjoining vowel. Boothroyd and Medwetsky (1992) analyzed the spectral peaks of /s/ in repeated tokens before and between the vowels /i/, /u/, and /a/. The lowest spectral peaks averaged around 4.9 kHz for the /u/ context, 5.6 kHz for the /a/ context, and 6 kHz for the /i/ context. The authors observed that these acoustical differences are not important for the normal hearing listener's perception of /s/ but these differences are important for hearing-impaired listeners using limited bandwidth amplification.

The same study found that the spectrum of /s/ varies from speaker to speaker with the lowest spectral peaks of /s/ differing between speakers by as much as 5 kHz. There were dramatic differences between talkers with the spectral peaks for /s/ ranging from 3.2 kHz to 8.4 kHz. The women subjects generated consistently higher frequency /s/ sounds than the men, but there were also large differences within the gender groups. The authors concluded that hearing-impaired subjects would require access to frequencies of 8 kHz or more in order to perceive the /s/ produced by all talkers in all contexts.

10. CONCLUSIONS

The research studies have described the numerous speech perception and speech production deficits exhibited by the hearing-impaired. Both speech production and speech perception deficits have been found to correlate with hearing loss and with each other. However, the mechanisms that result in these deficits is still unclear. One hypothesis is that because hearing loss results in poor speech perception it will result in poor speech production. The other hypothesis is that hearing loss results in poor speech production and this results in poor speech perception. The intervention studies cited demonstrated that production training improves production. What is not clear is how much of a role perception has played. Similarly it is not clear whether improved production automatically leads to improved perception performance as might be predicted when one considers that knowledge of what is to be perceived is as important as access to the sensory evidence.

11. PURPOSE OF THE STUDY

The general goal of the study to be described was to enhance our understanding of the relationships between production and perception training and their consequences. Specific goals were:

1. To use a broadband amplification system for training perception of the /s/-/sh/ contrast.
2. To train production of the /s/-/sh/ contrast.
3. To measure the effects of both types of training on speech perception and speech production of the contrast during training periods, and during no-training periods.
4. To determine if similar improvements are seen in perception and production tasks on which the subjects do not have any training.

Two additional goals concerning perception were:

5. To compare /s/-/sh/ perception scores for two talkers, one male, the other female.
6. To compare subjects' perception performance scores when using the broadband amplification system with performance scores obtained when using their personal hearing aids.

Chapter 3

Materials and preparation of test recordings

This chapter describes the two tests used in the training program and the preparation of test recordings.

The training program required recordings of the two tests: an /s/-/sh/ articulation test and the IMSPAC test. The /s/-/sh/ articulation test was recorded by one male talker and one female talker for training and testing of perception of the contrast. The IMSPAC test, was recorded by the male talker only. In addition to the recordings of normal talkers to be used in perception training and testing, recordings of hearing-impaired subjects' speech were made for later evaluation by normal hearing listeners.

The articulation test, preparation of recordings for the perception of the test stimuli, preparation of recordings of the subjects' productions of the test stimuli, and editing and digitizing of the tapes of the subjects' productions, will be described first. A description of the materials for the IMSPAC test, and preparation of the test recordings will follow.

/S/-/SH/ ARTICULATION TEST

The materials used for articulation testing consisted of minimal pairs of syllables, words, and sentences that differed only by the /s/-/sh/ contrast. The testing materials consisted of 12 pairs, giving a total of 24 stimuli, as shown in Table 3.1. For purposes of testing, the stimuli were presented in random order. A number of computer-generated randomizations (i.e., test forms) were used in this study.

Preparation of recordings for the test of perception of the /s/-/sh/ contrast

The perception test was administered from recorded materials. Two talkers, native speakers of English with North American accents, were recorded, one male and one female. DAT recordings were made within a single-walled IAC enclosure, using the ½ inch sound field microphone of a B & K sound level meter (2235). The microphone was placed 18 inches in front of, and in line with, the talker's mouth. The sound level meter was set to a random response and its AC output was recorded, using a Panasonic digital audiotape recorder (SV 255). The range of the sound level meter was set to 70-90 dB in order to maximize the signal-to-noise ratio. The speakers were instructed to read the test materials keeping the intonation pattern constant throughout the recordings and using the carrier phrase 'now say'. Each test

Table 3.1 Stimuli for /s/-/sh/ Articulation Test

Form A	Form B
plus	sore
plush	shore
eesee (isi)	sell some beans
eeshee (iʃi)	shell some beans
sew	cats
show	catch
save my legs	sea
shave my legs	she
my sack	oosoo (usu)
my shack	ooshoo (uʃu)
aasaa (asa)	what's a sole
aashaa (aʃa)	what's a shoal

item was spoken twice. For each pair of items, one was picked at random unless there was a problem with the articulation of one in which case the other one was chosen. The utterances were digitized at 22.5 KHz and 16 bits.

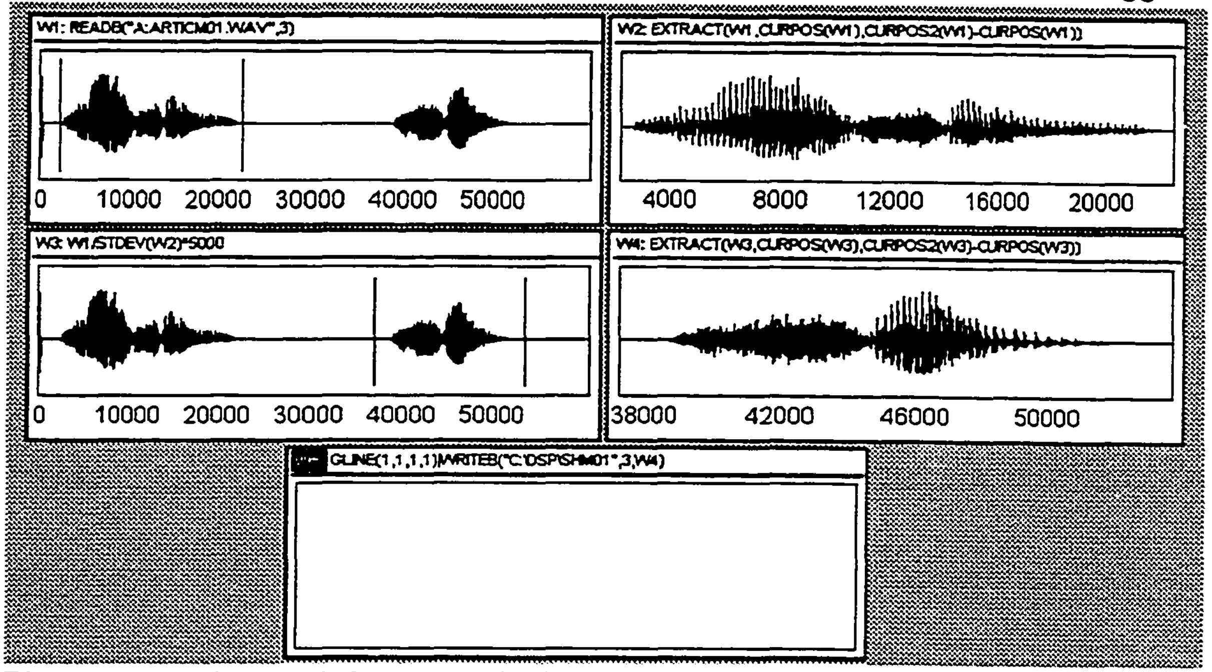
The digitized items were then normalized for intensity as follows:

1. The rms. level of the carrier phrase 'now say' was measured.

2. The rms. level of the complete utterance 'now say' + test stimulus was raised or lowered so that all the carrier phrases had the same rms. level.

3. The carrier phrase was then discarded and the normalized test word was saved in a separate computer file.

4. The processing was carried out in Dadisp - an array processing program from DSP corporation. Figure 3.1 shows the Dadisp worksheet used for intensity normalization of articulation test and training stimuli, and describes the window functions of the worksheet.



W1: READB("A:ARTICM01.WAV",3)

W2: EXTRACT(W1,CURPOS(W1),CURPOS2(W1)-CURPOS(W1))

W3: W1/STDEV(W2)*5000

W4: EXTRACT(W3,CURPOS(W3),CURPOS2(W3)-CURPOS(W3))

GLINE(1,1,1,1)|WRITEB("C:\DSP\SHM01",3,W4)

Figure 3.1 Dadisp worksheet used for intensity normalization of articulation test stimuli. Window functions are as follows:

W1: READB("A:ARTICM01.WAV",3)
Reads the digitized file from disc. Cursors are set to define carrier phrase
W2: EXTRACT(W1,CURPOS(W1),CURPOS2(W1)-CURPOS(W1))
Carrier phrase is extracted
W3: W1/STDEV(W2)*5000
Level of window 1 is adjusted so that rms level (i.e., standard deviation) of carrier phrase = 5000 digital units. Cursors are set to define test phrase.
W4: EXTRACT(W3,CURPOS(W3),CURPOS2(W3)-CURPOS(W3))
Test phrase is extracted
W5: GLINE(1,1,1,1)|WRITEB("C:\DSP\SHM01",3,W4)
Normalized test phrase is saved under a new name.

Preparation of recordings of subjects' productions of the /s/-/sh/ stimuli for off-line evaluation.

In order to evaluate the subjects' productions of the /s/-/sh/ stimuli it was necessary to edit the recordings of their speech so that they could be presented to listeners. A description of the process follows.

Editing and Digitizing of the Speech Production Tapes

1. Preparation of recordings of subjects' imitations of the /s/-/sh/ stimuli

During testing each subject wore a clip-on microphone and a DAT recorder to record the subject's production for later editing.

2. Editing

The subjects' imitations were digitized and edited to remove all but the subjects' utterances and each utterance was placed in a separate computer file. The utterances were digitized at 20 kHz and 12 bits.

IMSPAC

IMSPAC, a more general test of contrast perception and production, was administered to each subject at the beginning and end of the training program. In IMSPAC testing, the subject imitated a series of syllables obtained by using prerecorded models - produced by one of the speakers used in the /s/-/sh/ perception training and testing.

Materials

The IMSPAC test provides an estimate of the subject's ability to produce, by imitation, utterances that provide a listener with phonetically contrastive information. There are ten phonologically significant speech contrasts. Two are suprasegmental contrasts: intonation and syllable number. Eight are segmental contrasts: vowel height, vowel place, initial consonant voicing, initial consonant continuance, initial consonant place, final consonant voicing, final consonant continuance, and final consonant place. The ten contrasts are presented in pairs for a total of five subtests. A subtest consists of eight syllables, resulting in 40 syllables for each test form. There are four different forms of the test: A, B, C, and D. These are reproduced in Appendix A. For each form there is a different selection of test stimuli. The stimuli are chosen from the four response alternatives that will eventually be presented to listeners. For this project the existing version of IMSPAC was modified. The set of utterances for the syllable number and intonation subtest was changed to reflect all four vowels used in the other subtests, that is, /i/, /u/, /ɛ/, and /ɔ/.

Test recordings for IMSPAC stimuli

The instrumentation and recording equipment were the same as those described for the recording of the articulation test. For IMSPAC, however, only a recording of the male speaker was made. The speaker read the test materials keeping the intonation pattern constant throughout the recording (except for list 5 - syllable and intonation contrast). No carrier phrase was used for the recording of this test, and each test item was only spoken once.

Chapter 4

Method

OVERVIEW

Six hearing-impaired children were exposed to training on the /s/-/sh/ contrast during two training periods. One period was devoted exclusively to production of the contrast. The other was devoted exclusively to its auditory perception. These two training periods were separated, preceded, and followed by periods in which no formal training was given. At the beginning and end of each no-training period, two tests were administered - one to measure the accuracy of production of the /s/-/sh/ contrast, the other to measure the accuracy of its auditory perception. This basic design is illustrated in Figure 4.1.

In addition to tests of /s/-/sh/ contrast perception and production, a more general test of contrast production and perception (not involving the /s/-/sh/ contrast) was administered at the beginning of the first no-training period and at the end of the last no-training period. This test, labeled IMSPAC in Figure 4.1 served as a control for the possibility that any /s/-/sh/ improvements were simply by-products of increased attention and familiarity with the perception and production tasks. Note, also, that the /s/-/sh/ contrast test was administered one final time with subjects using their personal

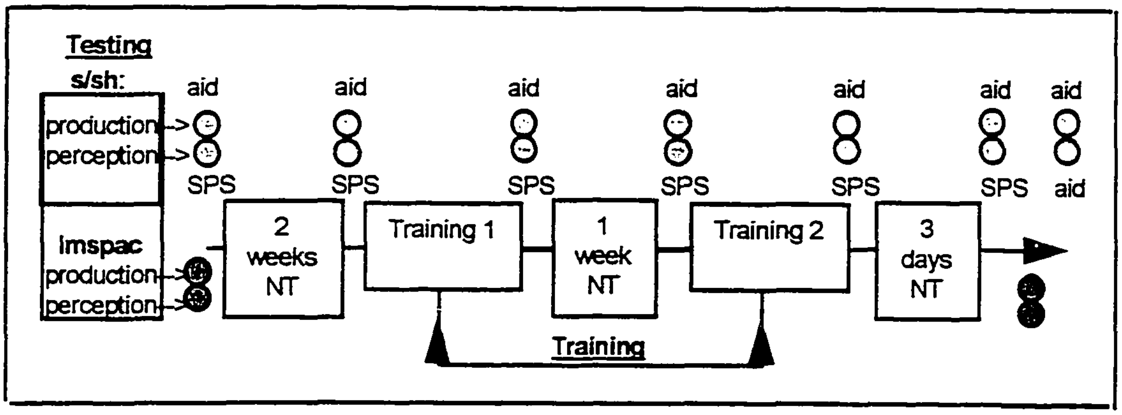


Figure 4.1 is a schematic illustration of the experimental design. Each circle represents a test. Each rectangle represents a treatment or no treatment period. (NT = no treatment; SPS = Stimulus Presentation System; Imspac = Imitative test of Speech Pattern Contrast Perception). Subjects wore their personal hearing aids for all production testing. They used the SPS for all perception testing except for the last testing session when they used their personal hearing aids.

hearing aids, instead of the Stimulus Presentation System (SPS), during the auditory perception testing. Subjects wore personal hearing aids during all production testing sessions.

SUBJECTS

Six hearing-impaired children with prelingually acquired sensorineural hearing losses, served as subjects. Ages ranged from 8.11 to 12.4 years. Mean age was 10.2 years. The three frequency, pure tone average threshold (500, 1000, and 2000 Hz) for the better ear, ranged from 58.3 to 95 dB HL.

The group mean was 81.11 dB HL (Table 4.1). Figure 4.2 shows the better ear audiograms for the 6 subjects. The children were enrolled in a school for the deaf that used a total communication program. The criteria for subject selection were as follows: prelingual deafness to avoid the effects of age-at onset of deafness; a 100 dB upper limit for hearing loss to ensure that the subjects had the necessary auditory capacity for the aided detection of /s/ and /sh/; an eight year lower age limit because of the need for the subjects to read the test materials. The subjects had no other recorded handicapping classification other than hearing impairment. In fact it became clear during the study that subject 1 and 3 had additional difficulties. In addition subject 2 had only limited educational experiences and limited hearing aid use.

Table 4.1 Demographic and audiometric characteristics of 6 experimental subject

Subject	Age	Gender	Etiology			Frequency (Hz)						
				Ear	PTA	250	500	1000	2000	4000	6000	8000
S1	8.11	M	Unknown	R	70	30	40	85	85	60	60	55
				L	82	25	45	95	105	115	NR	NR
S2	11.10	M	Unknown	R	92	75	85	95	95	110	NR	NR
				L	85	70	80	85	90	80	80	80
S3	9.5	M	Unknown	R	93	70	85	95	100	95	95	NR
				L	95	75	95	95	95	85	85	100
S4	10.5	M	Unknown	R	92	35	85	95	95	105	110	NT
				L	85	55	70	95	90	115	100	NT
S5	12.4	M	Unknown	R	58	25	40	65	70	55	65	65
				L	60	25	45	65	70	55	65	65
S6	10.1	F	Unknown	R	105	85	95	110	110	95	NT	110
				L	95	85	95	105	100	95	NT	100

NR= No response at maximum
NT= Not tested

Subject 1 has cerebral palsy,
Subject 2 had had limited formal education and had only worn hearing aids for eighteen months.
Subject 3 had been evaluated for medication to control attention deficits and hyperactivity.
These students were retained in the sample because of the limited availability of subjects.

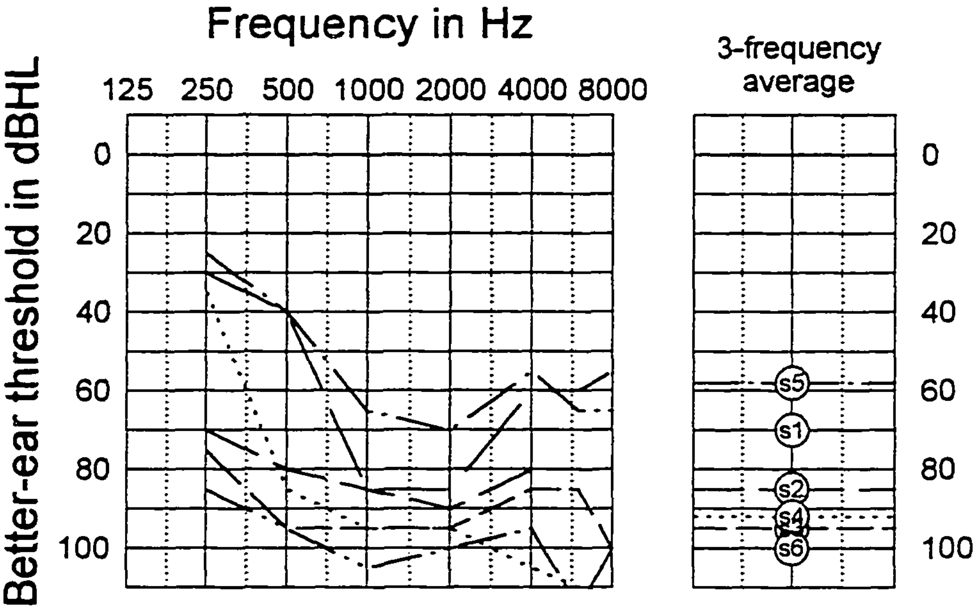


Figure 4.2. Better-ear audiograms of 6 experimental subjects.

INSTRUMENTATION SETUP

Instrumentation for perception and production training

A Toshiba T6400SX IBM compatible portable computer was connected to a Zeos IBM compatible portable computer through their serial ports. The Stimulus Presentation System (SPS) box was connected to a pro audio spectrum 16 bit soundboard which was in the Toshiba portable computer. The SPS contained a preamplifier with a volume control and level indicator. The output of the preamplifier was connected to a pair of power amplifiers capable of delivering 136 dB SPL from TDH 50 headphones. Passive attenuators, between the power amplifiers and the headphones permitted binaural adjustment of presentation level in 2 dB steps. The subjects wore headphones, (Telephonics TD50), through which they received the stimuli from the Toshiba soundboard which had been amplified by the Stimulus Presentation System #6. Stimuli from the Toshiba soundboard output was also fed into the tester's headphones (Seinheiser MD 414). The subject wore a Realistic clip-on microphone for the DAT recordings for the /s/-/sh/ articulation test and for IMSPAC. A portable printer was connected to the Zeos portable computer so that the subject data could be printed out. When subjects used their personal hearing aids stimuli were presented via a

Realistic Minimus 77 speaker. Figure 4.3 illustrates the instrumentation setup.

A digitized calibration tone was used to set the gain of the SPS box at the beginning of each session. To create the tone, eight syllable stimuli were first chosen from the recorded IMSPAC test. There were two samples used for each of the following vowels: /i/, /u/, /ɔ/, and /ɛ/. The stimuli ranged in intensity (measured as the rms. peak) by 7 dB, with a low of 72.5 to a high of 79.5 dB. The rms. value of the calibration tone was made equal to the peak value of the most intense vowel.

The /s/ indicator

The /s/ indicator used in this study was developed several years ago at the Clarke School for the Deaf by Marc Damashek (Boothroyd and Damashek, 1975). It is battery-operated and consists of a hand-held black box with a single button, a microphone port, and a single light. Holding the button turns the device on. Releasing the button turns it off. The user speaks a few inches from the microphone. Whenever a sound is received whose spectral content is primarily high frequency, the light is illuminated. The criterion for 'high' is set by a screwdriver adjustment on the back of the unit. In use, the device is set so that a clear /s/ illuminates the light, but a clear

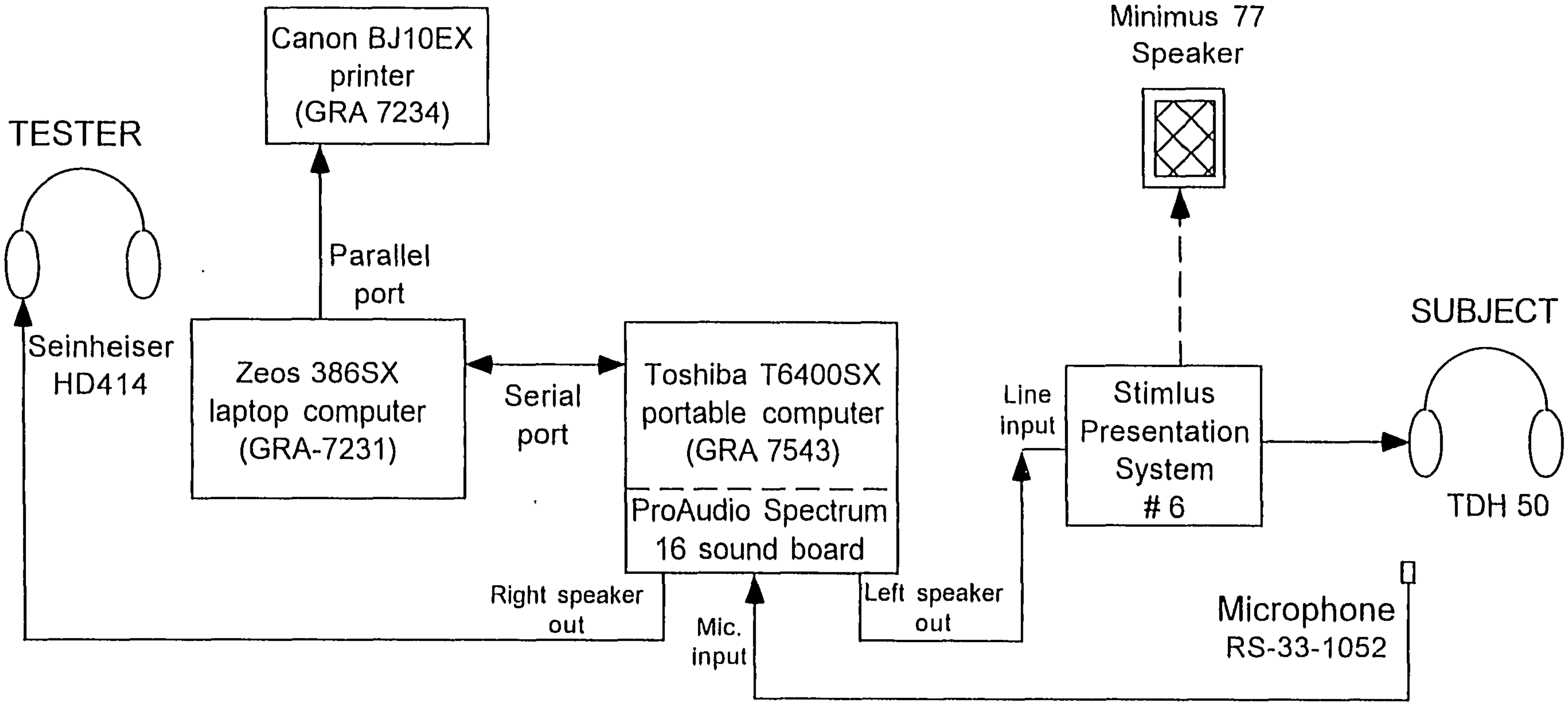


Figure 4.3 Instrumentation setup for speech training program

/sh/ does not. In this way the user can practice the production of word pairs such as 'sip' and 'ship' and ensure that an effective contrast is maintained between the /s/ and the /sh/. The device functions by counting the number of zero crossings in each 100 msec of the waveform. While it does not teach the user how to produce appropriate sounds, it can be helpful in rehearsing and consolidating correct productions, in a variety of contexts, once the articulatory gestures have been learned (Boothroyd, 1975).

