To the Graduate Council:

I am submitting herewith a thesis written by Laura Elise Brock entitled "Temporary Threshold Shift in Organists' Hearing." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Audiology.

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TEMPORARY THRESHOLD SHIFT IN ORGANISTS' HEARING

A Thesis

Presented for the

Master of Arts

Degree

The University of Tennessee, Knoxville

Laura Elise Brock
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DEDICATION

This thesis is dedicated to my parents,
Mr. John P. Brock, Jr. and Mrs. Dinah L. Brock,
for being patient and supportive throughout my entire education,
and for teaching me all the things that formal education cannot.

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ABSTRACT

Ten organists (6 male, 4 female) aged 23-54 years, 80% of which were asymptomatic for otologic pathology, the exceptions being one flat, moderate sensorineural hearing loss and one moderate, low frequency sensorineural hearing loss, were evaluated with hearing history questionnaire, otoscopic exam, otologic questionnaire and pure tone audiometry. Bone conduction testing verified no conductive hearing loss in any subject. With respect to age and number of years playing, findings indicate normal or better than expected hearing for 50% of the subjects and a pattern of a slight noise notch at 6 k Hz in the other 50%. After audiometric examination each organist played the organ for two hours under identical practice conditions and was retested with puretones to assess temporary threshold shift (TTS) in hearing. There was no significant TTS in any subject when data was statistically analyzed, however TTSs as large as 15 dB were recorded in individual cases. Spectral content of the organ music played in the sessions was found to have a dominant frequency at approximately 500-750 Hz.

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LIST OF ABBREVIATIONS

Decibel	dB
Hearing Threshold Level	HTL
Hertz	Hz
Equivalent Level	Leq
Nonindustrial Noise Exposed Population	NINEP
Noise Induced Hearing Loss	NIHL
Permanent Threshold Shift	PTS
Temporary Threshold Shift	TTS
Sound Level Meter	SLM
Sound Pressure Level	SPL

I. INTRODUCTION

Temporary Threshold Shift in Hearing

It has been established in the past that excessive noise and other auditory stimuli have a damaging effect on the auditory system: hearing loss (Kryter, 1985). The effects of noise on hearing can be categorized as temporary threshold shift (TTS), permanent threshold shift (PTS), and acoustic trauma. In the event of acoustic trauma, a single exposure to a very high level of sound can cause damage to cochlear structures. This will result in some degree of permanent hearing impairment. PTS is a loss of hearing sensitivity that cannot be regained (Kryter, 1985). TTS is a temporary reduction in hearing sensitivity as a result of an auditory stimulation (Rintelmann, Lindgren, and Smitely, 1971