SPEECH MATERIALS

The materials used for articulation training consisted of minimally contrasted pairs of syllables, words, and phrases, that differed only by the s/sh contrast, such as: sue' versus 'shoe.'

The complete set is shown in Appendix B.

TRAINING

General Training

Training took place during two periods, each lasting two weeks. During a single training period, each child was seen for 20 minutes per day over 8 consecutive school days. These training periods were preceded by one or two sessions in which the child was orientated to the tasks. Note that for subjects 1,3, and 5, production training was given before perception training. For subjects 2, 4, and 6, perception training was given before production training. Prior to the first session the training program was explained to the subjects and they were given the opportunity to participate or not participate in the program. During this session the subjects' speech awareness thresholds were determined using a broadband amplifier and headphones. This information was used for subsequent setting of the amplification system. During the second session the tester reviewed the vocabulary to be used in the training program, using written and visual materials.

Two test sessions occurred before Training A, between the two trainings, and after training B. This resulted in six test sessions during which the tests for perception and production of the /s/-/sh/ contrast were administered. The IMSPAC test was administered during the initial and after the final test sessions. An additional test session occurred at the end of the program when the subjects used their personal hearing aids. An attempt was made to provide two week no-treatment periods. However, practical constraints made it necessary to shorten these no-treatment periods on several occasions (see Figure 4.1).

Perception Training

Informal Training

Before beginning auditory training it was necessary to ensure that the subjects could read and understand all the information presented on the computer monitor. To accomplish this the subject was required to read a computer-generated minimally contrasted pair. This was followed by presentation of the text for only one member of that pair. The minimally contrasted pair was then generated again and the subject had to identify which member of the pair he had seen. The subject indicated his choice by pressing one of two marked computer keys. The subjects also signed which of the two phonemes they had seen in the stimulus, that is the, /s/ or /sh/. Some subjects also signed the complete utterance. During training the subject was given the option of making a judgment after more than one presentation of the minimally contrasted pair. For repetition of the pair he pressed a marked computer key. Throughout training, feedback on performance was given. A correct response was rewarded by one of a column of 12 computer-generated boxes being highlighted.

In the original experimental design subjects were expected to gain

100% on this task before moving to the auditory perceptual training. However, during the actual project this criteria was not met by subjects 2, 3, and 4. Subject 2 had difficulty doing the task because of poor reading skills. Subject 3's average score was 88%. Subject 4's average score was 66%. The trainer used this information to ensure that during formal training the subjects were focused before presentation of each stimulus. The trainer also used illustrations depicting each stimulus during training.

Formal Training

Stimuli were prerecorded and presented by computer from digital storage. The software presented the response alternatives, provided the feedback (highlighted column of computer-generated boxes), and saved the responses. The training and testing stimuli were recorded by one male talker and one female talker is described in Chapter 3. The subject read the text on the computer screen and listened to a computer-generated minimally contrasted pair. The subject then heard only one member of the pair. The computer then showed the text for the minimally contrasted pair on the monitor and the subject identified which one of the pair he had heard. The subject indicated his choice by pressing one of two marked keys.

Initially, the items were not randomized, the subjects were able to hear them in sequence, that is the six utterances with the 's' sibilant, followed by the six utterances with the 'sh' sibilant. The stimuli recorded by the male speaker were used first. When the subject scored 100% on the task, the stimuli were randomized. The same procedure was followed using the stimuli recorded by the female speaker. During each training session the subject received training using the recordings made by both the male and female speakers. Throughout the training feedback on performance via the computer was given. Feedback on performance was given in the same manner as for preparatory training.

Production Training

Informal Training

The subjects were trained to produce the /s/-/sh/ contrast in various contexts. Descriptive techniques such as describing how the phoneme is produced, visual materials such as drawings of the articulators, and instrumental techniques, such as the 's' indicator, were used to contrast production of the two phonemes. The /s/ indicator was described earlier in this chapter. The subjects were given feedback related to the production of the two phonemes, i.e., if the production was incorrect the tester analyzed which articulatory movements the subject had made, and of those, which articulatory movements were correct and which were incorrect. The tester then discussed with the subject what needed to be done to improve production. Subjects used their personal hearing aids during informal training and the SPS with headphones during computer-based training, but no attempt was made to draw attention to the acoustic properties of the sounds.

Training Hierarchy for Production of the /s/-/sh/ contrast

The following production skill hierarchy was followed:

1. Production of /s/ in isolation.
2. Production of /sh/ in isolation.
3. Randomized production of /s/ and /sh/ in isolation.
4. Production of initial /s/ in CV.
5. Production of initial /sh/ in CV.
6. Production of final /s/ in VC.
7. Production of final /sh/ in VC.
8. Production of initial /s/ in single words - CVC.
9. Production of initial /sh/ in single words - CVC

10. Production of final /s/ in single words - CVC

11. Production of final /sh/ in single words - CVC.

12. Production of medial /s/ in single words - VCV.

13. Production of medial /sh/ in single words - VCV.

14. Production of /s/ in 2-3 word phrases.

15. Production of /sh/ in 2-3 word phrases.

16. Production of /s/ and /sh/ in various word positions in sentences.

In order to encourage generalization of correct production of the /s/-/sh/ contrast, and to encourage subject participation, the subjects generated their own phrases and sentences in the later stages of training.

Computer- based training

The foregoing face-to-face training was supplemented with computer-based training. The equipment consisted of two computers connected via their RS 232 ports. One computer was in front of the student, and the other was in front of the tester. Neither could see the other's screen. The software was written for this project by E. Yeung and is presented in Appendix C.

The computer-based training procedure was as follows. The subject saw a computer-generated minimally contrasted pair on the screen, and then only one member of that pair was displayed. The subject was then required to say that stimulus. The tester listened to the subject's production and made a judgment as to which one of the minimal pair the subject had said. The tester pressed the computer key corresponding to that stimulus and that one was highlighted on the subject's monitor. If the stimulus chosen by the tester corresponded with the one on the subject's monitor then one of the computer-generated boxes, in a column of 12, on the right side of the subject's monitor, was highlighted. There were 12 trials and 12 possible correct responses. The number of highlighted boxes showed the number of correct responses. If the subject's production of the sibilant was judged incorrect by the tester then the minimal pair was generated again with the correct one highlighted. The setup showing the subject's computer monitor with some of the computer-generated boxes highlighted is shown in Figure 4.4. Initially the items were not randomized, that is, the utterances using the 's' sibilant were followed by the utterances using the 'sh' sibilant. During later presentations the stimuli were randomized.

Maintaining subject motivation during both perception and production training

In addition to immediate feedback on performance during the training, tangible reinforcers were given after participation in each of the training and testing sessions. The tangible reinforcers used were subject- dependent. Subject 5 completed the program without any tangible reinforcers. Subject 2 was on a behavior modification program and received tickets for each activity he completed during the school day. During this speech training program he received up to five tickets for each session, but the exact number depended on his level of participation. If participation was poor he received four tickets and if participation was excellent he received a bonus ticket. The other four subjects received a tangible reinforcer at the end of each session. A variety of reinforcers were offered and each subject was able to choose which one he wanted. Reinforcers were changed frequently to maintain interest.

No-training periods

In the original experimental design there was a two-week no-training period between training 1 and training 2. However, real world scheduling constraints allowed for only a one week no-training period between the two training periods.

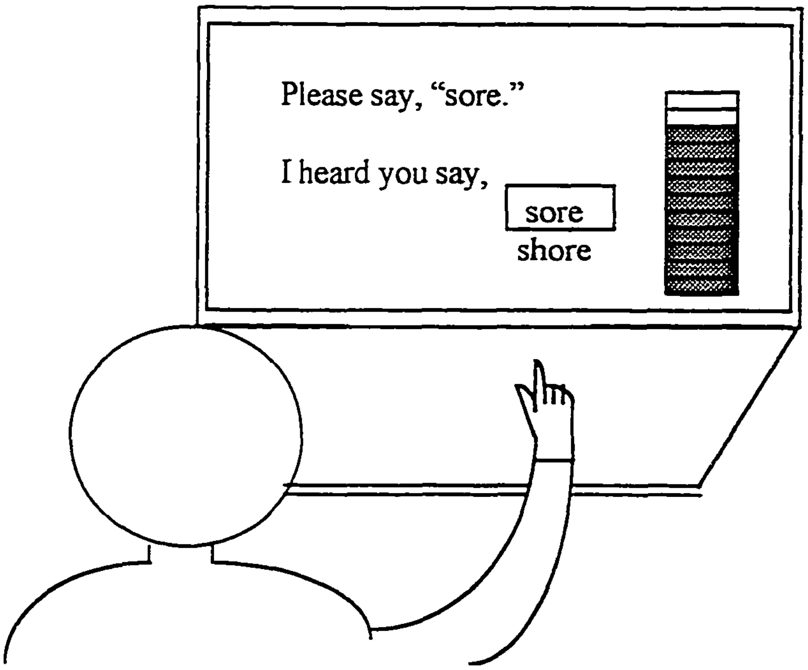


Figure 4.4 shows the subject's view of his computer monitor with his response and some of the computer-generated boxes highlighted.

TESTING

Test Session - Pre 1

This occurred two weeks before training. The IMSPAC test, and the tests for perception and production of /s/-/sh/ were administered.

Test Session - Pre 2

This occurred one day before Training 1. The tests for perception and production of the /s/-/sh/ contrast were administered

Test Session - Mid 1

This occurred one day after Training 1. The tests for perception and production of the /s/-/sh/ contrast were administered.

Test Session - Mid 2

This occurred one day before Training 2. The tests for perception and production of the /s/-/sh/ contrast were administered.

Test Session - Post 1

This occurred one day after Training 2. The tests for perception and production of the /s/-/sh/ contrast were administered.

Test Session - Post 2

This occurred five days after Training 2. The tests for perception and production of the /s/-/sh/ contrast were administered.

Test Session 7

The IMSPAC test was administered six days after Training 2.

Test Session - Post 3

The test for perception of the /s/-/sh/ contrast was administered with the subjects using their personal hearing aids. This session was an additional follow-up test for the test of production of the /s/-/sh/ contrast.

Amplification used during perception testing

During perceptual testing the subjects used broadband amplification (SPS). The stimuli were amplified by a broadband amplifier and were presented to the subjects binaurally through headphones. The attenuators in the SPS box permitted adjustment of listening levels which are shown in Table 4.2. The listening level was based on the subject's awareness

Table 4.2 Audiometric Output Levels

Output level was adjusted for each subject using the Stimulus Presentation System

	Pure Tone Average		Output level - based on the subject's awareness threshold, or highest comfortable levels.	
Subject Number	Right Ear (dB HL)	Left Ear (dB HL)	Right Ear (dB SPL)	Left Ear (dB SPL)
1	70	82	115	130
2	92	85	125	130
3	93	95	125	125
4	92	85	136	136
5	58	60	100	105
6	105	95	136	136

threshold, or highest comfortable listening levels.

Perception testing for /s/-/sh/ contrast

Only the test stimuli were used during testing (i.e. the additional training stimuli were not used). The subject heard the computer-generated minimally contrasted pair and simultaneously saw the pair in print on the monitor. Then the subject heard only one member of the pair. The subject saw the pair on the monitor again and had to identify which one of the pair he had heard. In order to obtain response reliability the particular response required was subject-dependent. Subject response could be by item number, signing the utterance, and/or signing the phoneme, that is, /s/ or /sh/. The tester keyed in the subject's response on the tester's computer. The subject received no feedback on performance.

Hearing aid condition

After the final testing session with the SPS box the subjects used their personal hearing aids for an additional test of speech perception and speech production. Personal hearing aids were checked auditorily before the testing to ensure that they were in good working order. Specifically, Ling's five sound test and a stethoscope were used to check the hearing aids.

Instrumentation and procedure for production testing of the /s/-/sh/ contrast

Only the test stimuli were used during testing (i.e. training materials were not included). The computer-generated a minimally contrasted pair which was shown on the screen and was followed by only one member of the pair being shown. The subject's task was to say that one. A clip-on microphone and a DAT recorder were used to record the subject's production for later editing. The subject received no feedback on performance.

IMSPAC

Instrumentation

The IMSPAC test materials and preparation of test recordings of the stimuli were described in the previous chapter. For this experiment the tester and the subjects used the same back-to-back two-computer system that was used during perception and production training and testing for the /s/-/sh/ contrast. Noise was presented in the tester's headphones during stimulus presentation of each IMSPAC stimulus to prevent the tester from hearing the auditory signal presented to the child.

IMSPAC Testing

In a single test session, IMSPAC was administered twice. The first time input consisted of sound and vision, (in this experiment sound and print). The subject heard the utterance, and read the item on the computer monitor. The second time input consisted of sound alone. The subject's imitations of the utterance were recorded during both conditions for later editing. For each of the subject's imitations (in this experiment) the tester also made an on-line computer-based decision, within a four-alternative forced-choice format.

Testing and Training Conditions for the Articulation Test and for IMSPAC

The training and testing were administered in a small room by the side of the stage in the school auditorium. The room was not sound treated, and there was a four foot square opening in one of the walls, from which the stage could be viewed. The auditorium was used by the school faculty and students throughout the day while the speech training and testing program was proceeding. This was far from ideal but was all that could be made available within the school's space and scheduling constraints.

Off-line evaluation of recordings for production testing of the contrast

Listeners

Four normal hearing adults, native speakers of English, served as listeners in the study and audited the recordings of all 6 subjects. All listeners were recruited from the Ph. D. Program in Speech and Hearing Sciences at the City University of New York. None of the listeners were familiar with the children's speech, their background, or their audiological status.

Evaluation of Production Tapes for the /s/-/sh/ contrast

Stimuli were presented binaurally to the four hearing listeners at a comfortable output level, through headphones, in a quiet room. Each listener was given a sheet with instructions that described the listening task. The test stimuli were presented to the listeners in a binary choice task. The listener heard a test item and was presented with two response alternatives.

For example:

Stimulus: asa

Responses: 1. asa 2. asha

The subject circled the chosen response on the answer form (see

Appendix D for sample form). The order of the speech tapes was randomized for presentation for both subject and test session. Unlimited repetitions of the utterances were permitted on the listening task.

Evaluation of IMSPAC Recordings

Stimuli were presented to the four hearing listeners binaurally at a comfortable output level through headphones in a quiet room. Each listener was given a sheet of instructions that described the listening task (see Appendix E). The listener saw four response alternatives and had to choose which one she thought the child was trying to produce. The listener pressed the appropriate response key on the computer. The computer program allowed for one repetition of the utterance. Before data collection began, the normal hearing listeners were presented with practice recordings for the testing format in order to familiarize them with the procedure and the listening task, and to establish inter-listener reliability (Eran 1996). Two practice recordings were used. One was of a hearing-impaired child taken from the hearing - aid user database for IMSPAC. The second recording was of a normal hearing speaker and is also used as part of the standard test protocol. The criteria for inter-listener reliability for each of the two recordings was a composite IMSPAC score within +/- 10%. All four listeners scored within the target criterion, and as a result, additional training was not provided. The order of the tapes was randomized for presentation to the listeners for both subject and test session.

TREATMENT OF THE DATA

General

Answers to the research questions were based on the results of the tests of production and perception for the /s/-/sh/ contrast. Each subject provided scores on these tests at seven points in the protocol (see, also Figure 3.1):

Scores on the contrast test were expressed in several ways:

1) An /s/ score, p_s = proportion of /s/ responses to /s/ targets.

2) An /sh/ score, p_{sh} = proportion of /sh/ responses to /sh/ targets.

3) A contrast score, $p_c = (p_s + p_{sh})/2$

4) A bias score, $p_b = (p_{sh} - p_s)$

In the case of the perception test, separate scores were obtained for the male and the female talker. These scores were also averaged to provide a general perception score.

RESEARCH QUESTIONS

Question 1: Does perception and production performance for the /s/-/sh/ contrast improve in the course of a program of perception and production training geared solely to this contrast?

This question was addressed for the group by tracking group mean scores as a function of testing sessions. In the case of perception a 5-way repeated measures analysis of variance for order of training, sibilant, talker gender, subject, and test session (time) was used to determine the significance of performance changes over time for the means of the population represented by this sample. A simple 5-way analysis of variance was used to determine the significance of performance changes over time for perception for this sample of subjects.

A 4-way repeated measures analysis of variance and a 4-way simple analysis of variance was used to determine the significance of performance changes over time for the production data.

Question 2. Are any performance improvements for perception or production of the /s/-/sh/ contrast greater during training than during no-training periods?

This question was addressed by examining the group mean scores of all testing sessions. Post Hoc testing was used to determine if there were any significant change in test scores between the testing sessions.

Question 3. Are any performance improvements for perception or production of the /s/-/sh/ contrast within training periods dependent on the type of training being given (perception versus production training)?

This question was addressed for both perception and production through the repeated measures analyses by examining the interaction between training order (perception first versus production first) and time (i.e. session number).

Question 4. Are differences in performance as a function of session for perception and production of the /s/-/sh/ contrast similar across subjects?

This question was addressed for both perception and production through the simple analyses by examining the interactions between subject and time.

Question 5. Are similar improvements seen in perception and production tasks with which the subjects did not have training (i.e. IMSPAC)?

A 1-way repeated measures analysis, using group mean scores for the segmental contrasts for audition alone, was used to determine if there were significant changes in perception performance between pre and post testing.

A 1-way repeated measures analysis, using group mean scores for the segmental contrasts for audition+vision, was used to determine if there were significant changes in production performance between pre and post testing.

Two additional questions concerned perception training for the /s/-/sh/ contrast:

Question 6. Does perception performance, or changes in perception performance, differ for the two talkers?

This question was addressed through the 5-way repeated measures analysis of variance for this sample of the population. The 5-way simple analysis was used to address the question for this group of subjects.

Question 7. After training how do personal hearing aids compare with broadband amplification in terms of perception of the /s/-/sh/ contrast?

This question was addressed by examining the group mean scores for the testing sessions through the 4-way repeated analysis. Post Hoc testing was used to determine if there were significant differences in scores between Post 1 and Post 3, and between Post 2 and Post 3.

Summary of research analysis design

This is a mixed between- and within-group (repeated-measures) design. The grouping variable is training order represented by two levels (perception training first and production training first). There are two dependent variables - perception performance and production performance. For the perception performance analysis there are three repeated measures - talker at two levels, sibilant at two levels, and time (or session) at seven levels. In addition there was a control task (IMSPAC) for general learning effects, and a substudy (perception via broadband amplification versus personal hearing aids). The 5-way repeated-measures analysis addressed the significance of effects for the means of the population represented by this sample and the 5-way simple analysis addressed the significance of effects for this group of subjects.

For production performance analysis there are two repeated measures - sibilant at two levels, and time (or session) at seven levels. The control task for general learning effects used for perception performance was also used for production performance. The 4-way repeated analysis addressed the significance of effects for the means of the population represented by this sample and the 4-way simple analysis addressed the significance of effects for this group of subjects.

Chapter 5

Results

5.1 Raw Data

The raw data, expressed as percent correct score without correction for guessing, are shown in the Appendices. Appendix F contains the /s/-/sh/ perception data. Appendix G contains the production data. Appendix H contains the IMSPAC data, which includes both perception (i.e., audio-only) and production (i.e., audio-visual) scores.

5.2 Analysis of Variance in the perception data

Table 5.1 shows the results of analyses of variance in the scores on the /s/-/sh/ perception test. Two analyses are shown. In both analyses, order of training (perception-first or production-first) is treated as a grouping variable, with three subjects in each group.

In the first analysis, talker (male or female), sibilant (/s/ or /sh/), and time (i.e., test session) are treated as repeated measures. This analysis estimates the probability that observed differences can be explained by random variability among subjects. Any conclusions of significance, therefore, relate to the means of the population from which these subjects are assumed to be randomly sampled.

Table 5.1. Analyses of variance in the perception results for 6 subjects.

Source of	Sum of	Degrees of	Mean	Repeated-measures analysis				Simple 5-way analysis			
Variance	Squares	Freedom	Square	Error term	F	p		Error term	F	p	
O(Order)	200	1	200	SW	0.06	0.81306		GSTxSW	1.06	0.31400	
G(Gender)	3057	1	3057	GxSW	0.99	0.37667		GSTxSW	16.22	**0.00060**	*
S(Sibilant)	279	1	279	SxSW	1.12	0.34990		GSTxSW	1.48	0.23560	
T(Time)	17625	6	2938	TxSW	6.80	**0.00026**	*	GSTxSW	15.58	**0.00000**	*
OG	200	1	200	GxSW	0.06	0.81190		GSTxSW	1.06	0.31350	
OS	2026	1	2026	SxSW	8.11	**0.04647**	*	GSTxSW	10.75	**0.00320**	*
GS	372	1	372	GSxSW	9.79	**0.03520**	*	GSTxSW	1.97	0.17330	
OT	1131	6	188	TxSW	0.44	0.84744		GSTxSW	1.00	0.45410	
GT	2117	6	353	GTxSW	0.63	0.70677		GSTxSW	1.87	0.12770	
ST	1422	6	237	STxSW	0.48	0.81577		GSTxSW	1.26	0.31680	
OGS	200	1	200	GSxSW	5.27	0.08337		GSTxSW	1.06	0.31350	
OGT	5066	6	844	GTxSW	1.50	0.22001		GSTxSW	4.48	**0.00360**	*
OST	3380	6	563	STxSW	1.14	0.36819		GSTxSW	2.99	**0.02520**	*
GST	1191	6	198	GSTxSW	1.05	0.41719		GSTxSW	1.05	0.41880	
OGST	714	6	119	GSTxSW	0.63	0.70366		GSTxSW	0.63	0.70480	
SW	12546	4	3137					GSTxSW	16.64	**0.00000**	*
GxSW	12388	4	3097					GSTxSW	16.43	**0.00000**	*
SxSW	999	4	250					GSTxSW	1.32	0.29100	
TxSW	10371	24	432					GSTxSW	2.29	**0.02380**	*
GSxSW	152	4	38					GSTxSW	0.20	0.93590	
GTxSW	13493	24	562					GSTxSW	2.98	**0.00490**	*
STxSW	11825	24	493					GSTxSW	2.61	**0.01120**	*
GSTxSW	4524	24	188								
Total	105278	167	630								

SW=Subject within order-group

* = significant interaction p<0.05

In the second analysis, subject is treated as fixed effect and the 5-way interaction between order, talker, sibilant, time, and subject-within groups provides the error term for all estimates of F ratio. This analysis estimates the probability that observed differences can be explained by random test-retest variability within subjects. Any conclusions of significance, therefore, relate only to the means for individuals or to the means for this specific sample of subjects. The second analysis is included because of the small sample size, the presence of large inter-subject differences, and the obvious violation of the random-sampling assumption. Genuine effects that are present in all or some of these six subjects might be obscured in the repeated-measures analysis.

5.3 Changes in perception performance over time

5.3.1 Accuracy of /s/-/sh/ perception

Accuracy of contrast perception is indicated by the percentage of occasions on which a sibilant was correctly identified. In other words, it is the average of the percent correct scores for /s/ and /sh/. Note that this score is not affected by response bias which, though it would cause an increase in score for one sibilant, would produce a corresponding decrease in score for the other.

Figure 5.1 shows the group mean accuracy of sibilant perception,

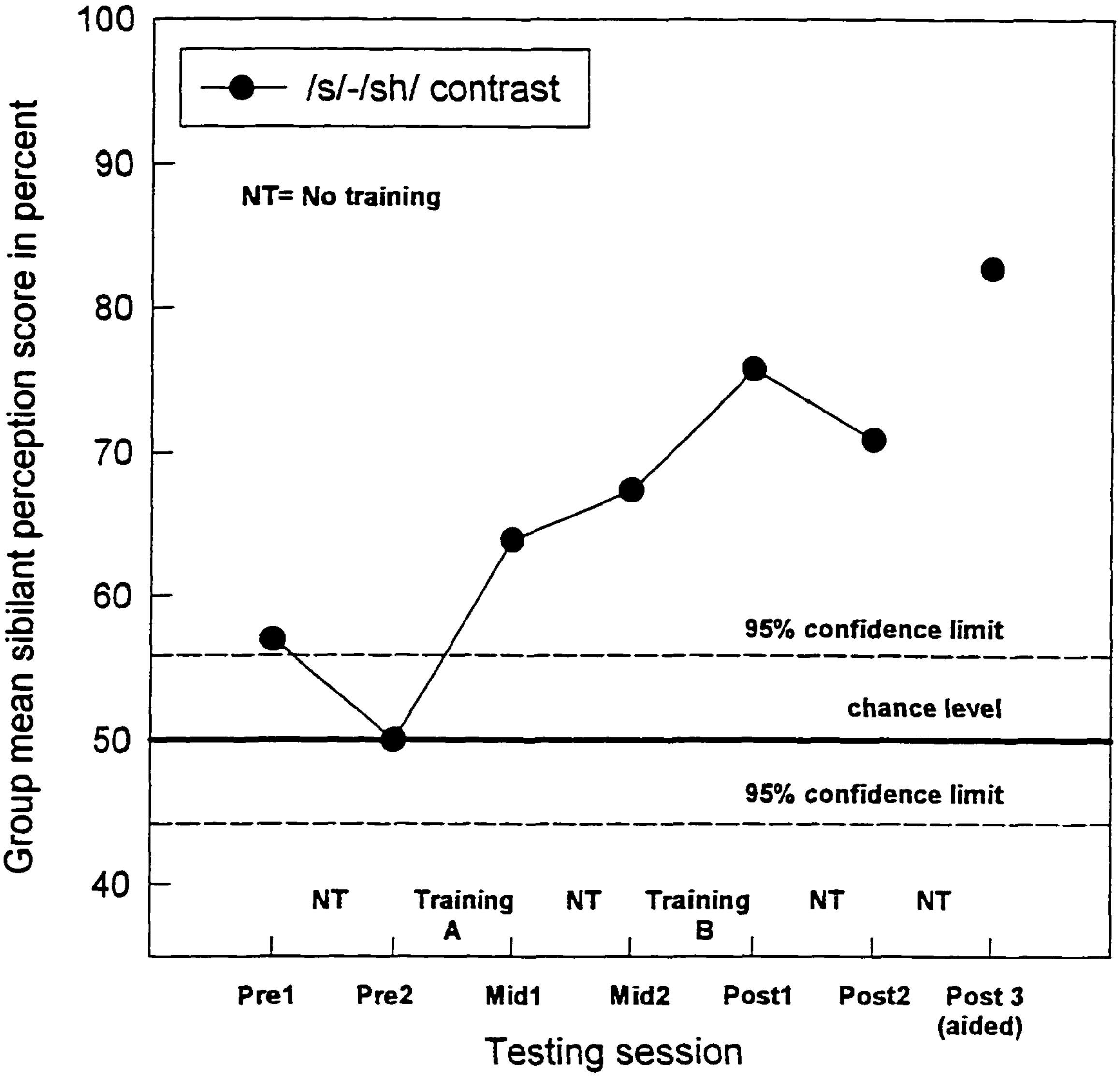


Figure 5.1 shows mean percent scores for the perception of the /s/-/sh/ contrast, for the group, as a function of test session. Data are collapsed across male and female talkers. Note that a score of 50% represents random guessing. Dashed lines show 95% confidence limits for scores expected on the basis of random guessing on every trial, (based on normal approximation to the binomial distribution for p=0.5 and n=288).

collapsed across talker and subject, as a function of test session. Also shownare the 95% confidence limits for scores that would be expected if every subject were guessing on every trial. These confidence limits are based on the normal approximation to the binomial distribution for a guessing probability of 0.5 and 288 trials per score (12 tokens x 2 sibilants x 2 talkers x 6 subjects).

It will be seen from Figure 5.1 that the group mean sibilant score was at or near chance levels at the beginning of the study and rose to around 75% correct by the end of the study. (Note that we are, for the time-being, ignoring the final test score which was obtained via personal hearing aid). Both the repeated-measures and the simple 4-way analysis of Table 5.1 confirm the significance of the main effect of time. In other words, the differences among the group mean scores at the various test sessions cannot be attributed either to test-retest variability within subjects or to random variability among test subjects. Moreover, the pattern of change is, clearly, one of increasing score once training has begun. In post-hoc testing, (using data from the simple 5-way analysis and the least-significant difference test) all scores are significantly higher than either of the pretest scores by the first mid-test session ($p<0.05$).

These data support the conclusion that group mean performance on the /s/-/sh/ contrast test improved during the course of this study. Moreover, it may be concluded that the same would be true for the mean of the population represented by these subjects when exposed to the same program of training and evaluation.

5.3.2 Bias in /s/-/sh/ perception

Response bias is indicated by the difference between the /s/ and /sh/ scores. The difference is illustrated in Figure 5.2 which shows the group mean % correct recognition for /s/ and /sh/ separately. At the first pre-test, there is a tendency for group mean responses to be biased towards /sh/. After this, however, there is little evidence of a consistent bias for the group as a whole.

In the repeated-measures analyses of Table 5.1, it will be seen that sibilant failed to reach the 5% level of significance, either as a main effect or in interaction with time. There is, therefore, no evidence to support the conclusion that there was a general group bias or that the pattern of change over time was different for the two sibilants.

There is, however, a significant interaction between sibilant and order of training, suggesting the presence of general bias in at least one group. Figure 5.3 shows the difference in bias between the two sibilants at each

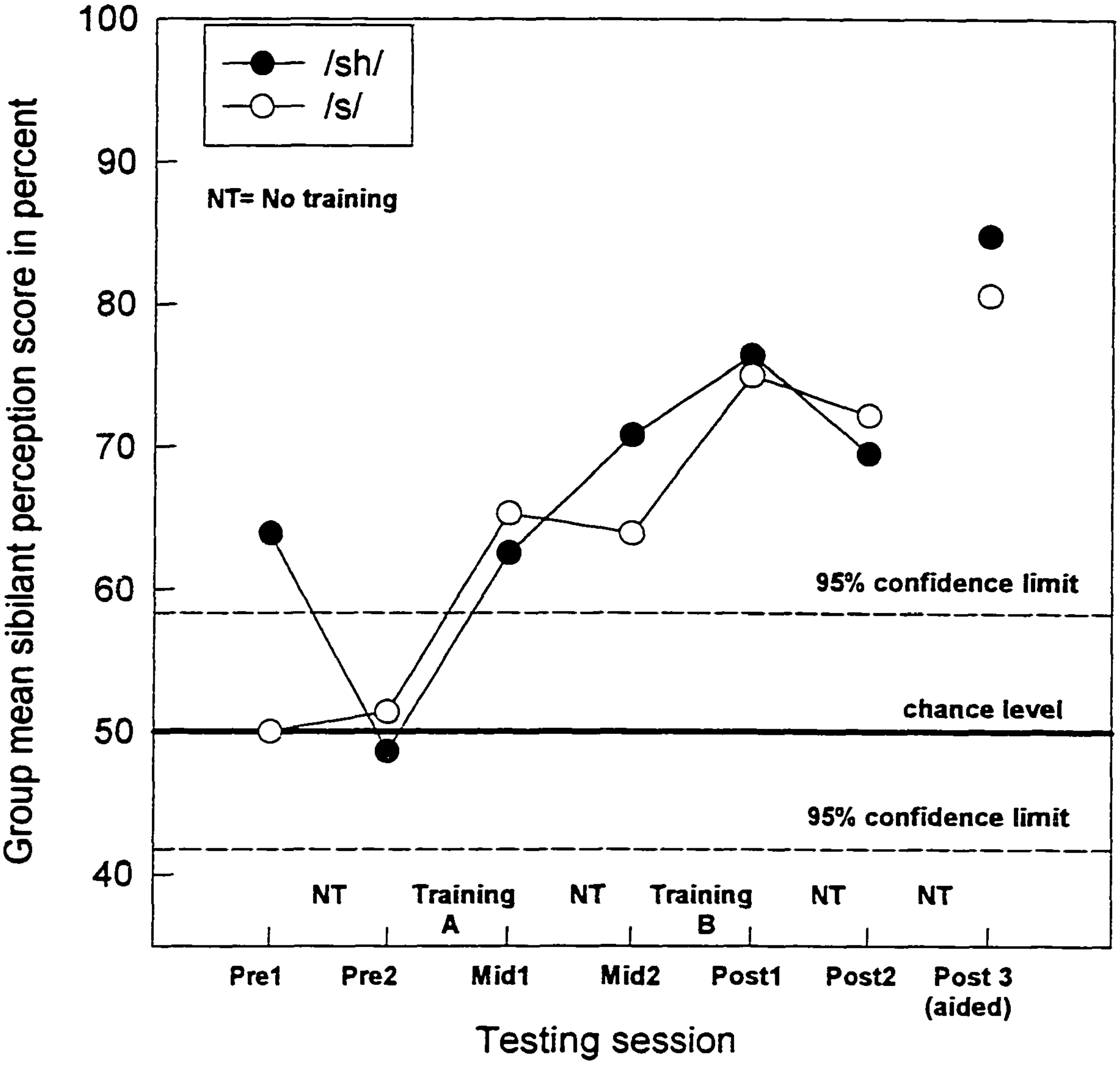


Figure 5.2 shows mean percent scores for the perception of the /s/ and /sh/,for the group, as a function of test session Data are collapsed across male and female talkers. Note that a score of 50% represents random guessing. Dashed lines show 95% confidence limits for scores expected on the basis of random guessing on every trial, (based on normal approximation to the binomial distribution for p=0.5 and n=144).

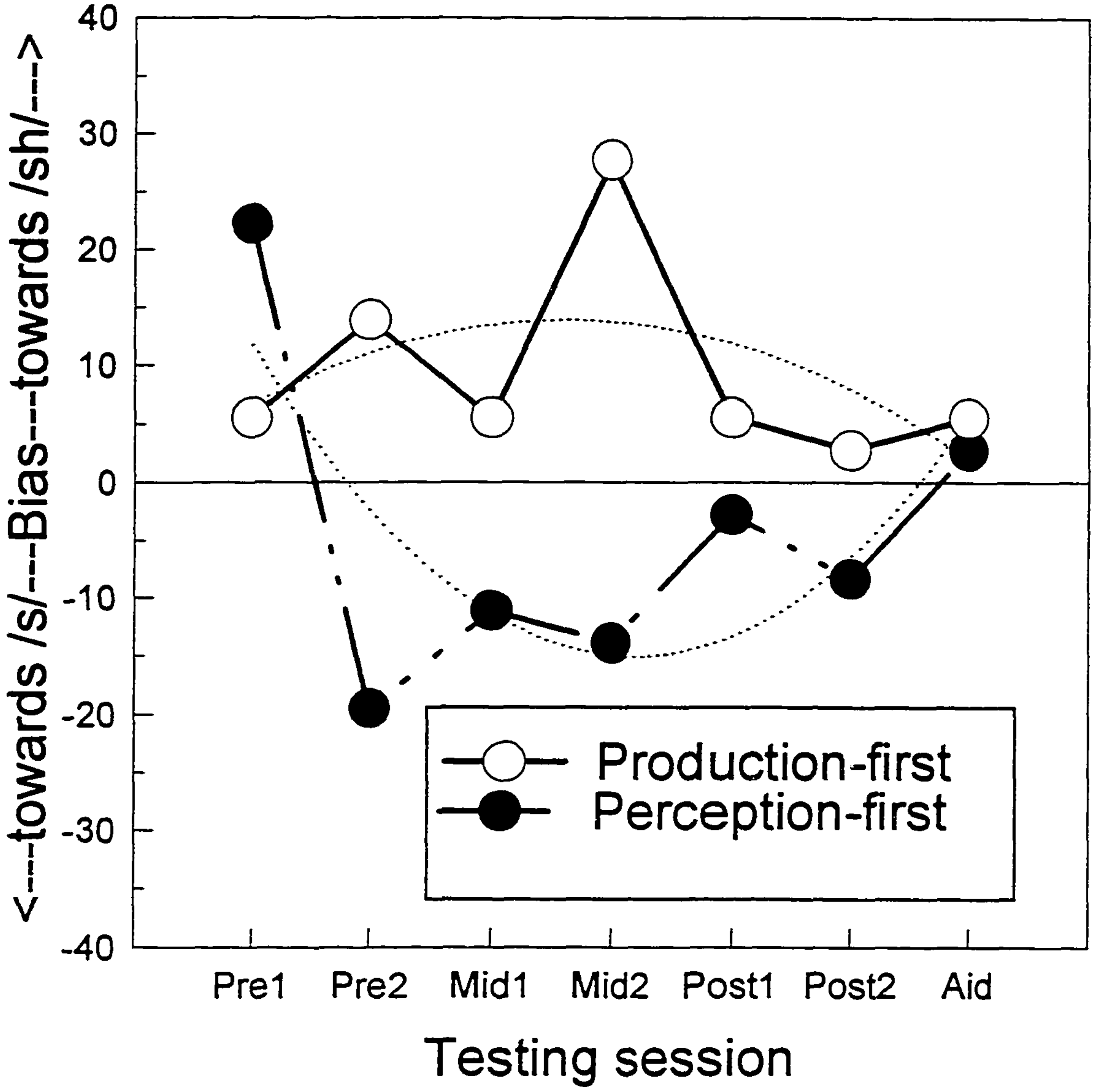


Figure 5.3 shows the difference in bias between /s/ and /sh/ at each testing session for the two groups. The dotted lines show second order regression

testing session for the two groups. The group receiving production training first showed a bias towards /sh/ (72% versus 63%) whereas the other group showed a bias towards /s/ (67% versus 63%). These effects tend to cancel each other when the six subjects are examined as a single group.

Evidence for a difference between the two order groups in terms of change of bias over time is provided by a significant interaction between order, sibilant, and time. This effect appears only in the simple 4-way analysis of Table 5.1 and cannot, therefore, be assumed to apply to the means of the population from which these subjects are sampled. The effect is illustrated in Figure 5.4 which shows the difference between /s/ and /sh/ scores as functions of time for the two groups. It will be seen that the opposing biases tended to be greater towards the beginning of the study and to diminish later in the study. Most probably, the differences between the two groups, both overall, and as a function of time are attributable to the assignment of subjects to the groups rather than to training order itself.

5.3.4 Combined accuracy and bias plot for perception data.

Figure 5.4 represents an alternative method of illustrating changes of accuracy and bias across test sessions. The probability of responding correctly to an /s/ is plotted on the y axis and the probability of responding correctly to an /sh/ is plotted on the x axis. Each data point is based on the

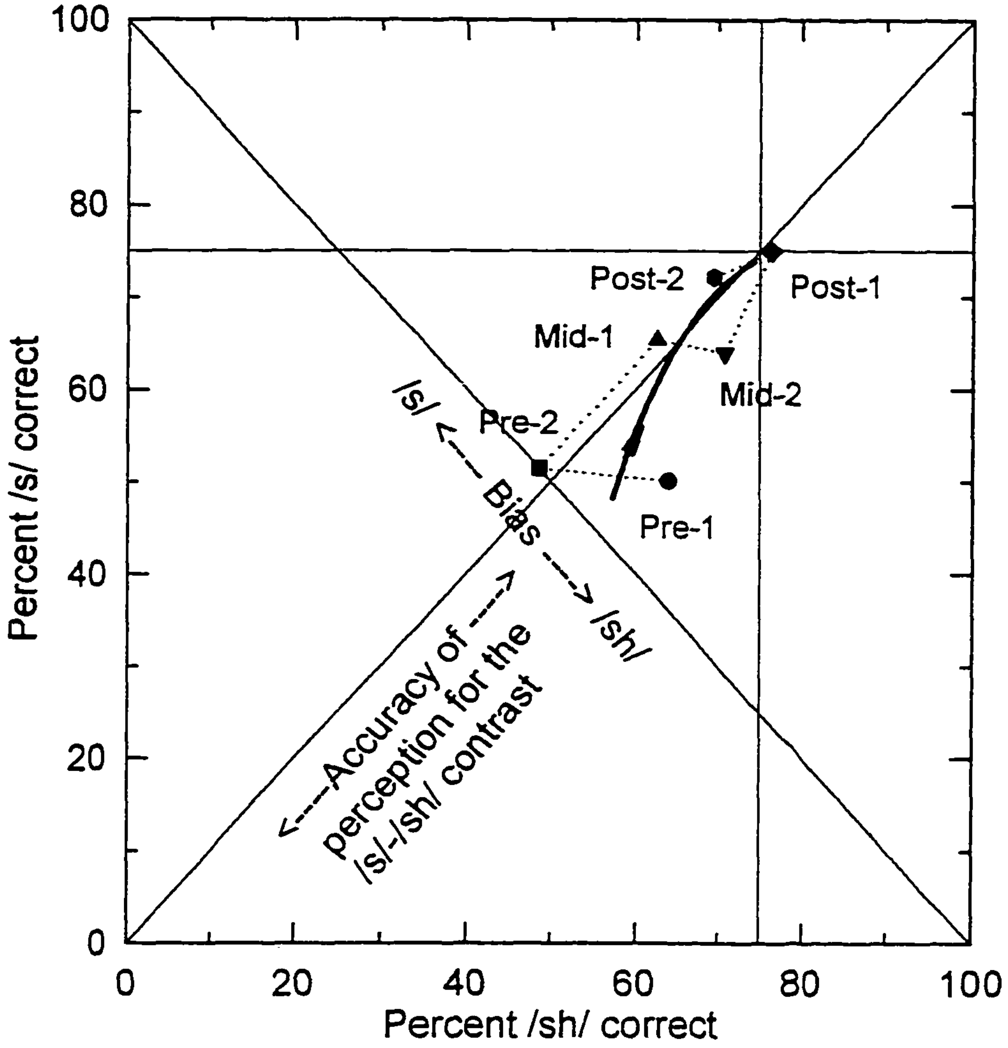


Figure 5.4 shows mean scores for the group obtained on the /s/-/sh/ perception test for six sessions. The solid curve shows a smoothed 'learning' curve. The mean data show an 'ideal' pattern. Initial scores are close to chance with a small /sh/ bias and end close to the 75% criterion for both /s/ and /sh/.

group means for a single test session. Note that the data for the final test session (personal hearing aid) are not included. The solid curve shows the estimated group learning trajectory and is derived as follows. The data for /s/ score as a function of session number were fit with a second order polynomial function using a least squares procedure. The data for /sh/ score were fit the same way. These two curves provided predicted /s/ and /sh/ scores as functions of time. The predicted /s/ score at a given time was then plotted as a function of the predicted /sh/ score at that time. The result is a best-fitting curve in a 2-dimensional space. Note, that in this representation, changes along the rising diagonal represent changes in accuracy of contrast perception, with chance performance at the 50% point. Data points above this diagonal represent bias towards /s/ while data points below it represent bias towards /sh/.

Figure 5.4 illustrates in a single plot, the group improvement of /s/-/sh/ contrast score during the study, together with small /sh/ bias at onset which is eliminated as the study progresses.

5.3.5 Summary of accuracy and bias results for the perception task

On the basis of these data it may be concluded that group mean performance on the /s/-/sh/ perception task improved during the course of this study, going from near chance levels before training, to around 75% correct after training. There was no evidence of a significant response bias for the group as a whole. There was evidence, however, to indicate that the two order groups were biased in opposite directions and that these biases tended to diminish during the course of the study.

5.4 Effects of training

If training is primarily responsible for the changes in performance on the speech perception task, then we would expect greater change during training periods than during no-treatment (control) periods. To test this prediction, additional post hoc testing was carried out on the main effect of time (test session) in Table 5.1.

From the residual error term of the simple 5-way analysis, it was determined that two means needed to differ by 7.9 percentage points or more to reach significance at the 5% level. Applying this criterion to pairs of consecutive means demonstrates significance for changes during the two training periods (13 and 9 percentage points) but not for changes during the three no-treatment periods (-7, +4, and -5 percentage points).

These data provide evidence in support of the conclusion that the training contributed to the improvements in scores obtained on the /s/-/sh/ perception task during the study.

5.5 Effects of type of training

If one type of training was more effective than the other in terms of improving scores on the /s/-/sh/ perception task than the pattern of change over time would be different for the two order groups. In other words, we would expect a significant interaction between order (production training first versus perception training first) and time (test session). In fact, this interaction fails to reach the 5% level of significance in either the repeated-measures analyses or the simple 5-way analysis of Table 5.1. These data do not, therefore, support the conclusion that the specific type of training was important in terms of enhancing accuracy of performance on the /s/-/sh/ contrast test.

As indicated earlier (Section 5.3 and Figure 5.3) there was a significant interaction between sibilant, order, and time, indicating that the pattern of change in bias over time was different for the two order groups. The fact that the two groups began with biases in different directions, however, suggests that this finding may reflect inherent differences between the two groups, rather than a differential type of training effect.

5.6 Individual differences in perception performance

5.6.1 Individual change of accuracy over time

The simple 5-way analysis of Table 5.1 shows a significant interaction between time and subject within the group. In other words, subjects differed in terms of the pattern of change in accuracy of performance over time. The differences are illustrated in Figure 5.5 which shows accuracy as a function of test session for each of the 6 subjects. This figure parallels the group data of Figure 5.1 except that the estimated confidence limits for random guessing (+/- 14.3 percentage points) are based on only 48 trials per session (12 tokens x 2 sibilants x 2 talkers)

It will be seen from Figure 5.5 that, with one exception, all of the pretest scores were at or close to chance levels[1]. Moreover, all subjects showed a general pattern of improvement over time. There were notable differences, however, in terms of scores at the end of the study and in the time taken to exceed chance performance.

5.6.2 Individual changes of bias over time

The simple 5-way analysis of Table 5.1 shows a significant interaction between time, sibilant, and subject within group. In other words, subjects differed in terms of the pattern of change in bias over time.

These differences are illustrated in Figure 5.6 which shows individual plots of /s/ score versus /sh/ together with best-fitting learning trajectories. This Figure parallels the group data of Figure 5.4. It will be seen that the

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[1] The exception is the first pretest for subject 5(OG) on which he scored 80% correct. This high score is completely out of line, not only with the other subjects' scores, but also with this subject's second pretest score which was at chance levels. Note, however, that a similar dramatic drop was observed for this subject between the first to second mid-tests. The most likely explanation is good inherent discrimination capacity but erratic attention.

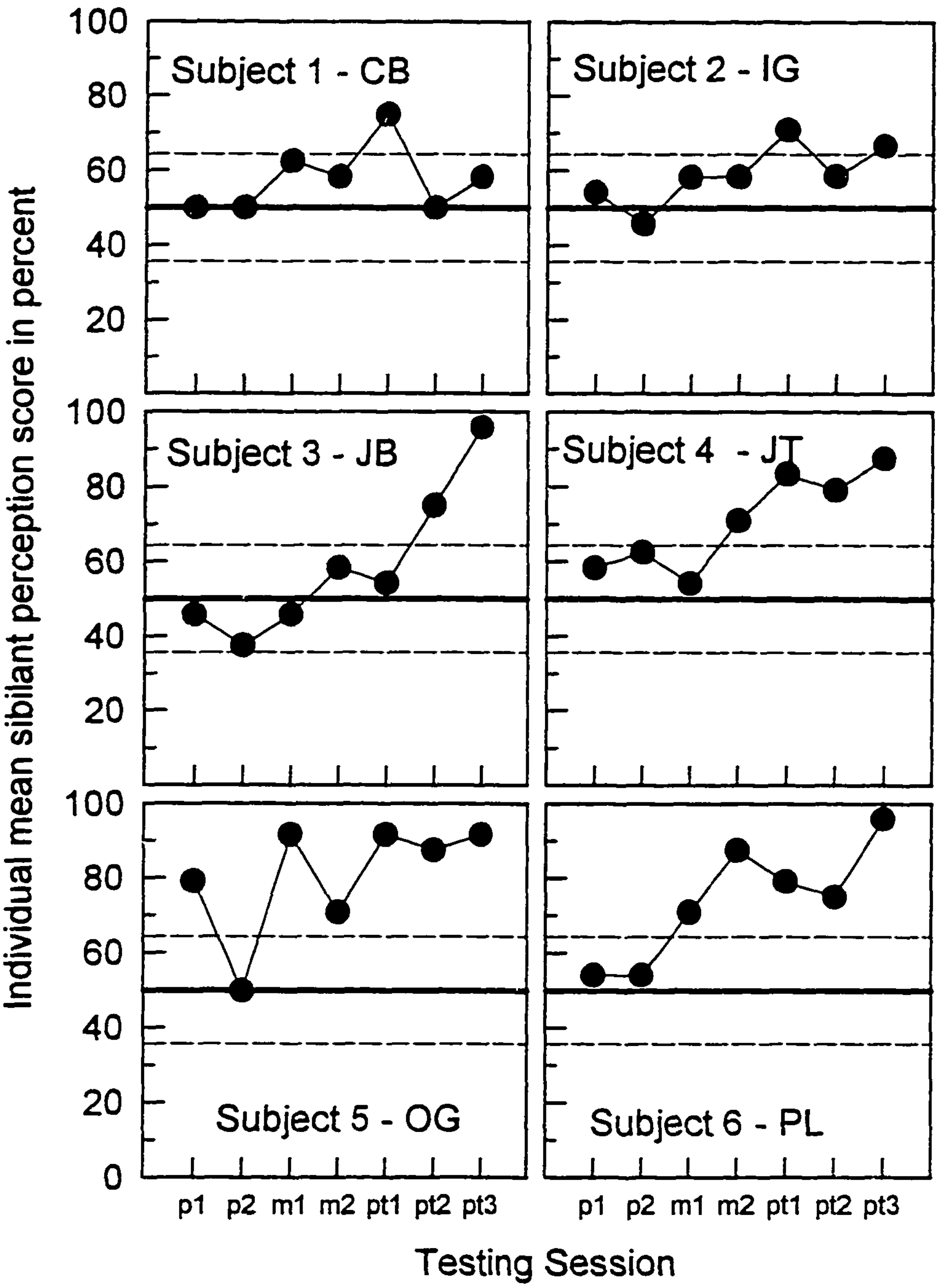

Figure 5.5 shows the mean percent scores for the perception of the /s/-/sh/ contrast for the six subjects as a function of test session. Data are collapsed across male and female talkers. Note that a score of 50% represents random guessing and is represented by a solid line. The dashed lines show 95% confidence limits for scores expected on every trial (based on normal approximation to the binomial distribution).

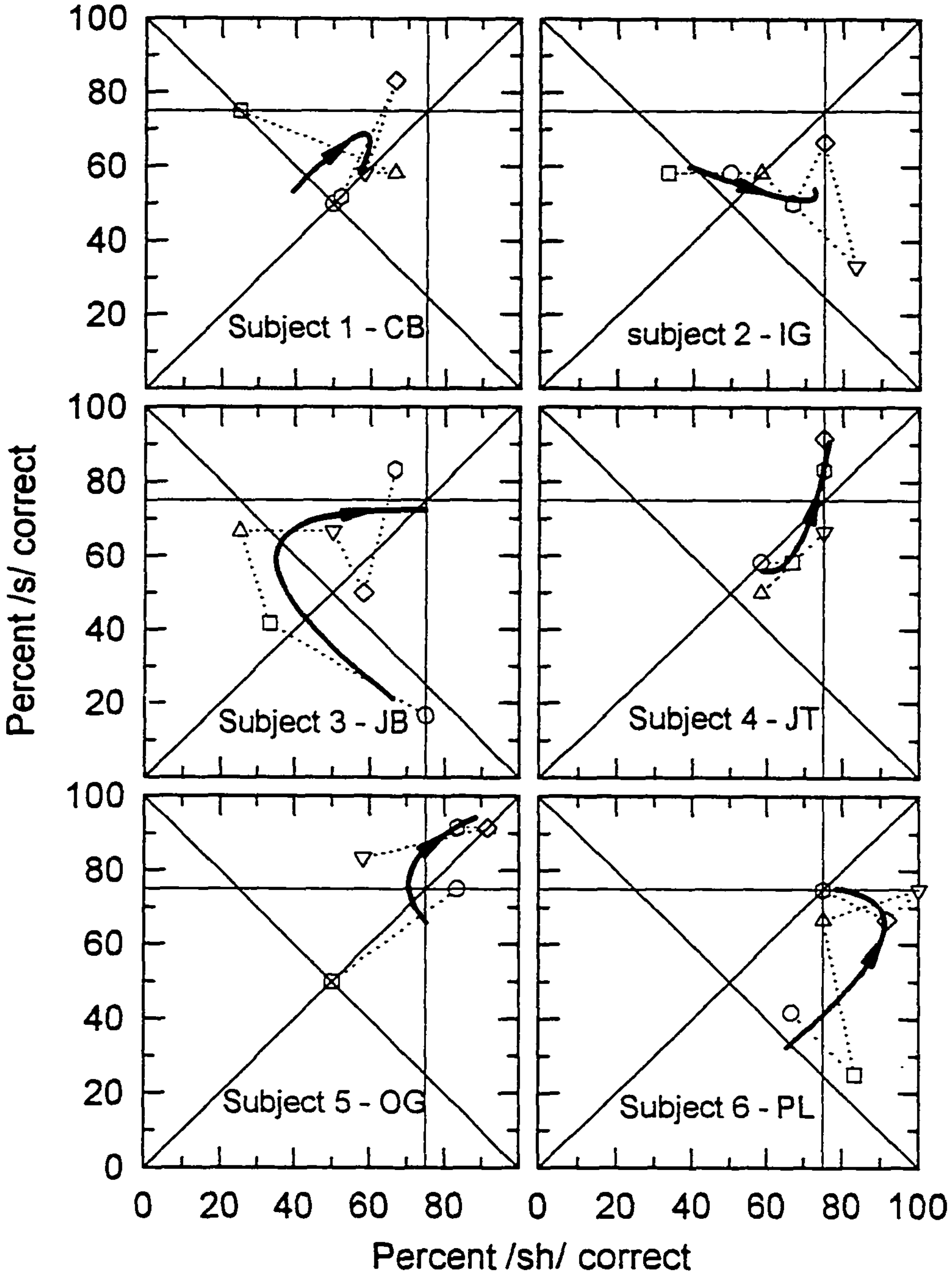

Figure 5.6 Individual scores obtained on the /s/-/sh/ perception test (excluding data for the final hearing aid condition). Curves show smoothed 'learning' contours. Subjects 1, 3, and 5 received perception training first.

Test Session

···○···	Pre-1	···▽···	Mid-2
···□···	Pre-2	···◇···	Post-1
···△···	Mid-1	···○···	Post-2

amount and direction of bias was different for different subjects and changed differently for differentsubjects over time. In general, subjects 1, 3, and 5 were more often biased towards /s/ while subjects 2, 4, and 6 were biased towards /sh/[2].

5.7 Perception scores on the IMSPAC test

The IMSPAC test was included as a control task, involving the perception and production of contrasts for which no specific training was given during this study. If any improvements in performance on the /s/-/sh/ task were simply the result of such things as the attention given to subjects, their familiarity with the tester, the equipment, and the general testing procedures, increased confidence, aimproved attention, then similar improvements of performance would be expected on the perception component of the IMSPAC test. If, on the other hand, improvements in performance on the /s/-/sh/ perception task were dependent solely on the experience provided on this specific contrast then no change in score on the perception component of IMSPAC would be expected. In fact, the group mean score for the perception component (i.e., audio-only) component of IMSPAC was 69% at the beginning of the study and 73% at the end. Although the 4 percentage point improvement was small, it reached

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[2] Although not planned that way, these groupings were also the order groupings (i.e. production training first versus perception training first). Hence the significant order x time and order x sibilant x time interactions in the analyses of Table 4.1.

statistical significance in a 1-factor repeated-measures analysis of variance (F(1,5)=6.61, ($p<0.05$). Nevertheless this improvement is much less than the 20 percentage point improvement (from 53% to 73%) observed between the two pre-tests and the two post tests for perception of the /s/-/sh/ contrast.

These findings support the conclusion that a major portion of the improvements in performance on the /s/-/sh/ contrast test is attributable to the experience provided on this specific contrast during the study.

5.8 Talker effects

In the repeated-measures analysis of Table 5.1, the main effect of talker does not reach the 5% level of significance. It cannot be concluded, therefore, that the mean scores for the two talkers would differ in the population represented by this sample of subjects. The simple 4-way analysis, however, shows a highly significant main effect of talker. The discrepancy is accounted for by the highly significant interaction between talker, time, and subject within order group. These data indicate that subjects differ a) in terms of their relative performance for the two talkers, and b) in terms of the change in relative performance for the two talkers over time.

These effects are illustrated for the group means in Figure 5.7 and for individual subjects in Figure 5.8. In both Figures, accuracy of performance on

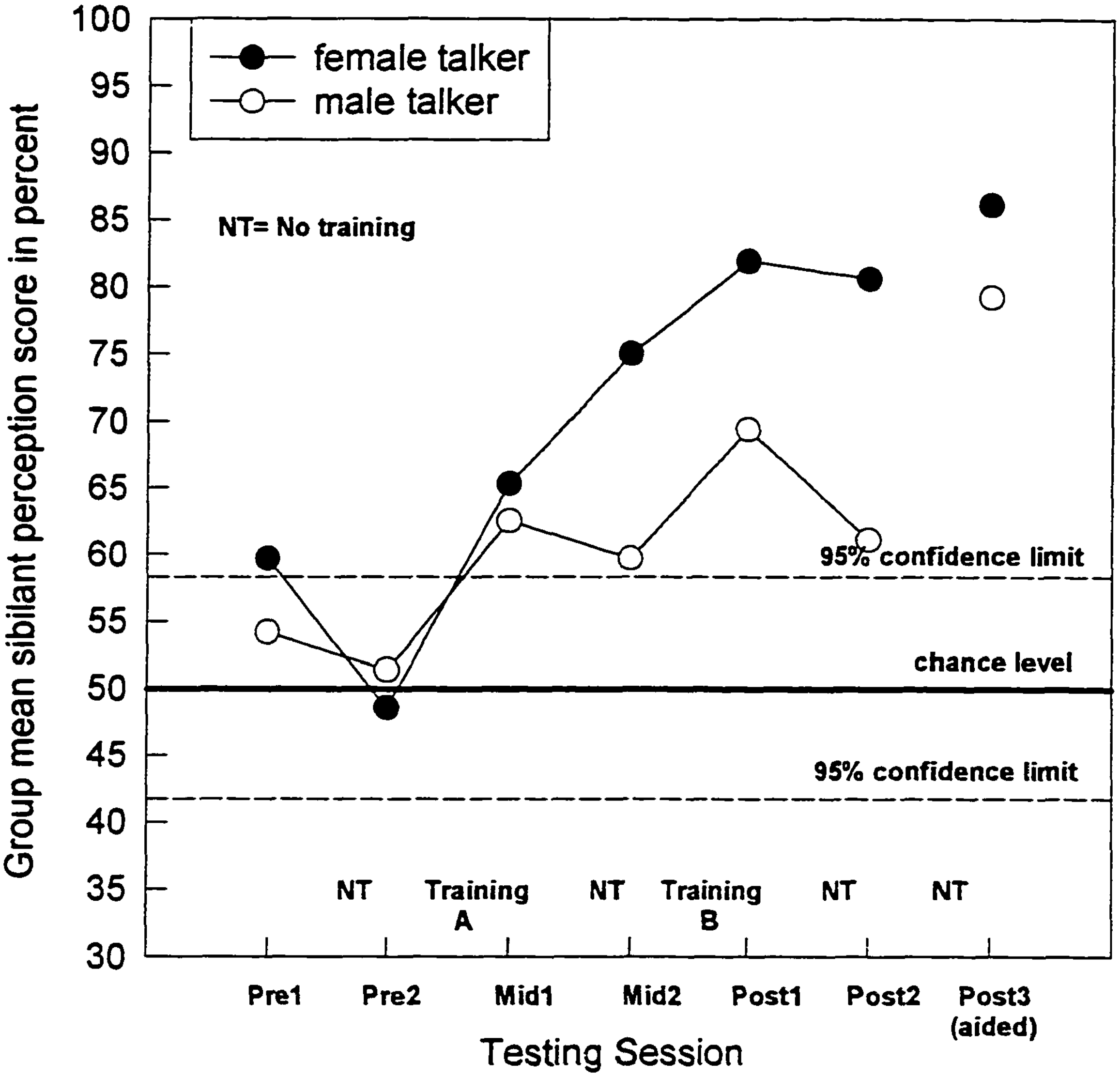

Figure 5.7 shows mean percent scores for the perception of /s/-/sh/ contrast spoken by the male and female talkers, for the group, as a function of test session. Note that a score of 50% represents random guessing. The dashed lines show the 95% confidence limits for scores expected on the basis of random guessing on every trial (based on normal assumption of binomial distribution for p=0.5 and n=144)

the /s/-/sh/ perception task is plotted as a function of test session for the two talkers separately.

It will be seen from Figure 5.7 that group mean performance for the two talkers was similar (and close to chance level) at the beginning of the study. After the first mid-test, however, group mean performance was higher for the female talker than for the male talker. From Figure 5.8 it will be seen that the superiority of performance for the female talker was marked for subjects 3, and 6. For the other four subjects the difference was small or non-existent. In no case was performance better for the male talker. The data for subject 3 are particularly noteworthy. After training this subjects was scoring close to chance for the male talker. This difference vanished when the personal aid was used for testing - but more of this below. The data for subject 6 are also interesting in that performance for the female talker was already well above chance at the pretest sessions. From these data we may conclude that there are differences in subjects' perception performance for the two talkers. These differences, however, were highly subject-specific.

5.9 Perception performance via personal hearing aids

In the rationale for this study, it was argued that subjects of the type studied here require amplification with an extended high-frequency response in order to have full access to the acoustic cues needed for the recognition

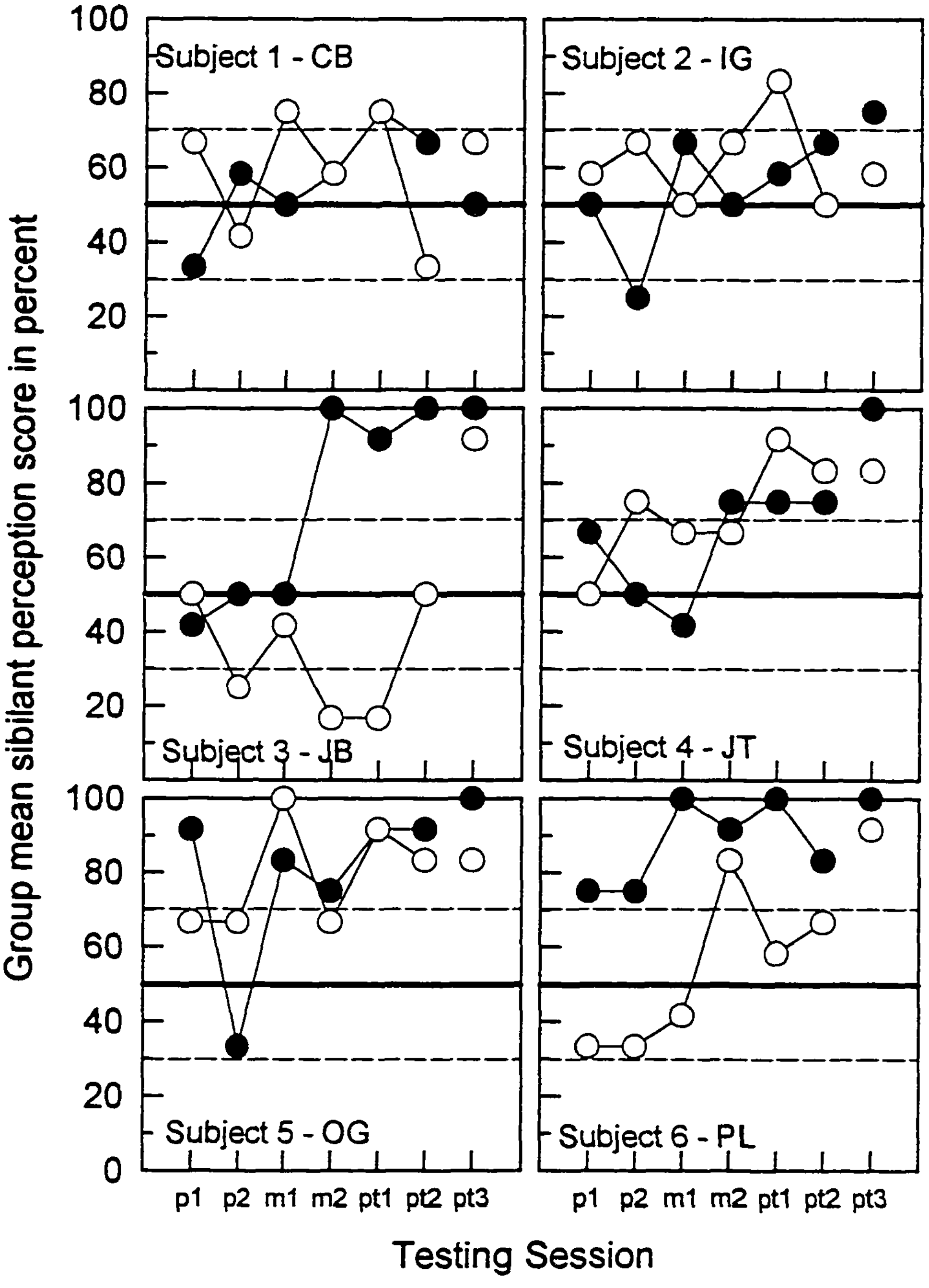

Figure 5.8 shows the mean percent scores for the perception of the /s/-/sh/ contrast, spoken by the male and female talkers, for the six subjects as a function of test session. The open circles represent the male talker and the filled circles represent the female talker. Note that a score of 50% represents random guessing and is represented by a solid horizontal line. The dashed horizontal lines shows 95% confidence limits for scores expected on the basis of random guessing on every trial (based on normal assumption of binomial distribution for p=0.5, and n=24).

and discrimination of /s/ and /sh/. For this reason, training and testing in /s/-/sh/ perception were carried out under headphones with a system having an upper frequency limit in the region of 8 kHz. It was expected that a switch to personal hearing aids - with their upper frequency limit in the region of 3.5 kHz would result in a significant reduction of performance at the end of the study.

This prediction was not borne out. It will be seen from Figure 5.1 that the group mean score with personal hearing aids was higher than that for either of the two post-test sessions in which broad-band amplification was used. In post-hoc testing, using the least-significant difference test, the difference is significant in the simple 5-way analysis of variance in Table 5.1. It is not significant however in the repeated measures analysis. The discrepancy can be attributed to the large inter-subject variability which is apparent from Figure 5.6. Subjects 3 and 6 show a large increase in score when the switch is made to personal aid. For the other 4 subjects the increase is small or non-existent.

From Figure 5.8 it is also apparent that the increase in performance with personal hearing aid is accounted for mainly by improvement in performance with the speech of the male talker. This effect, too, is listener-specific and is attributable mainly to the data for subjects 3 and 6 (see Figure 5.8). Possible reasons for these unexpected findings will be explored in the discussion.

5.10 Summary for findings for the perception data

Group mean perception scores on the /s/-/sh/ perception task improved significantly during the course of the study. The improvement was apparent during training periods but not during no-treatment periods. There was no evidence, however, that the pattern of improvement depended on the type of training (perception or production). The amount of improvement was some 5 times greater than that observed for the untrained IMSPAC task. Subjects differed significantly in terms of overall performance, improvement over time, and bias towards /s/ or /sh/ responses. Performance for the speech of the female talker was generally better than that of the male talker. This effect was most marked after the initial training session, for certain subjects, and when testing was carried out with broadband equipment. When a final test was given with personal hearing aids, the performance of some subjects improved, especially for the female talker.

5.11 Analyses of variance in the production data

Table 5.2 shows the results of analyses of variance in the scores on the /s/-/sh/ production test. Two analyses are shown. In both analyses, order of training (perception-first or production-first) is treated as a group variable, with 3 subjects in each group. In the first analysis, sibilant (/s/ or /sh/), and time (i.e., test session) are treated as repeated-measures. This analysis estimates the probability that observed differences can be explained by

Table 5.2. Analyses of variance in the production results for 6 subjects.

				Repeated-measures analysis			Simple 4-way analysis		
Source	SumSq	df	EMS	Error term	F	p	Error term	F	p
O(Order)	428	1	428	SW	0.41	0.55897	STxSW	2.01	0.16940
S(Sibilant)	7112	1	7112	SxSW	2.67	0.17763	STxSW	33.37	**0.00000** *
T(Time)	4820	6	803	TxSW	2.63	**0.04181** *	STxSW	3.77	**0.00870** *
OS	860	1	860	SxSW	0.32	0.60034	STxSW	4.03	0.05600
OT	469	6	78	TxSW	0.26	0.95176	STxSW	0.37	0.89260
ST	1320	6	220	STxSW	1.03	0.42899	STxSW	1.03	0.42910
OST	1201	6	200	STxSW	0.94	0.48586	STxSW	0.94	0.48580
SW	4223	4	1056				STxSW	4.95	**0.00480** *
SxSW	10657	4	2664				STxSW	12.50	**0.00000** *
TxSW	7325	24	305				STxSW	1.43	0.19360
STxSW	5116	24	213						
Total	43531	83							

SW=Subject within Order group

* = significant interaction p<0.05

random variability among subjects. In the second analysis, subject is treated as fixed effect and the 3-way interaction between talker, sibilant, time, and subject-within groups provides the error term for all estimates of F ratio. Note that, in these analyses, a single score is biased on the average judgments of four normally hearing listeners who were asked to decide whether the intended sibilant was /s/ or /sh/. At each test session, each judge heard 12 tokens intended to be /s/ and 12 tokens intended to be /sh/.

5.12 Changes in production performance over time

5.12.1 Accuracy of /s/-/sh/ production

Figure 5.9 shows group mean accuracy of sibilant collapsed across subject, and sibilant, as a function of test session. Also shown are the 95% confidence limits for scores that would be expected if every judge were guessing on every trial. These confidence limits are based on the normal approximation to the binomial distribution for a guessing probability of 0.5 and 576 trials per score (12 tokens x 2 sibilants x 4 judges x 6 subjects). Note, that unlike the perception results the final session simply represents a third post-test session - all production testing was done while subjects were wearing personal hearing aids.

It will be seen from Figure 5.9 that the group mean sibilant score was near chance levels (57%) at the first pretest but rose to around 68% at the second pretest. Steady improvement continued during the training portion of

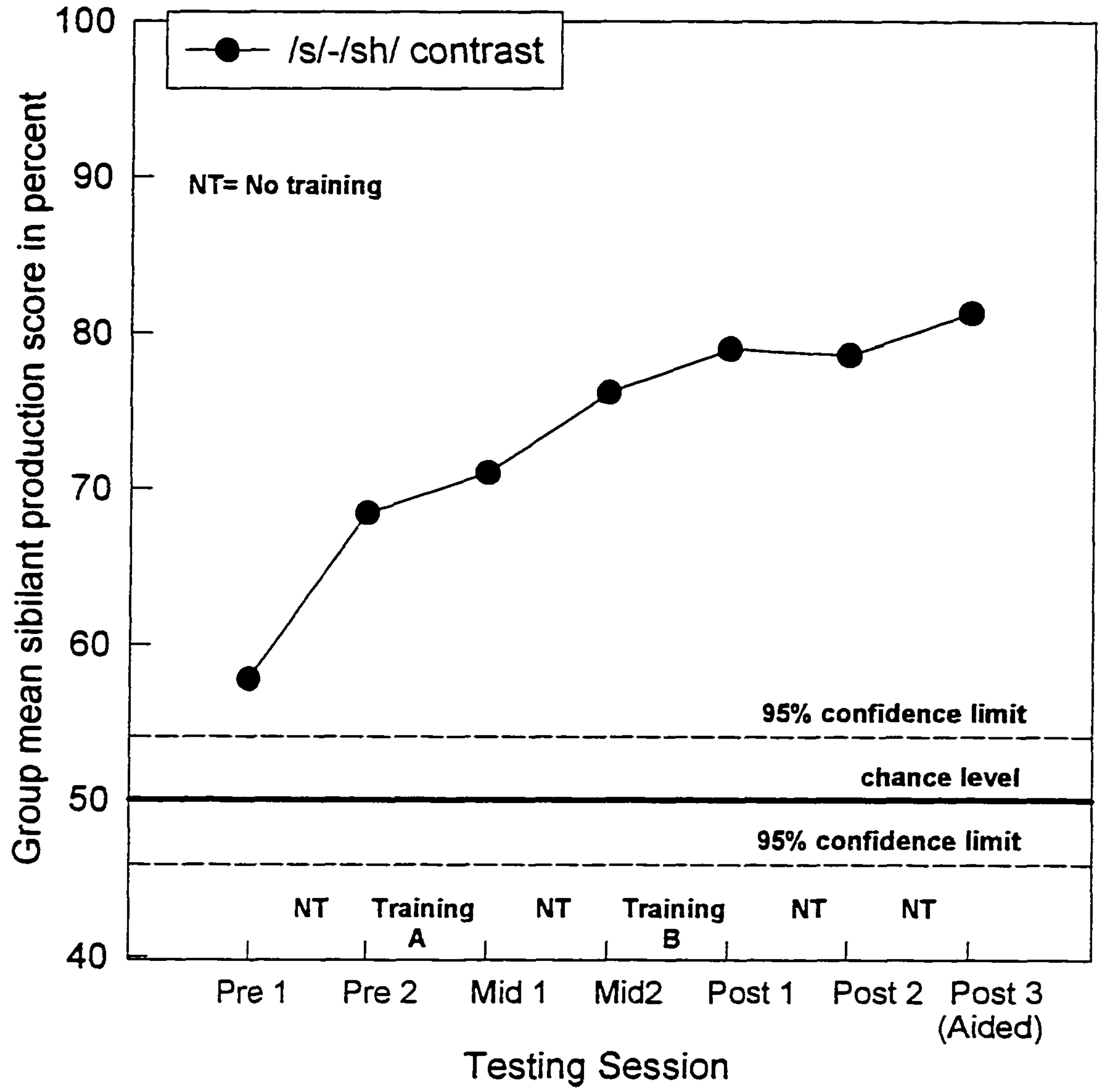

Figure 5.9 shows mean percent scores for the production of the /s/-/sh/ contrast, for the group, as a function of test session. Note that a score of 50% random guessing. The dashed lines show 95% confidence limits for scores expected on the basis of random guessing on every trial (based on normal assumption of binomial distribution for p=0.5 and n=576).

the study and performance remained fairly stable at around 80% during the 3 post-test sessions.

Both repeated-measures and the simple 4-way analysis of Table 5.2 confirm the significance of the main effect of time. In other words, the differences among the group mean scores at the various test sessions cannot be attributed either to test-retest variability within subjects or to random variability among test subjects. Moreover, the pattern of change is, clearly, one of increasing score across test sessions.

From the residual error term of the simple 4-way analysis it was determined that a critical difference of 11.7 percentage points is needed for the difference between two means to be considered significant at the 5% level. This criterion is met for all test sessions after the first pretest. After the second pretest session, however, the criterion is not reached until the last post test.

These data support the conclusion that group mean performance on the production component of the /s/-/sh/ contrast test improved during the course of this study. Moreover, it may be concluded that the same would be true for the mean of the population represented by these subjects when exposed to the same program of training and evaluation. However, a major portion of the improvement occurred between the first and second pretest sessions when no training was provided.

5.12.2 Bias in /s/-/sh/ production

The bias in production of /s/ and /sh/ (i.e., in the perception of /s/ and /sh/ by the judges) is illustrated in Figure 5.10 as the difference in /s/ and /sh/ scores at each test session. It will be seen that, after the initial pretest, there is a steadily increasing /sh/ bias in production which stabilizes by the post test sessions.

In the repeated-measures analysis of Table 5.2. sibilant failed to reach the 5% level of significance, either as a main effect or in interaction with time. There is, therefore, no evidence to support the conclusion that there would be a mean bias in the population represented by this sample of subjects. In the simple 4-way analysis, however, the main effect of sibilant is highly significant, confirming that the effects here are not explained in terms of within-subject test-retest variability - there is a real /sh/ bias in the group means. The interaction between sibilant and time, however, is not significant. There is no evidence, therefore, for the pattern of change over time being different for the two sibilants.

In the simple 4-way analysis, the sibilant x order interaction approaches the 0.05% level of significance - providing weak evidence for the conclusion that the inherent difference of perceptual bias between the two order groups is also present at the production level. Unlike in the perceptual data, however, there is no significant interaction between order, sibilant, and time. In other words, there is no evidence to support the notion that the

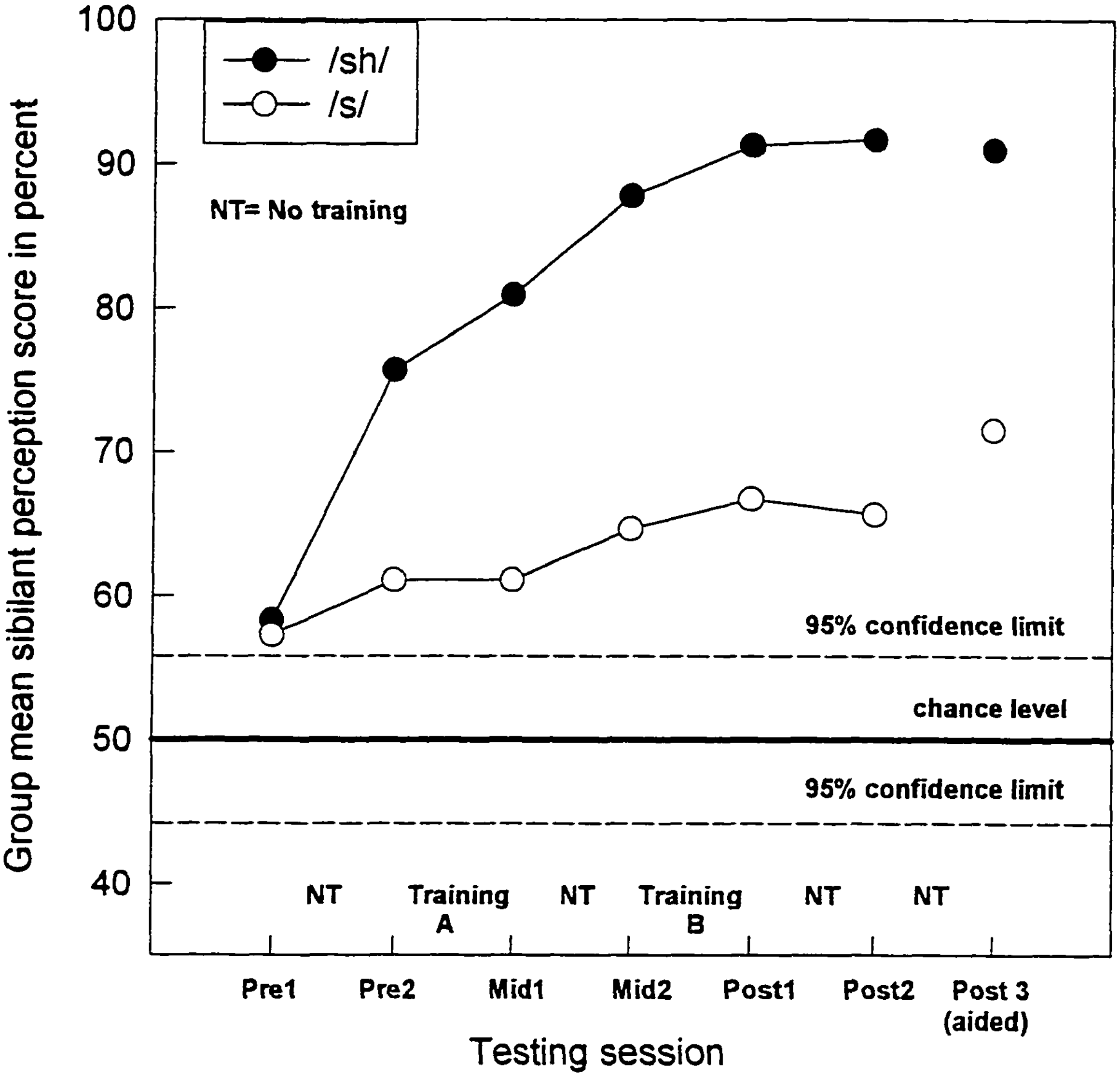

Figure 5.10 shows mean percent scores for the production of the /s/ and /sh/, for the group, as a function of test session Data are collapsed across male and female talkers. Note that a score of 50% represents random guessing. Dashed lines show 95% confidence limits for scores expected on the basis of random guessing on every trial, (based on normal approximation to the binomial distribution for p=0.5 and n=288).

pattern of change in production bias over time differed between the two order groups.

5.12.3 Combined accuracy and bias plot for the production data.

Figure 5.11 replicates the earlier 2-dimensional plots for the perception data. The group mean /s/ score is plotted as a function of the /sh/ score. Each data point shows a separate test session. The solid line shows a learning trajectory obtained by combining 2nd order polynomial fits to each score as a function of time. The figure clearly illustrates the improvement in accuracy over time but with a bias towards /sh/ reflecting the fact that the improvement in the /sh/ score was greater than in the /s/ score.

5.13. Effects of training

Unlike the perceptual data, the production results do not support the conclusion that performance improved more during training periods than during no-treatment periods. The change during no-treatment periods averaged around 3.5 percentage points while the change during the training periods averaged only 2.5 percentage points. In fact, the greatest group mean improvement between successive sessions (11.5 percentage points) occurred during the initial pre-test period - before any training began.

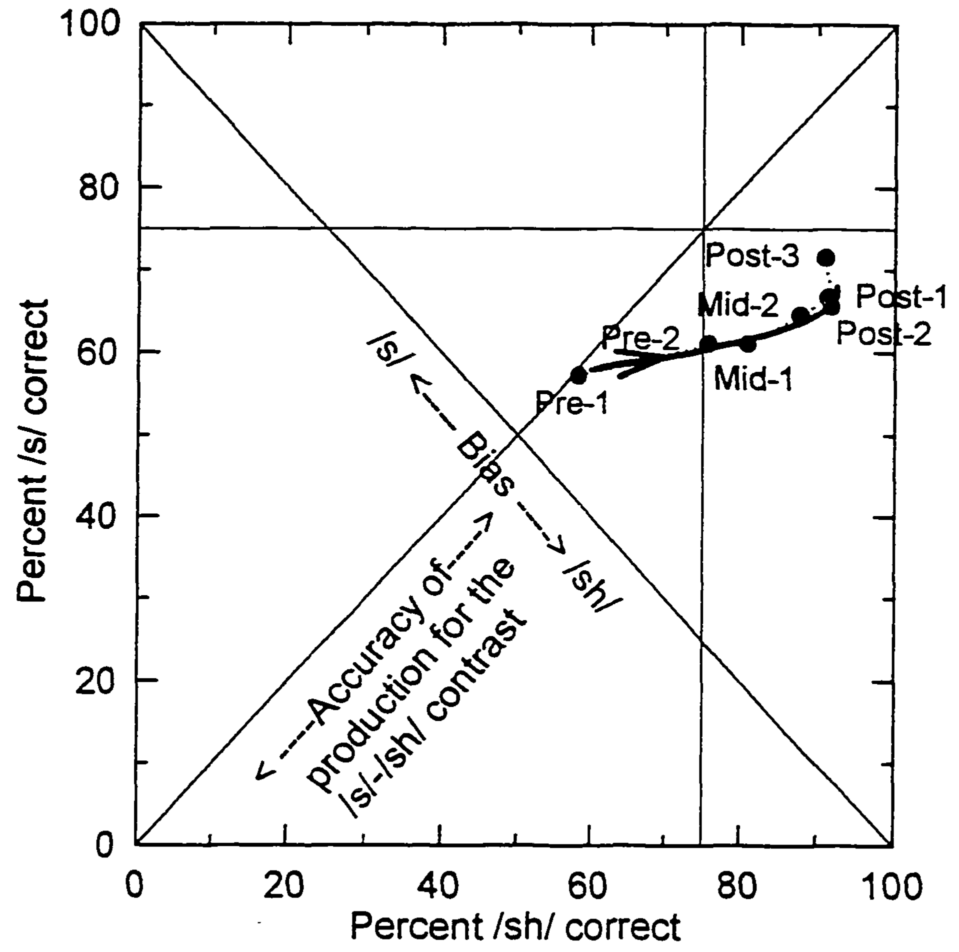

Figure 5.11 shows mean scores for the group obtained on the /s/-/sh/ production test for seven sessions. The solid curve shows a smoothed 'learning' contour. The mean data show the initial score to be above chance and with no /s/-/sh/ bias. By the end of training, production of /sh/ is much better, production of /s/ has improved only slightly, and the bias has changed in favor of /sh/.

5.14 Effects of type of training

Similarly, there is no evidence to support the conclusion that the specific type of training was related to any pattern of performance change. Order of training fails to reach significance either as a main effect or in interaction with time in both analyses of Table 5.2.

5.15 Individual differences in production performance

5.15.1 Change of production accuracy over time

Figure 5.12 shows individual scores (collapsed across sibilant) as a function of test session. Five of the six subjects show similar pattern of rising score across test sessions. The exception is subject 2 whose performance, if anything gets worse over time. The simple 4-way analysis of Table 5.2 confirms the significance of overall accuracy differences among subjects. There is, however no significant interaction with time. It cannot be concluded, therefore that subjects differed in terms of the pattern of production change over time. The apparent differences of Figure 5.12 might well be the result of within - subject test-retest variability.

5.15.2 Changes in production bias over time

Figure 5.13 shows "learning" trajectories for the six subjects. It will be seen that 5 of the 6 subjects had a clear /sh/ bias during most of the study. The exception is subject 5 who showed a moderate /s/ bias. Note also that

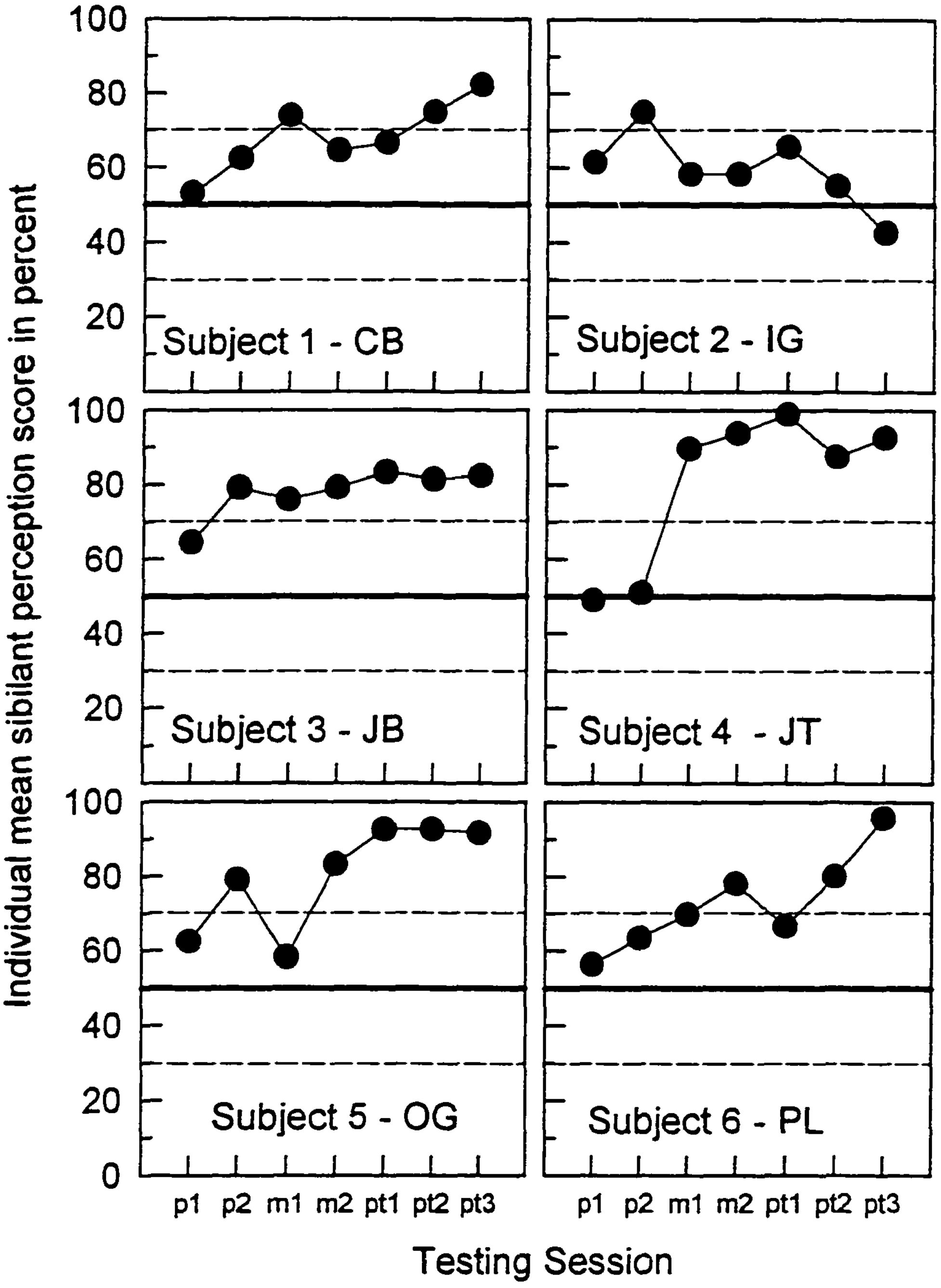

Figure 5.12 shows the mean percent scores for the production of the /s/-/sh/ contrast for the six subjects as a function of test session. A score of 50% represents random guessing and is shown as a solid line. Dashed lines show the 95% confidence limits for scores expected on every trial (based on normal assumption of binomial distribution for p=0.5 and n=24).

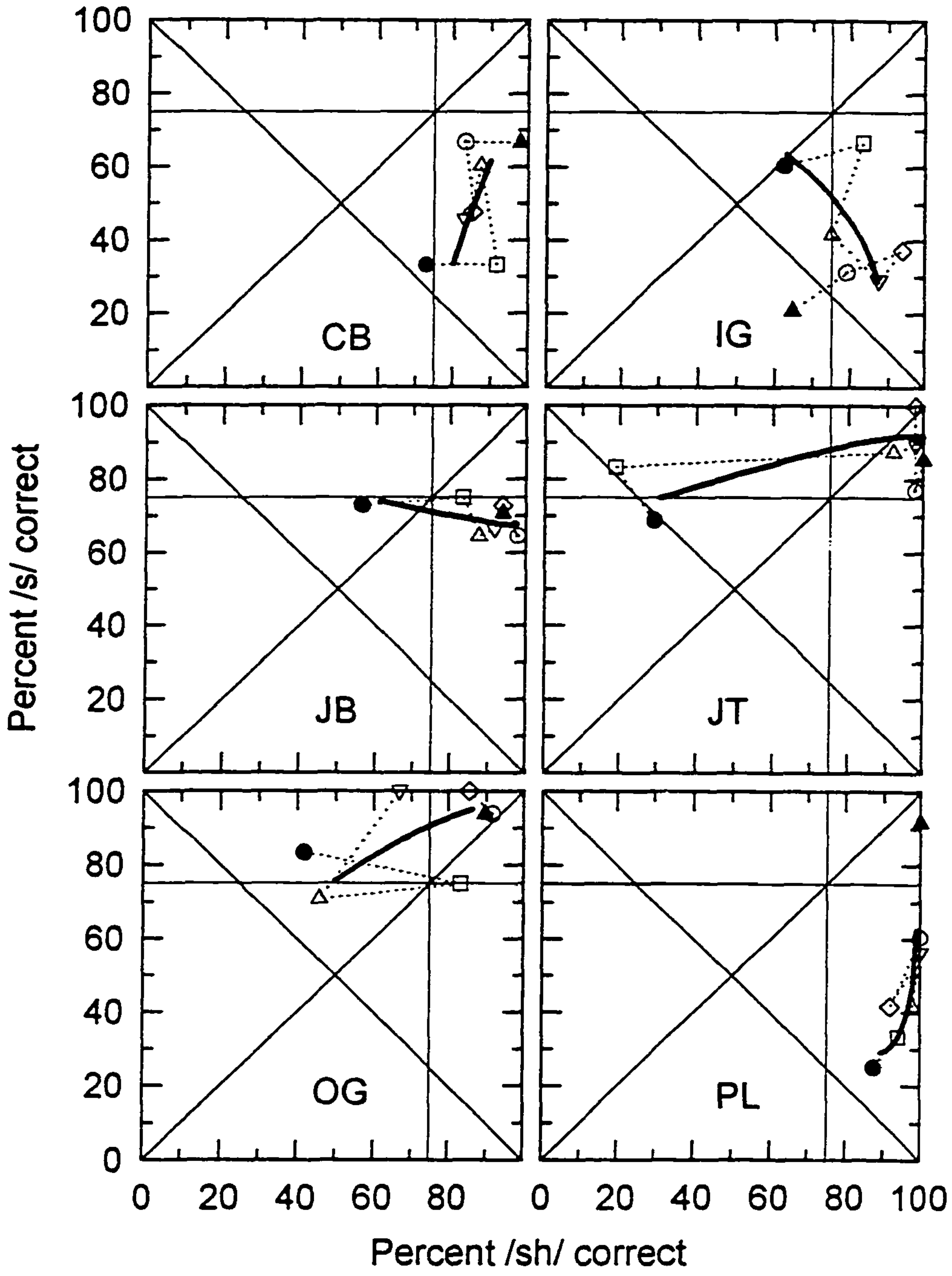

Figure 5.13 shows individual scores obtained on the /s/-/sh/ production test for all testing sessions. Sessions pre 1 and post 3 have filled symbols. Curves show smoothed "learning' contours. Subjects 1, 3, and 5 received perception training first.

Test Session

- ···●··· Pre-1
- ···□··· Pre-2
- ···△··· Mid-1
- ···▽··· Mid-2
- ···◇··· Post-1
- ···⊖··· Post-2
- ···▲··· Post-3

subject 2 gave no evidence of improved accuracy during the study but did show an increasing /sh/ bias.

Individual differences of overall bias are confirmed by the presence of a significant interaction between sibilant and subject in the simple 4-way analysis of Table 5.2. Unfortunately, the data do not permit testing of the hypothesis that subjects differed in terms of the pattern of change in bias over time because the subject x sibilant x time interaction provides the error term in this analysis.

5.16 Production scores on the IMSPAC test.

The group mean score for the production (i.e., audio-visual) component of IMSPAC was 83% at the beginning of the study and 89% at the end. The 6 percentage point improvement approached statistical significance in a 1-factor repeated-measures analysis of variance (F[1,5,]=6.41, p=0.052). This improvement is, however, much less than 23 percentage point improvement (from 58% to 81%) observed between the first pretest and the average of the three post tests for production of the /s/-/sh/ contrast. It is also less than the 11.5 percentage point improvement between the second pretest and the average of the final three post test scores.

These findings support the conclusion that a portion of the improvement in performance on the /s/-/sh/ production test is attributable to the experience provided on this specific contrast during this study.

5.17 Summary findings for the production data.

These data support the conclusion that group mean accuracy of /s/-/sh/ production improved during the course of this study. There is, however, no evidence to support the notion that this improvement coincided with periods of training, or that the type of training made any difference. The amount of production improvement, when measured from the first pretest session, was some 3.5 times greater than that observed for the untrained IMSPAC task. When measured from the second pretest session the amount of improvement was twice that observed for the untrained IMSPAC task. Subjects differed significantly in terms of overall performance and bias towards /s/ or /sh/ responses. There was no evidence, however, to support the conclusion that they differed in terms of pattern of change of accuracy over time.

5.18 Do the perception data predict the production data (or vice versa)?

Figure 5.14 shows the group mean production data plotted against the group mean perception data at each of the testing sessions. The significant r value (r(5)=0.82, p=0.024) suggests that group production performance was linearly related to group perception performance over the course of the training program. This figure shows both group mean sibilant production and perception scores increasing over the course of the training program.

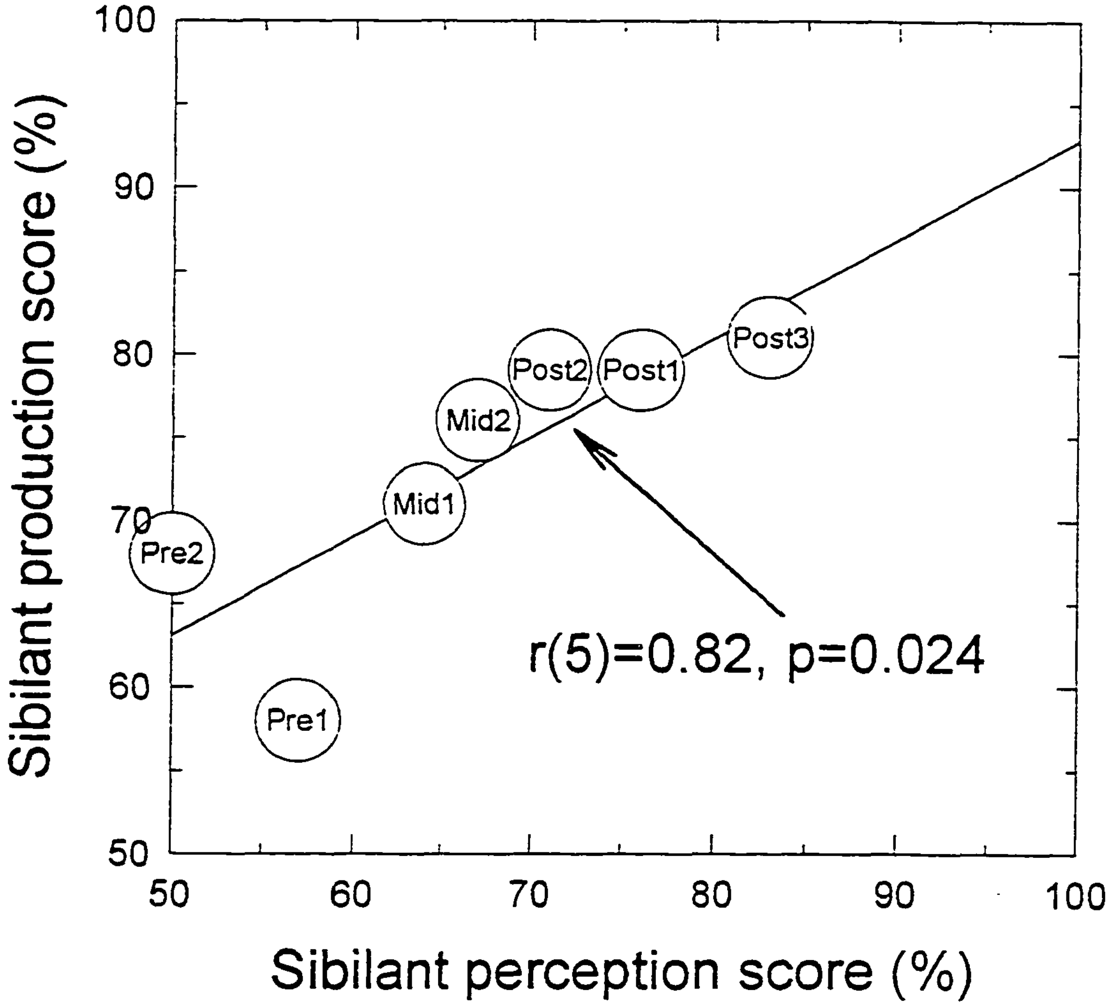

Figure 5.14 shows the group mean sibilant production score as a function of the group mean sibilant perception score at the seven testing sessions. The line shows the linear regression for production on perception.

However, small differences in the improvement in the group mean perception and production data at different sessions are evident. A notable exception is session pre 2 where the group mean production score is 16 percentage points higher than the group mean perception score.

Figure 5.15 shows the sibilant production scores, averaged across the three post-training sessions, as a function of personal aided sibilant perception scores for the six subjects. For these subjects production does not appear to be linearly related to perception because the r value failed to reach significance. The figure shows different patterns for the perception and production data among the subjects. Two of the subjects, (subject 4(JT) and subject 5(OG)), achieved similar scores on perception and production tests. Three subjects, (subject 2(IG), subject 3(JB) and subject 6(PL)), achieved a higher perception score than production score. One subject, (subject 1(CB)), achieved a higher production score than perception score. The variability among the subjects suggests that the perception data cannot be used to predict the production data for individual subjects.

These data suggest that the group mean perception data may be used to predict the group mean production data. This finding suggests that the same would be true for the mean of the population represented by these subjects. However, the data also suggest that it is difficult to predict production data from perception data for individual subjects.

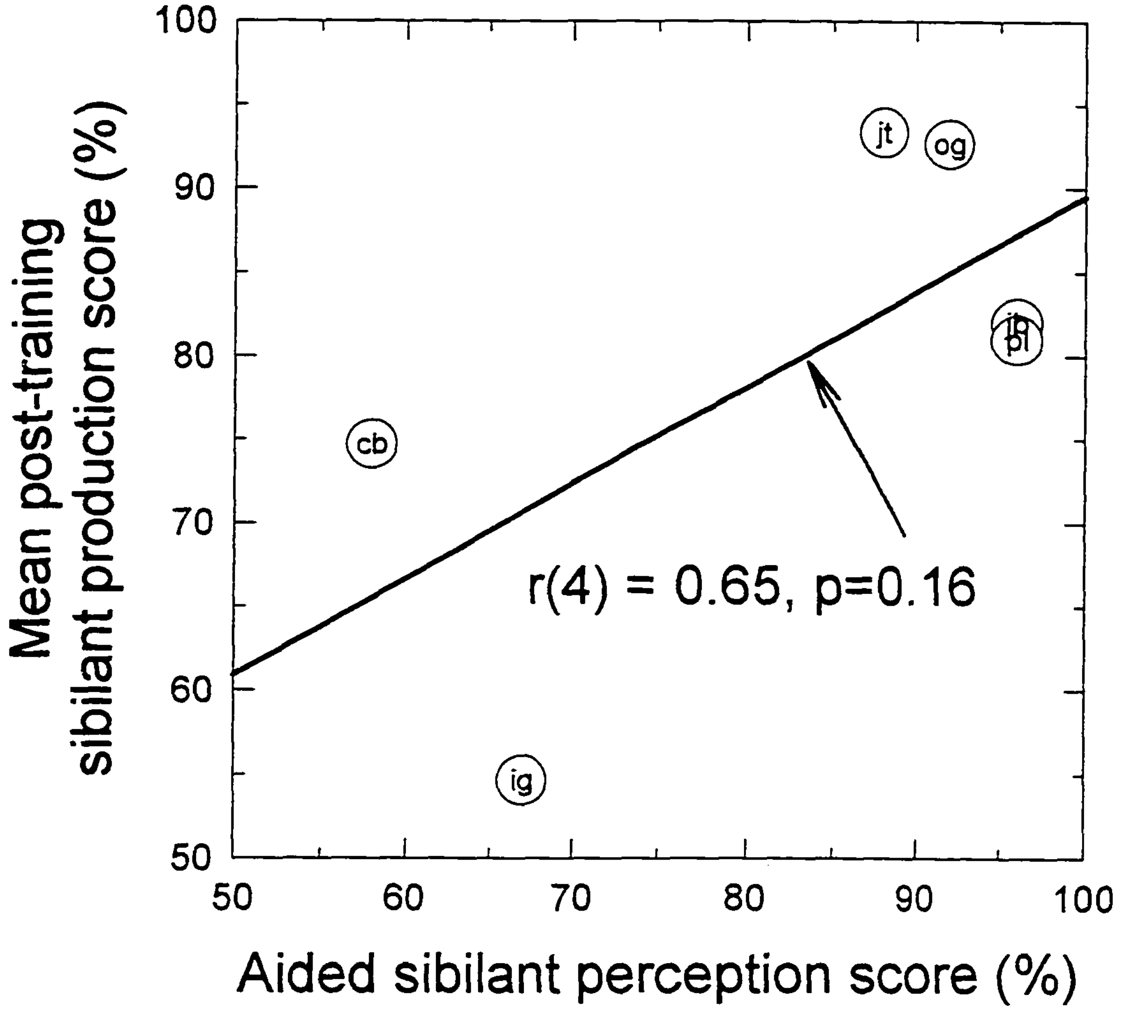

Figure 5.15 Sibilant production scores, averaged across the three post-training sessions, as a function of aided sibilant perception scores for the six subjects. The line shows the linear regression for production on perception.

5.19 Summary of results

Group mean performance on the /s/-/sh perception and production task improved during the course of this training program. The pattern of improvement for perception was different from that for production. For perception, improvement occurred during training periods only whereas in production improvement did not coincide with the training periods. There was no evidence, for either perception or production, that the pattern of improvement depended on the type of training given. The amount of improvement was much greater, for both perception and production, than that seen for the untrained IMSPAC task. Subjects differed significantly in terms of overall performance, improvement over time, and bias towards /s/ or /sh/. For the perception task the performance for the speech of the female talker was better than for the male talker, with the effect being more marked for certain subjects. Some subjects' performances improved on the perception task (particularly for the male talker) when they used their personal hearing aids.

Chapter 5

Discussion

The purpose of the present study was to investigate the relationship between speech perception and speech production in an experimental speech-training program for hearing-impaired. Two hypotheses were offered. One hypothesis was that training speech production would result in improved speech production and perception. The other hypothesis was that training in speech perception would result in improved speech perception but not speech production.

It was also hoped that the results would lead to a better understanding of the relationship between speech perception and speech production.

Experimental design considerations

Experimental sample

It proved difficult to randomly select a small group of hearing-impaired subjects from the population of the collaborative school because of the subject requirements (see method section). These requirements limited the number of possible candidates for inclusion in the experimental training program to only seven subjects. Parental permission to participate in the program was given for six subjects. Some of the subjects had additional handicaps such as cerebral palsy, and attention deficit disorder. These subjects were allowed to remain in the sample because of the shortage of subjects. The consequences of including these subjects added to the heterogeneity of the sample. In addition, the subjects had different degrees of hearing loss, different history of amplification, and different educational experiences. These factors conspired to reduce the sensitivity of the design-especially for the 'between groups' variable of training order. Evidence for the influence of using a small heterogeneous sample comes from the group difference of /s/-/sh/ bias found in the analysis of variance.

A second problem was the audiometric characteristics of the subjects and their assignment to a particular group. Subjects were randomly assigned to one of the two order training groups. Group assignment was not based on the audiometric characteristics. In fact the group that received perception training first tended to have better high frequency hearing and might have been expected to respond better to training. In retrospect better use should have been made of the audiometric characteristics of the subjects when assigning subjects to order-of-training groups.

Uniformity of training

A second problem relates to the difficulty of providing equivalent training across subjects. This sample of subjects demonstrated widely different starting skills and learning styles. Much individualization of training was required. The computer-based training was designed to provide some uniformity but, in fact, it was difficult for some subjects. In consequence, the assumption that all subjects were exposed to the same treatment is not justified. However, all subjects received training, including some computer-based training.

Validity of the measures

Perception

The validity for the binary forced-choice test of contrast perception is questionable. Any differences in the sensations produced by the two sibilants could be used as a criterion for response-regardless of its relevance to its phonemic content. In a binary-choice test after extensive training and feedback on performance subjects may learn to respond correctly on the basis of cues that have little or no value in phoneme recognition across contexts and talkers. For example, a consistent difference of perceived loudness for /s/ and /sh/ would provide subjects with enough information to learn to make correct responses even if they didn't recognize either. In extreme cases the /sh/ might have been audible while the /s/ was inaudible. Indeed this is a distinct possibility given the fact that the major energy content of the typical /sh/ falls within the frequency range of most hearing aids while that for /s/ falls outside that range (Boothroyd and Medwetsky, 1992). Evidence that this phenomenon affected the present results comes from the fact that subjects tended to obtain higher scores on the perception task when listening to the female talker. A second piece of evidence is that performance with band-limited personal aids was better than with broadband amplification. If we assume that /s/-/sh/ perception (meaning both recognition and discrimination) depend on access to high-frequency resonances, everything would point to better performance with the male talker (whose resonances are lower – see Appendix I) and with broadband amplification. If we assume, however, that, for purposes of the task used here, any difference of perceived loudness is enough to ensure accuracy (especially because we provided feedback on performance) then the broad-band amplification might obscure differences for the male talker, that are retained for the female. In addition, band-limited personal amplification would enhance the /s/-/sh/ loudness difference.

The subjects in this training program improved performance, with training, on the auditory perception task. However, it does not follow that the skills learned would aid in the development of the internal knowledge needed for recognition, discrimination, and production of /s/-/sh/ across contexts, talkers, and listening situations.

Production

The task for the listeners on the production test for the /s/-/sh/ contrast was to make a binary, forced-choice decision for each test item. The listener had to decide whether the subject was trying to use an /s/ or an /sh/. A problem with this approach is that bias on the part of the listener could artificially enhance either the /s/ or the /sh/ score. This results in the validity of the individual sibilant scores being questionable. However, the validity of the scores for the /s/-/sh/ contrast (i.e. the average score for the two sibilants) is better because of the use of a binary choice procedure. The listener hears the sibilant in a context and has to make a decision on the basis of the characteristics of the sound. Any bias towards an /sh/ response will lower the /s/ score and a bias towards an /s/ response will lower the /sh/' score. Hence the average (sh+s)/2 gives an unbiased estimate of the ability to contrast the two. Empirical support for this conclusion comes from Boothroyd and Gorzycki (1977) who reported that a two-alternative forced choice response for evaluating sibilant production eliminated the effects of listener experience. Thus, one must be careful, in the interpretation of production data for the individual sibilants. The contrast data, however, raise less concern-at least in terms of listener bias.

Discussion of the research questions

Speech Perception

The mean group score for the perception of the /s/-/sh/ contrast showed patterns of change that suggest learning. Moreover significant improvements of the group mean scores[1] were confined to the training periods, suggesting that the training itself was responsible. In both analyses of variance the order variable is also a grouping variable. Most of the

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[1] There was a significant change in the group mean score (in the negative direction) between test sessions pre 1 and pre 2 for perception of the /s/-/sh/ contrast. The change in the group mean score was primarily attributable to one subject (S5) whose contrast score dropped 29 percentage points (79.2% to 50%).

instances where order appears as a significant factor can be attributed to the fact that the two groups were essentially different to begin with. An interaction involving order and time would suggest a real order effect but that was not evident in the 5-way repeated analysis. An order effect was shown in the 5-way simple analysis involving time and this underscores the essential differences between the subjects in each group. We cannot conclude, therefore that order of training had an effect on the pattern of change in performance over time. Moreover, there is no evidence from this analysis that the specific type of training (production or perception) was relevant. There was, however, a tendency for perception scores to increase more during perception training. This issue clearly needs further investigation.

A surprising finding was the significant increase in group mean scores for perception of the /s/-/sh/ contrast between post 2 and post 3 test sessions. Subjects used broadband amplification in test sessions pre1 through post 2. At post 3 test session subjects used their personal hearing aids. It was expected that performance would drop as the personal hearing aids deprived the children of the high frequency information that had been available during training. In fact the change was in the other direction. As indicated earlier, a possible explanation is that subjects were using the strategy of deciding a stimulus contained an /s/ if there was a weak or absent sound. An absence of sound for an /s/ would occur when subjects were using their personal hearing aids because the spectral peaks for /s/ were above the 3500 Hz cutoff. This strategy would not be successful when subjects were using the broadband amplification system because the speech cues for /s/ in the higher frequencies were available to them.

At first sight, the data seem to suggest that the personal hearing aid is better than broadband amplification. In fact these findings point to the danger of using binary forced-choice discrimination tests in studies of this type.

The results indicated significant variability in individual performance scores. The audiometric characteristics of the six subjects suggest that subject 1 and subject 5 were ideal candidates for the program because of their good high frequency hearing. Indeed, the scores for subject 5 were above the 95% confidence level on all test sessions, except session pre 2. However, the scores for subject 1 were different from what was expected. This subject's scores only exceeded the 95% confidence level at one test session (post 1).

The audiometric characteristics of subject 2 and subject 3 suggested that they should have been good candidates for the program because of their fair high frequency hearing. However, performance scores for subject 2 were different from what was expected. This subject's scores exceeded chance level at one test session only (post 1). In the method's chapter subject 2 is described as an eleven-year-old male who had only worn hearing aids consistently for two years. The performance of subject 3 is in line with the expectations based on his audiometric characteristics. His scores increased during the program and were above the 95% confidence level at sessions post 1 and post 2.

The audiometric characteristics of subject 4 and subject 6 (severe-to- profound hearing loss) suggested that they were questionable candidates for the program. However the scores for both these subjects resulted in successful performances. Subject 4 exceeded chance performance from the mid 2 test session onward and subject 6 exceeded chance performance after the first training (mid 1) was completed. Reports indicated that subject 6 was enrolled in an early intervention program for hearing-impaired children that emphasized the use of amplification with auditory-oral training.

These findings, concerning individual subjects' performance, suggest that caution is necessary when attempting to predict a subject's performance from audiometric data alone. Other factors, such as a subject's previous training, attention, and motivation, may also impact on his or her performance in a speech-training program.

A surprising finding was that subjects' scores for contrast perception for the female talker were better, on average, than for the male talker. There was no difference in the intensity of the items in each of the talkers' recordings. During editing intensity normalization was used for each of the items in the articulation test. Acoustic analysis for three pairs of stimuli from the /s/-/sh/ articulation test revealed the peak values for /sh/ and /s/, for the female talker, to be at higher frequencies (6300-8000 Hz) than for the male talker (3200-5100 Hz). Appendix I contains a table with the lowest peak values for the three /s/-/sh/ pairs from the Articulation test. Appendix J contains spectrograms for one pair of the /s/-/sh/ stimuli for the male talker and the female talker. The measured values for /s/ are consistent with the data published by Boothroyd and Medwetsky, (1992) who found that females had higher spectral peak frequencies for /s/ (6.2 kHz – 8.4 kHz) than males (3.2 kHz – 5.1 kHz). These data support the notion that subjects were not using the frequency cues but the strategy of 'absent s,' (that is, that a stimulus contained an 's' if there was a weak or absent sound). This strategy would be more successful with the female talker than with the male talker.

Speech Production

The production scores for the /s/-/sh/ contrast for the group improved over the course of the experimental-training program. The improvement in speech production scores is in keeping with previous experimental speech-training (Boothroyd and Gorzycki 1977, Osberger, Johnstone, Swarts, and Levitt 1978, Olmstead and Ling 1984), which found that training hearing-impaired children's speech resulted in improved speech scores. In fact, this author knows of no experimental speech-training program that has not reported improved speech production for the enrolled subjects.

The results reported in this study are similar to those in the speech-training program reported by Boothroyd and Gorzycki, (1977). The authors reported that by the end of their speech-training program over half the subjects were producing two sibilants that were judged by listeners, to be acceptable (i.e. 75% probability of correct identification). In the present study 3 of the 6 subjects produced scores above 75% for the contrast.

An unexpected finding in the production data was that much of the improvement occurred between session pre1 and session pre 2, which was a no-treatment period. A possible explanation is that the subjects had to spend part of the first session (pre 1) becoming familiar with the test procedures and equipment that they would be using in the training program. In retrospect, it might have been wise to include an additional pre-training test session to establish a baseline. In spite of this finding it is interesting to note that production scores continued to rise during the course of the program.

Even after the second pretest, there is no evidence to support the conclusion that production scores improved more during treatment than no-treatment periods. It should be noted, however, that motor skills often continue to improve after formal training. The absence of an association between the change in scores and formal training periods does not therefore exclude the possibility that the training helped cause the improvement.

The experimental data revealed bias in favor of production of /sh/. The small improvement in production scores for /s/ and greater improvement for /sh/ could be attributed to the use of personal hearing aids during informal training. The subjects wore the headphones for the broadband amplification system during the computer-based training. The bandwidth of high powered personal hearing aids is limited to around 3.5 kHz. The acoustic cues necessary for the perception of /s/, are outside the range of the subjects' personal hearing aids. The subjects would therefore have been unable to hear their own productions of /s/. Production training was directed towards subjects using appropriate lingual movements for the production of the /s/-/sh/ contrast. Subjects also would have heard the acoustic cues for /sh/ because the spectral energy was within the bandwidth of their personal hearing aids. This would result in subjects being more successful at integrating the motor and acoustic patterns for /sh/ because they could hear their production of /sh/. Training for /s/ would be less successful because subjects only heard their production of /s/ when they were wearing the headphones. Any future study should have subjects wear the headphones for the broadband amplification system during both informal and computer-based training.

How much of the improvement in production scores was due to the use of the /s/ indicator was not determined in this study. Subjects were able to operate the indicator themselves during rehearsal of consonant production and it provided subjects' with another type of feedback on production performance.

Results suggest that improvements in subjects' production and perception of the /s/-/sh/ contrast occurred during this experimental speech-training program. However this does not necessarily mean that the experimental-training caused the improved performances. To deal with this issue this experimental training program had two controls. One was the inclusion of no-treatment periods. The other was the inclusion of the IMSPAC test. The fact that there were not significant gains during the no-treatment periods seems to support a cause-effect relationship for the perception data. The small improvement in the subjects' scores on IMSPAC, for the audition condition, adds support for the improved perception performance being the result of the training. Results do not indicate, however, that the type of training the subjects received had an effect on the changes in performance.

There was a small improvement in the subjects' scores on IMSPAC for the audition + vision condition and this adds support to the notion that a general improvement in production resulted from the training program. However improvements in /s/-/sh/ production scores could not be tied to the type of training received, or even the presence of training.

There are two important differences between the /s/-/sh/ articulation test and IMSPAC. First the subjects had much more practice on the /s/-/sh/ task because there were seven testing sessions during the training program whereas there were only two testing sessions for IMSPAC. Secondly the /s/-/sh/ test has more internal consistency than IMSPAC because it tests the same contrast all the time. These differences could account for some of the differences seen between improvement on the /s/-/sh/ task and improvement on the IMSPAC tasks. In other word the IMSPAC test may not have been an ideal control.

The relationship between speech perception and speech production

The results suggest that the group mean perception data may be used to predict the group mean production data at specific testing sessions. There appears to be a correlation between the scores because both scores improved over time. However, the number of students participating in the experimental-training program was small and the validity of some of the test materials particularly for the test of perception was questionable. Results indicated that it was not possible to predict production scores from perception scores for specific subjects. There was no discernible relationship between the perception and production data for the individual subjects enrolled in this training program. Indeed, the production score for subject 1 was 16 percentage points higher than the perception score. The question concerning the exact nature of the relationship between perception and production remains unanswered.

Summary of perception and production findings

1. Group mean performance scores on both the perception and production test improved during the course of the experimental training program.
2. The improvements were greater than those observed on the perception and production components of the IMSPAC test – on which no training was given. This observation supports the conclusion that details of the training were, in some sense, the cause of the improvements.
3. The pattern of change over time was different for the perception and production tasks.
4. For the perception task it was clear that significant improvements occurred during training periods but not during no-treatment periods. Nevertheless,

there was no evidence that greater improvements occurred during perception training than during production training.

5. For the production task there was no evidence that improvements were greater during training than no training. In fact the largest improvement occurred during the first no-treatment period. Because the observed improvements were not associated with training periods, the question of the importance of the type of training is, for the production data, moot.
6. Contrary to expectations, there was strong evidence that performance on the perception task was better with the female talker than with the male talker.
7. There was also evidence that performance on the perception task was better with personal hearing aids than with the broad band system.

Conclusions.

1. These findings support the potential benefits to be obtained from systematic training in the perception and production of phonologically significant details of speech.
2. They do not however, tell us about the optimal approach to training. It is still not clear, for example, whether a production-based program, a perception-based program, or a program that combines the two, will produce the best results in terms of the comprehension of speech and the production of intelligible speech.

3. There is strong evidence from these findings to suggest that the perception test used here was telling us less about the perception of the /s/-/sh/ contrast and more about the perception of intensity difference.
4. The unexpected talker and personal aid effects throw into question the assumption that adding previously unavailable acoustic cues is necessarily beneficial. At least within the constraints of the program and the perception test used here, things got worse, rather than better, when the amplification bandwidth was increased.

Clinical implications

This experimental training program used a controlled analytic approach to study improved perception and production for one phonological contrast. The approach was successful because progress could be evaluated and changes in performance could be recorded.

The phonological approach to improving speech perception and production skills was successful. This approach focused attention on the perceptual and production elements of the contrast, that is, the features that distinguish /s/ from /sh/.

Daily practice improved both perception and production scores for the contrast. In order for hearing-impaired children to improve their speech perception and production skills habilitation programs should include regular practice in perceiving and producing speech. However the exact nature of a speech-training program, that is, perception, production, or a combination of both types of training, could not be determined from the empirical data gathered in this study.

A speech training aid, an /s/ indicator, was used during production training. The indicator was helpful during rehearsal of the sibilants but how much of the improved production was due to the use of the indicator was not determined.

Further research

The absent 's' explanation for the unexpected findings regarding perception of male/female speech and broadband amplification needs further testing. Specifically a larger sample of female and male talkers is needed to establish the generality of the findings. In addition, recognition and identification tasks should be used – without feedback – in place of the binary choice task.

Interpretation of results would be facilitated by in-the-ear measures of hearing aid responses.

It would be useful to seek the acoustic correlates of the production changes observed here. In fact the data required for such an analysis are already available in the recordings prepared for this study.

It is clear that the ability of the present study to address the primary research question was limited by a variety of factors. Future studies of this type should involve: 1) More subjects

2) A wider range of contrasts.

3) More extensive baseline testing.

4) Enhanced amplification characteristics for both perception and production training.

APPENDICES

Appendix A

Imitative Test of Speech Pattern Contrast Perception (IMSPAC) A. Boothroyd

	LIST			
SUBTEST	A	B	C	D
Initial Consonant Continuance/ Vowel Height	soo	taw	saw	too
	nee	deh	neh	dee
	meh	bee	mee	beh
	daw	noo	doo	naw
	boo	moo	baw	maw
	tee	seh	teh	see
	chaw	shaw	choo	shoo
	sheh	chee	shee	cheh
Final Consonant Continuance/ Vowel Place	ehb	ehm	awb	awm
	ees	oot	oos	eet
	een	eed	oon	ood
	oosh	ooch	eesh	eech
	oom	eeb	eem	oob
	awch	awsh	ehch	ehsh
	eht	ehs	awt	aws
	awd	awn	ehd	ehn
Initial Consonant Place and Voicing	faw	vaw	saw	zaw
	doo	poo	boo	too
	baw	kaw	gaw	paw
	shoo	zhoo	foo	voo
	see	zee	shee	zhee
	THoo*	thoo**	zoo	soo
	kee	gee	tee	dee
	vee	fee	THee	thee
Final Consonant Place and Voicing	eez	eef	ees	eev
	oop	oot	oob	ood
	awk	awb	awg	awp
	awzh	awv	awsh	awf
	ooth	ooz	ooTH	oos
	eed	eek	eet	eeg
	awv	awTH	awf	awth
	oos	oosh	ooz	oozh
Syllable Number/ Intonation	oo!***	oo?	oo-oo!	oo-oo?
	oo?****	oo-oo!	oo-oo?	oo!
	eh-eh?	eh!	eh?	eh-eh!
	eh-eh!	eh-eh?	eh!	eh?
	aw?	aw-aw!	aw-aw?	aw!
	aw!	aw?	aw-aw!	aw-aw?
	ee-ee!	ee-ee?	ee!	ee?
	ee-ee?	ee!	ee?	ee-ee!

*TH – voiced ***! – falling intonation

th – unvoiced **? – rising intonation

Note: In two-syllable items, falling or rising occurs in the second syllable.

Appendix B
Training materials for /s/-/sh/ perception and production

Form A	Form B
sealed	gas
shield	gash
Have a sip	They sift
Have a ship	They shift
lease	sour
leash	shower
A clean seat	same
A clean sheet	shame
sue	He was socked
shoe	He was shocked
There is an ass	Where's the sign?
There is an ash	Where's the shine?

Appendix C
IMSPAC II
ONLINE IMSPAC TESTING PROGRAM USING TWO COMPUTERS
Center for Research in Speech and Hearing Sciences
Engineering Support Services
Eddy Yeung

Part of the IMSPAC procedure is to have four normal listeners listen to test items produced by hearing-impaired children. After obtaining the best possible production for each test item on digital audiotapes, the utterances are digitized by a Data 12-bit A/D board. A computer program presents the child's production and records the normal listener's responses. The procedure takes about two to three weeks to complete from start to finish.

To look for alternatives to speed up the long process of IMSPAC testing, an online version of the procedure was set up. One computer presents digitized test items to the hearing-impaired child via headphones while another computer is used by the tester, who is also the listener, to record the judgements made by the tester. The tester computer controls the subject computer via serial cable. Since the tester should not hear what the subject is listening, the tester is also under the headphones. To mask the test items from the tester, white noise was presented to the tester while the test items are being played. Once the test item is finished playing, a microphone, which is attached to the subject, is turned on to monitor the response from the subject.

The advantages of using this setup is that the test stimuli presented to the hearing-impaired child is not tester dependent and it is relatively fast. The disadvantages are that it is presented in text and/or audio only and more than one listener is needed to provide reliable data.

The setup was used by Chris Kosky for her dissertation and will be reported on later. The report will describe the hardware and software used for IMSPAC 2.

A detailed description of the IMSPAC procedure can be found in 'Speech perception and Production in Hearing-Impaired Children' (palm.doc).

DESCRIPTION

The IMSPAC 2 setup consists of two portable computers, a serial cable, a SPS (ESS #6) box, two headphones (Seinheiser MD414 and TDH-50), and a microphone (Realistic clip-on 33-1052). A block diagram is shown in Figure 1.

The tester computer controls all the functions on the subject computer via the serial port. Though all the control is on the tester computer, it does not require a powerful computer. A 386SX-laptop computer (Zeos 386SX) was used for CK's experiments (The computer was later stolen). The subject computer, which performs most of the major functions, contains a ProAudio

Spectrum 16 soundboard (discontinued) for sound playback. The computer was a 486Sx laptop computer (Toshiba 6400) with a built-in ISA slot for the soundboard. Newer computers would not require a soundboard because the sound functions are built-in or a PCMCIA sound card can be used instead.

The program for each computer was written in Microsoft Quick C for DOS V2.5. The testing computer software controls all the functions on the subject computer as well as the data collection and software.

The program on the tester computer is sub-divided into 5 sections and menu driven for easy usage. The sections are Run subject, Calibrate levels, Change parameters, Retrieve subject data, and Exit program.

The tester sets up the program by setting the parameters. The parameter section enable the tester to set the type of testing (IMSPAC, articulation perception, articulation production), test condition (testing, basic training, advance training), speaker (male, female), feedback, test order (random, in sequence), presentation condition if testing IMSPAC (audio only, text only, audio+text), stimulus ON time if not IMSPAC (0-2 sec), and response control if not IMSPAC (tester, subject). After the parameters are set, the tester should calibrate the presentation levels by selecting 'Calibrate levels' from the main menu. The levels can also be adjusted anytime while testing.

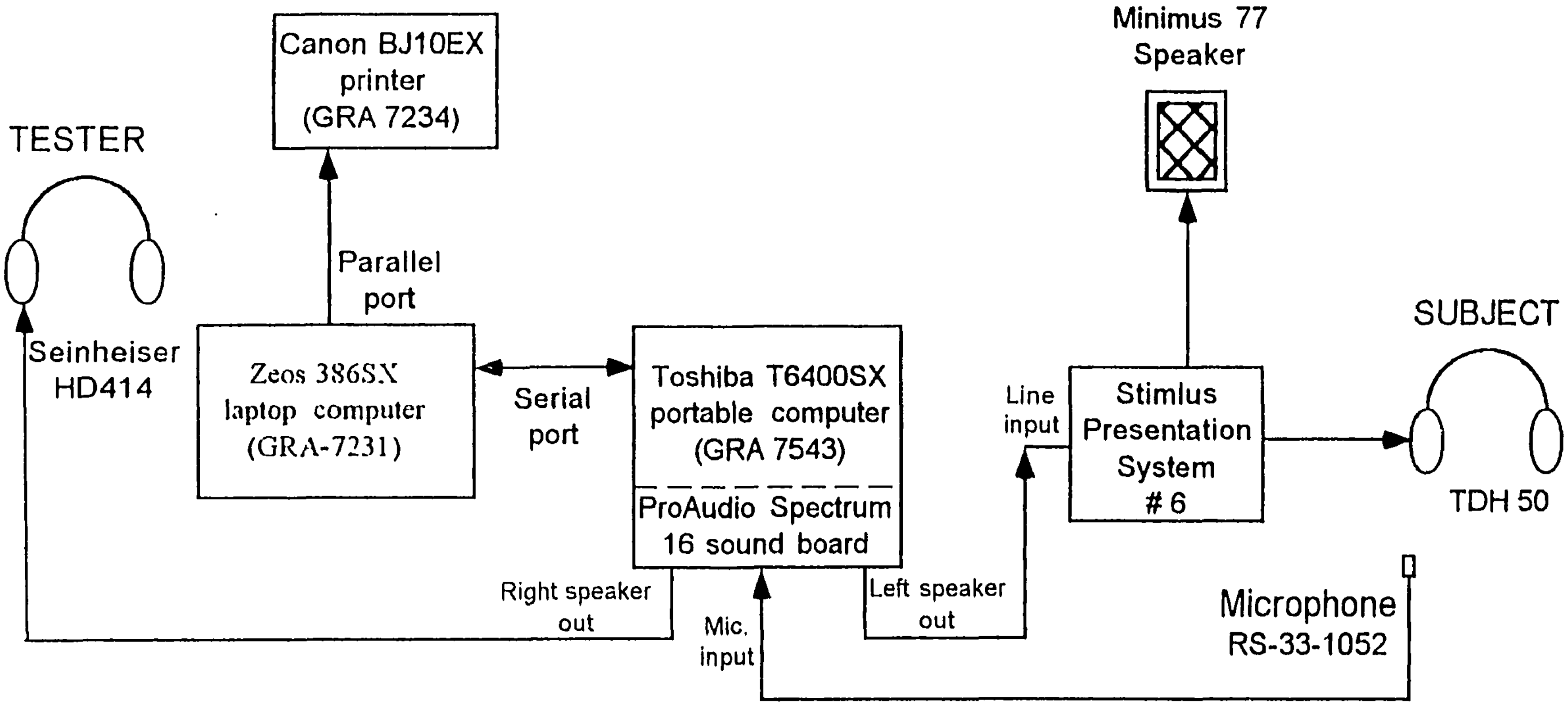
The 'Run subject' selection requires the tester to enter the subject's information and then updates a subject database that keeps track on the progress of the subject. After the subtest and form are picked, the testing begins. After the testing is completed, the subject data is automatically saved on the hard drive. The data can be printed right away or retrieved and presented at a later time.

All the commands used to communicate between the computers are listed in Table 1. The command uses a control sequence that tells the computer what to expect next. The testing parameters such as which subtest is sent to the subject computer by encoding the information in 2 bytes (integer).

The subject computer handles all the audio processing as well as handling subject responses when that option is selected. When the program starts, it initializes the ProAudio Spectrum 16 soundboard and set the volume levels to 70%. Then the program will wait until a command is sent from the testing computer. Essentially the subject computer is the slave computer and it handles most of the work.

All the sound files are stored on the subject computer. For the IMSPAC with any of the audio conditions, a stereo file is generated with the stimulus on the left channel and white noise on the right channel. This was done to mask the tester/listener from hearing the stimulus that is played to the subject.

To retrieve subject data, the user would enter the file name. The retrieved data can be displayed on screen or printed out on the printer.



BLOCK DIAGRAM FOR THE IMSPAC 2 TEST SYSTEM

Table 1. Control commands between computers

COMMAND	Function
CTRL.-A	Marks beginning of a word
CTRL.-B	Marks beginning for a group of words.
CTRL.-D	Marks beginning of answer.
CTRL.-E	Marks beginning of test parameters.
CTRL.-F	Provide feedback to subject.
CTRL.-H	Marks beginning of subtest selection.
CTRL.-I	Marks beginning of form selection.
CTRL.-J	Marks beginning of subject response.
CTRL.-K	Turn microphone level down 2%.
CTRL.-L	Marks beginning of volume level control.
CTRL.-M	Turn microphone level control up 2%.
CTRL.-N	Clear screen.
CTRL.-O	Play calibration signal.
CTRL.-P	Play speech signal.
CTRL.-Q	Quit current test.
CTRL.-R	Request volume level.
CTRL.-S	Play threshold signal.
CTRL.-T	Replay.
CTRL.-U	Turn tester volume level up 2%.
CTRL.-V	Turn tester volume level down 2%.
CTRL.-X	Exit program.
CTRL.-Z	End of testing.

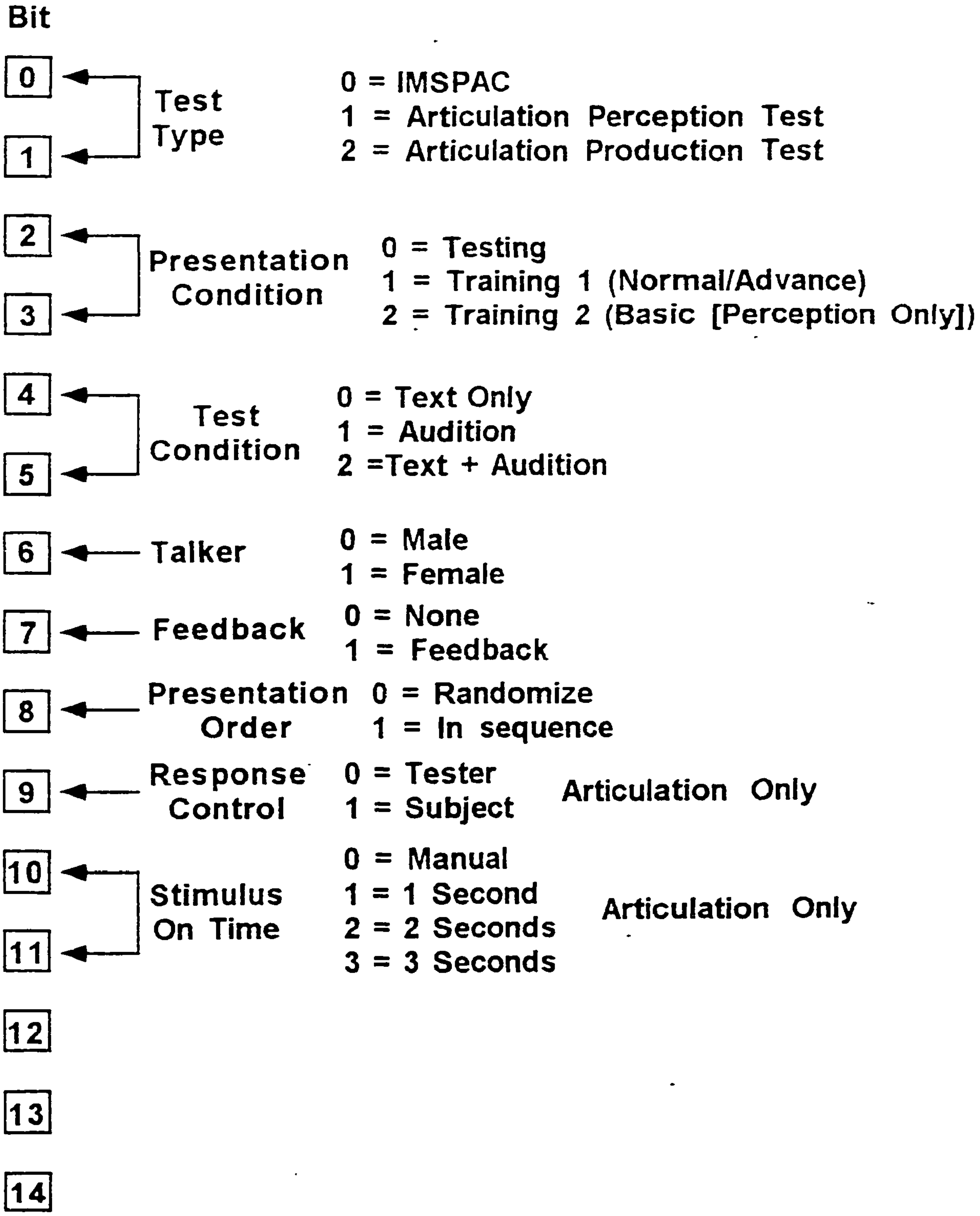


Figure 2. Parameter Data Encoding

Appendix D

Listener Response Form for Production of the /s/-/sh/ contrast

Subject:
Listener:
Date:

Listener's Instructions

You will hear an utterance spoken by a hearing-impaired child. For each test item there are two response alternatives on the answer form. One response contains the phoneme /s/ and the other response contains the phoneme /sh/. Please circle one of the two choices given for each test item. If an utterance does not sound like one of the two alternatives please make a guess and circle one of the choices.

1. aasaa

   aashaa

2. aasaa

   aashaa

3. plus

   plush

4. Save my legs

   Shave my legs

5. sew

   show

6. plus

plush

7. my sack

my shack

8. Save my legs

Shave my legs

9. eesee

eeshee

10. eesee

eeshee

11 sew

show

12. my sack

my shack

13. sore

shore

14. oosoo

ooshoo

15. oosoo

    ooshoo

16. Sell some beans

    Shell some beans

17. Sell some beans

    Shell some beans

18. What's a sole?

    What's a shoal?

19. see

    she

20. What's a sole?

    What's a shoal?

21. cats

    catch

22 . Sell some beans

    Shell some beans

23. see

    she

24. cats

catch

Appendix E

IMSPAC

INSTRUCTIONS FOR LISTENERS

You will be listening to a number of nonsense words spoken by hearing-impaired children. For each word you hear, you will see four (4) response alternatives on the monitor. Please push the number on the keyboard corresponding to the word you heard for each item. If you would like to hear an item a second time before you respond, push the spacebar on the keyboard.

It is possible that some items may not sound like the alternatives displayed on the monitor. Always guess if you are unsure. It is important that you respond for each item.

HINTS: UPPERCASE "TH" IS VOICED AS IN THE WORD 'THESE.'
LOWERCASE "th" IS UNVOICED AS IN THE WORD "THINK."
"OO?' HAS A RISING INTONATION AS IN A QUESTION.
"OO!" HAS A FALLING INTONATION AS IN A STATEMENT.

Appendix F

Percent correct perception scores for /sh/, /s/, and the average of the two as a function of testing session. Data are shown for each of the 6 subjects, the mean of the group, and the difference between /s/ and /sh/.

Subject	Sound	Pre1	Pre2	Pre-avg	Training A	Mid1	Mid2	Mid-avg	Training B	Post1	Post2	Post-avg	Postaid
CB	/sh/	50.0	25.0	37.5	Perception	66.7	58.3	62.5	Production	66.7	50.0	58.4	66.7
	/s/	50.0	75.0	62.5		58.3	58.3	58.3		83.3	50.0	66.7	50.0
	Both	50.0	50.0	50.0		62.5	58.3	60.4		75.0	50.0	62.5	58.4
	Diff	0.0	-50.0	-25.0		8.4	0.0	4.2		-16.6	0.0	-8.3	16.7
IG	/sh/	50.0	33.3	41.7	Production	58.3	83.3	70.8	Perception	75.0	66.7	70.9	66.7
	/s/	58.3	58.3	58.3		58.3	33.3	45.8		66.7	50.0	58.4	66.7
	Both	54.2	45.8	50.0		58.3	58.3	58.3		70.9	58.4	64.6	66.7
	Diff	-8.3	-25.0	-16.7		0.0	50.0	25.0		8.3	16.7	12.5	0.0
JB	/sh/	75.0	33.3	54.2	Perception	25.0	50.0	37.5	Production	58.3	66.7	62.5	91.7
	/s/	16.7	41.7	29.2		66.7	66.7	66.7		50.0	83.3	66.7	100.0
	Both	45.9	37.5	41.7		45.9	58.4	52.1		54.2	75.0	64.6	95.9
	Diff	58.3	-8.4	25.0		-41.7	-16.7	-29.2		8.3	-16.6	-4.2	-8.3
JT	/sh/	58.3	66.7	62.5	Production	58.3	75.0	66.7	Perception	75.0	75.0	75.0	100
	/s/	58.3	58.3	58.3		50.0	66.7	58.4		91.7	83.3	87.5	75
	Both	58.3	62.5	60.4		54.2	70.9	62.5		83.4	79.2	81.3	87.5
	Diff	0.0	8.4	4.2		8.3	8.3	8.3		-16.7	-8.3	-12.5	25.0
OG	/sh/	83.3	50.0	66.7	Perception	91.7	58.3	75.0	Production	91.7	83.3	87.5	91.7
	/s/	75.0	50.0	62.5		91.7	83.3	91.7		91.7	91.7	91.7	91.7
	Both	79.2	50.0	64.6		91.7	70.8	83.4		91.7	87.5	89.6	91.7
	Diff	8.3	0.0	4.2		0.0	-25.0	-16.7		0.0	-8.4	-4.2	0.0
PL	/sh/	66.7	83.3	75.0	Production	75.0	100.0	87.5	Perception	91.7	75.0	83.4	91.7
	/s/	41.7	25.0	33.4		66.7	75.0	70.9		66.7	75.0	70.9	100.0
	Both	54.2	54.2	54.2		70.9	87.5	79.2		79.2	75.0	77.1	95.9
	Diff	25.0	58.3	41.7		8.3	25.0	16.7		25.0	0.0	12.5	-8.3
Mean	/sh/	63.9	48.6	56.2		62.5	70.8	66.7		76.4	69.5	72.9	84.8
	/s/	50.0	51.4	50.7		65.3	63.9	64.6		75.0	72.2	73.6	80.6
	Both	56.9	50.0	53.5		63.9	67.4	65.6		75.7	70.8	73.3	82.7
	Diff	13.9	-2.8	5.6		-2.8	6.9	2.1		1.4	-2.8	-0.7	4.2

Percent correct perception scores for the male talker for /sh/, /s/, and the average of the two as a function of testing session. Data are shown for each of the 6 subjects, for the mean of the group, and for the difference between /s/ and /sh/ scores.

Subject	Sound	Pre1	Pre2	Pre-avg	Training A	Mid1	Mid2	Mid-avg	Training B	Post1	Post2	Post-avg	Postaid
CB	/sh/	66.7	16.7	41.7	Perception	83.3	50.0	66.7	Production	66.7	33.3	50.0	66.7
	/s/	66.7	66.7	66.7		66.7	66.7	66.7		83.3	33.3	58.3	66.7
	Both	66.7	41.7	54.2		75.0	58.4	66.7		75.0	33.3	54.2	66.7
	Diff	0.0	-50.0	-25.0		16.7	-16.7	0.0		-16.7	0.0	-8.4	0.0
IG	/sh/	50.0	50.0	50.0	Production	50.0	83.3	66.7	Perception	83.3	66.7	75.0	66.7
	/s/	66.7	83.3	75.0		50.0	50.0	50.0		83.3	33.3	58.3	50.0
	Both	58.3	66.7	62.5		50.0	66.7	58.3		83.3	50.0	66.7	58.3
	Diff	-16.7	-33.3	-25.0		0.0	33.3	16.7		0.0	33.3	16.7	16.7
JB	/sh/	66.7	16.7	41.7	Perception	33.3	0.0	16.7	Production	16.7	33.3	25.0	83.3
	/s/	33.3	33.3	33.3		50.0	33.3	41.7		16.7	66.7	41.7	100.0
	Both	50.0	25.0	37.5		41.7	16.7	29.2		16.7	50.0	33.3	91.7
	Diff	33.3	-16.7	8.3		-16.7	-33.3	-25.0		0.0	-33.3	-16.7	-16.7
JT	/sh/	50.0	83.3	66.7	Production	66.7	66.7	66.7	Perception	83.3	83.3	83.3	100.0
	/s/	50.0	66.7	58.3		66.7	66.7	66.7		100.0	83.3	91.7	66.7
	Both	50.0	75.0	62.5		66.7	66.7	66.7		91.7	83.3	87.5	83.3
	Diff	0.0	16.7	8.3		0.0	0.0	0.0		-16.7	0.0	-8.3	33.3
OG	/sh/	66.7	66.7	66.7	Perception	100.0	50.0	75.0	Production	83.3	83.3	83.3	83.3
	/s/	66.7	66.7	66.7		100.0	83.3	66.7		100.0	83.3	91.7	83.3
	Both	66.7	66.7	66.7		100.0	66.7	70.8		91.7	83.3	87.5	83.3
	Diff	0.0	0.0	0.0		0.0	-33.3	8.3		-16.7	0.0	-8.3	0.0
PL	/sh/	33.3	66.7	50.0	Production	50.0	100.0	75.0	Perception	83.3	50.0	66.7	83.3
	/s/	33.3	0.0	16.7		33.3	66.7	50.0		33.3	83.3	58.3	100.0
	Both	33.3	33.3	33.3		41.7	83.3	62.5		58.3	66.7	62.5	91.7
	Diff	0.0	66.7	33.3		16.7	33.3	25.0		50.0	-33.3	8.3	-16.7
Mean	/sh/	55.6	50.0	52.8		63.9	58.3	61.1		69.4	58.3	63.9	80.6
	/s/	52.8	52.8	52.8		61.1	61.1	56.9		69.4	63.9	66.7	77.8
	Both	54.2	51.4	52.8		62.5	59.7	59.0		69.4	61.1	65.3	79.2
	Diff	2.8	-2.8	0.0		2.8	-2.8	4.2		0.0	-5.6	-2.8	2.8

Percent correct perception scores for the female talker for /sh/, /s/, and the average of the two as a function of testing session. Data are shown for each of the 6 subjects, for the mean of the group, and for the difference between /s/ and /sh/ scores.

Subject	Sound	Pre1	Pre2	Pre-avg	Training A	Mid1	Mid2	Mid-avg	Training B	Post1	Post2	Post-avg	Postald
CB	/sh/	33.3	33.3	33.3	Perception	50.0	66.7	58.3	Production	66.7	66.7	66.7	66.7
	/s/	33.3	83.3	58.3		50.0	50.0	50.0		83.3	66.7	75.0	33.3
	Both	33.3	58.3	45.8		50.0	58.3	54.2		75.0	66.7	70.8	50.0
	Diff	0.0	-50.0	-25.0		0.0	16.7	8.3		-16.7	0.0	-8.3	33.3
IG	/sh/	50.0	16.7	33.3	Production	66.7	83.3	75.0	Perception	66.7	66.7	66.7	66.7
	/s/	50.0	33.3	41.7		66.7	16.7	41.7		50.0	66.7	58.3	83.3
	Both	50.0	25.0	37.5		66.7	50.0	58.3		58.3	66.7	62.5	75.0
	Diff	0.0	-16.7	-8.3		0.0	66.7	33.3		16.7	0.0	8.3	-16.7
JB	/sh/	83.3	50.0	66.7	Perception	16.7	100.0	58.3	Production	100.0	100.0	100.0	100.0
	/s/	0.0	50.0	25.0		83.3	100.0	91.7		83.3	100.0	91.7	100.0
	Both	41.7	50.0	45.8		50.0	100.0	75.0		91.7	100.0	95.8	100.0
	Diff	83.3	0.0	41.7		-66.7	0.0	-33.3		16.7	0.0	8.3	0.0
JT	/sh/	66.7	50.0	58.3	Production	50.0	83.3	66.7	Perception	66.7	66.7	66.7	100.0
	/s/	66.7	50.0	58.3		33.3	66.7	50.0		83.3	83.3	83.3	83.3
	Both	66.7	50.0	58.3		41.7	75.0	58.3		75.0	75.0	75.0	91.7
	Diff	0.0	0.0	0.0		16.7	16.7	16.7		-16.7	-16.7	-16.7	16.7
OG	/sh/	100.0	33.3	66.7	Perception	83.3	66.7	75.0	Production	100.0	83.3	91.7	100.0
	/s/	83.3	33.3	58.3		83.3	83.3	83.3		83.3	100.0	91.7	100.0
	Both	91.7	33.3	62.5		83.3	75.0	79.2		91.7	91.7	91.7	100.0
	Diff	16.7	0.0	8.3		0.0	-16.7	-8.3		16.7	-16.7	0.0	0.0
PL	/sh/	100.0	100.0	100.0	Production	100.0	100.0	100.0	Perception	100.0	100.0	100.0	100.0
	/s/	50.0	50.0	50.0		100.0	83.3	91.7		100.0	66.7	83.3	100.0
	Both	75.0	75.0	75.0		100.0	91.7	95.8		100.0	83.3	91.7	100.0
	Diff	50.0	50.0	50.0		0.0	16.7	8.3		0.0	33.3	16.7	0.0
Mean	/sh/	72.2	47.2	59.7		61.1	83.3	72.2		83.3	80.6	81.9	88.9
	/s/	47.2	50.0	48.6		69.4	66.7	68.1		80.6	80.6	80.6	83.3
	Both	59.7	48.6	54.2		65.3	75.0	70.1		81.9	80.6	81.3	86.1
	Diff	25.0	-2.8	11.1		-8.3	16.7	4.2		2.8	0.0	1.4	5.6

Appendix G

Percent correct production scores for /sh/, /s/, and the average of the two as a function of testing session. Data are shown for each of the 6 subjects, for the mean of the group, and for the difference between /s/ and /sh/.

Subject	Sound	Pre1	Pre2	Pre-avg	Training A	Mid1	Mid2	Mid-avg	Training B	Post1	Post2	Post-avg	Postaid
CB	/sh/	72.9	91.7	82.3	Perception	87.5	83.3	85.4	Production	85.4	83.3	84.4	97.9
	/s/	33.3	33.3	33.3		60.4	45.8	53.1		47.9	66.7	57.3	66.7
	Both	53.1	62.5	57.8		74.0	64.6	69.3		66.7	75.0	70.8	82.3
	Diff	39.6	58.3	49.0		27.1	37.5	32.3		37.5	16.7	27.1	31.3
IG	/sh/	62.5	83.3	72.9	Production	75.0	87.5	81.3	Perception	93.8	79.2	86.5	64.6
	/s/	60.4	66.7	63.5		41.7	29.2	35.4		37.5	31.3	34.4	20.8
	Both	61.5	75.0	68.2		58.3	58.3	58.3		65.6	55.2	60.4	42.7
	Diff	2.1	16.7	9.4		33.3	58.3	45.8		56.3	47.9	52.1	43.8
JB	/sh/	56.3	83.3	69.8	Perception	87.5	91.7	89.6	Production	93.8	97.9	95.8	93.8
	/s/	72.9	75.0	74.0		64.6	66.7	65.6		72.9	64.6	68.8	70.8
	Both	64.6	79.2	71.9		76.0	79.2	77.6		83.3	81.3	82.3	82.3
	Diff	-16.7	8.3	-4.2		22.9	25.0	24.0		20.8	33.3	27.1	22.9
JT	/sh/	29.2	18.8	24.0	Production	91.7	97.9	94.8	Perception	97.9	97.9	97.9	100.0
	/s/	68.8	83.3	76.0		87.5	89.6	88.5		100.0	77.1	88.5	85.4
	Both	49.0	51.0	50.0		89.6	93.8	91.7		99.0	87.5	93.2	92.7
	Diff	-39.6	-64.6	-52.1		4.2	8.3	6.2		-2.1	20.8	9.4	14.6
OG	/sh/	41.7	83.3	62.5	Perception	45.8	66.7	56.3	Production	85.4	91.7	88.5	89.6
	/s/	83.3	75.0	79.2		70.8	100.0	85.4		100.0	93.8	96.9	93.8
	Both	62.5	79.2	70.8		58.3	83.3	70.8		92.7	92.7	92.7	91.7
	Diff	-41.7	8.3	-16.7		-25.0	-33.3	-29.2		-14.6	-2.1	-8.3	-4.2
PL	/sh/	87.5	93.8	90.6	Production	97.9	100.0	99.0	Perception	91.7	100.0	95.8	100.0
	/s/	25.0	33.3	29.2		41.7	56.3	49.0		41.7	60.4	51.0	91.7
	Both	56.3	63.5	59.9		69.8	78.1	74.0		66.7	80.2	73.4	95.8
	Diff	62.5	60.4	61.5		56.3	43.8	50.0		50.0	39.6	44.8	8.3
Mean	/sh/	58.3	75.7	67.0		80.9	87.8	84.4		91.3	91.7	91.5	91.0
	/s/	57.3	61.1	59.2		61.1	64.6	62.8		66.7	65.6	66.1	71.5
	Both	57.8	68.4	63.1		71.0	76.2	73.6		79.0	78.6	78.8	81.3
	Diff	1.0	14.6	7.8		19.8	23.3	21.5		24.7	26.0	25.3	19.4

Appendix H

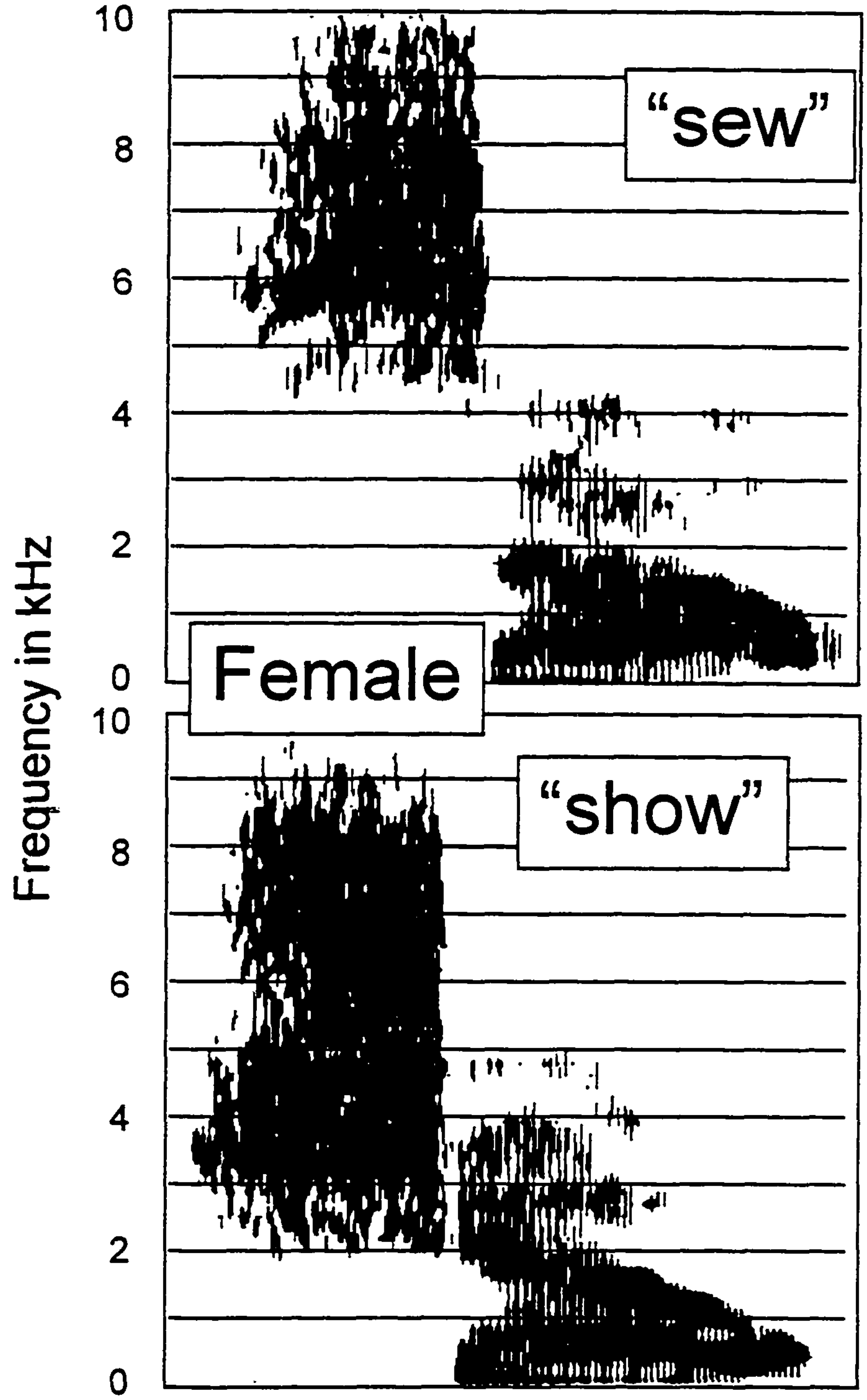
IMSPAC SCORES

	audition+ vision		audition alone	
Subjects	pre score	post score	pre score	post score
1-cb	87.5	98.8	76.3	87.5
2-ig	78.8	90.0	56.3	61.3
3-jb	83.3	86.3	60.0	76.3
4-jt	88.8	92.5	63.8	82.5
5-og	95.0	97.5	82.5	88.8
6-pl	91.3	97.5	70.0	87.5

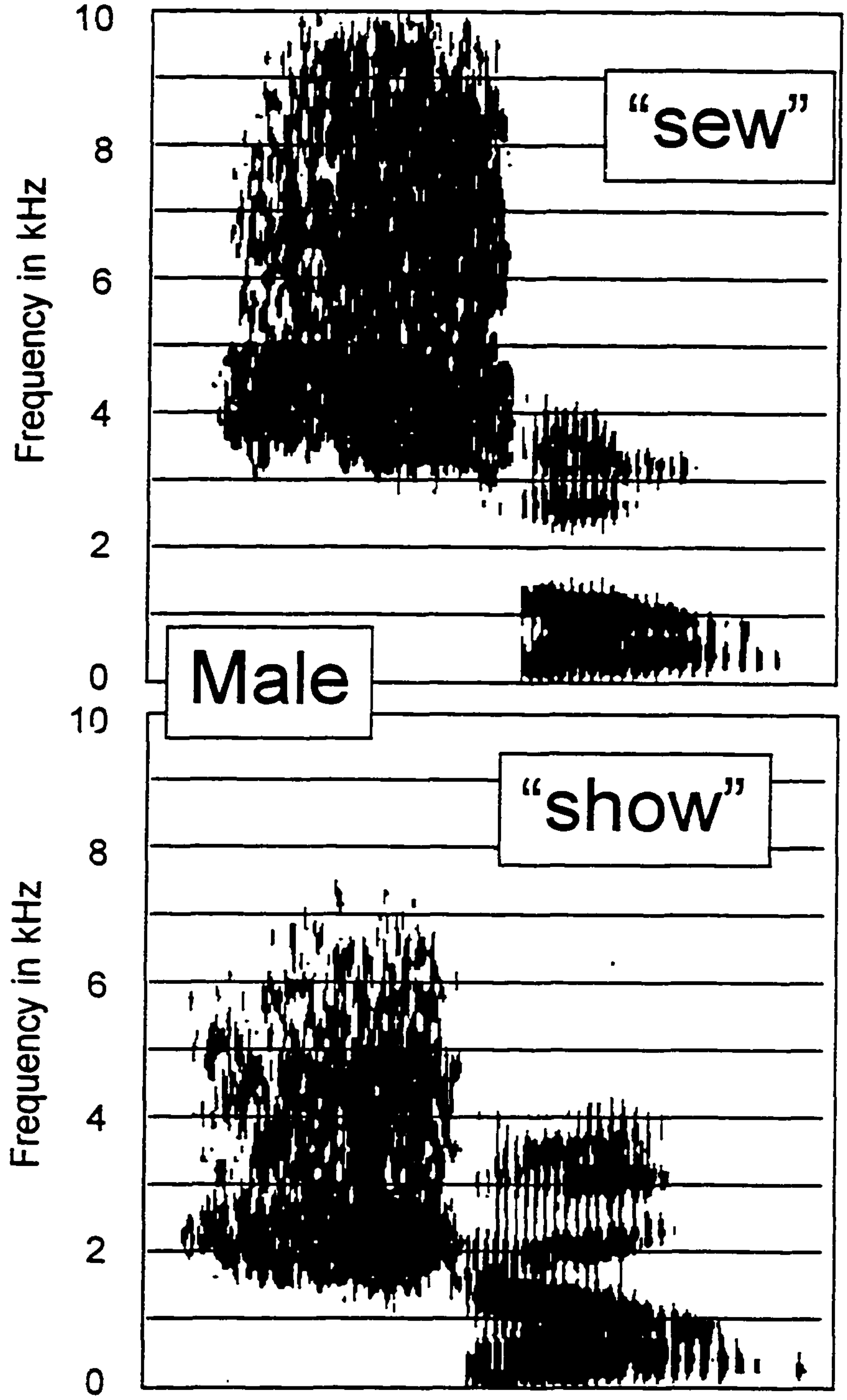
Appendix I

The lowest spectral energy peaks (Hz) for three of the /s/-/sh/ contrast pairs spoken by the male talker and the female talker.

	Male Talker		Female talker	
Spectral peak values	/s/	/sh /	/s/	/sh/
Contrast -Pair 1	4000	2500	6000	3500
- Pair 2	4000	2200	6500	3500
- Pair 3	4000	2300	7000	3000
Average peak value	4000	2333	6500	3333



Spectrograms of a sample pair of utterances from the /s/-/sh/ perception test, spoken by the female talker.



Spectrograms of a sample pair of utterances from the /s/-/sh/ perception tėst, spoken by the male talker.

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IMAGE EVALUATION
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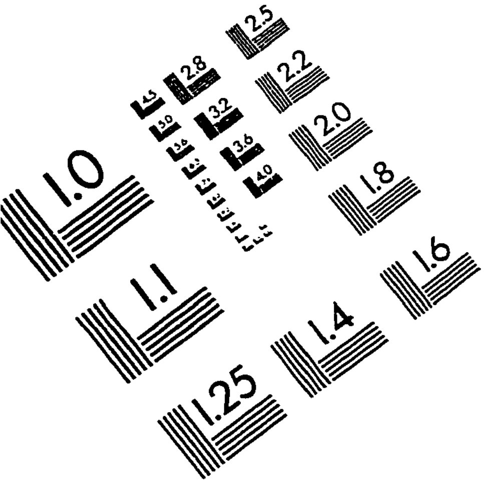

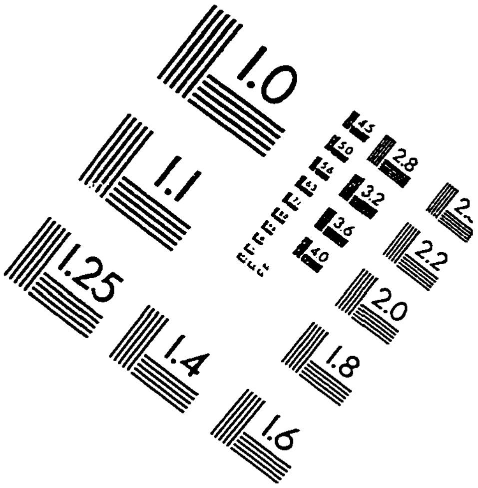

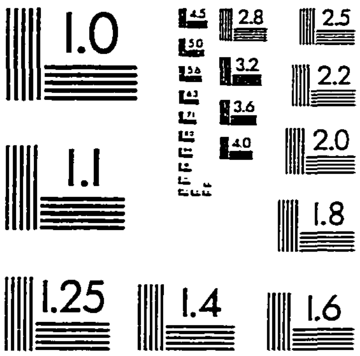

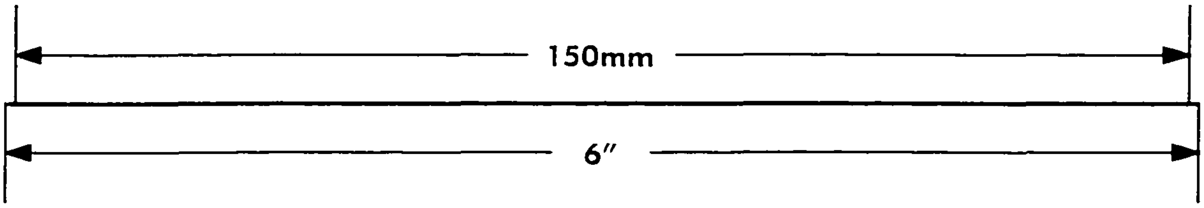

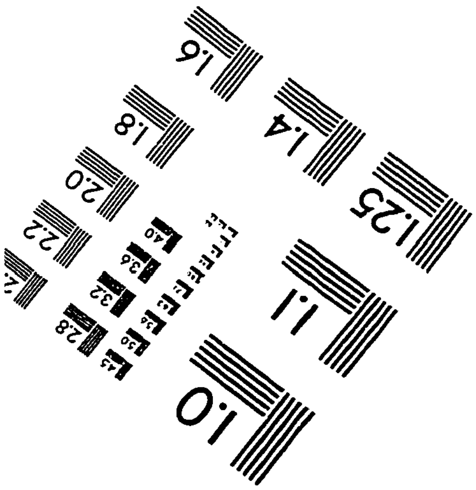

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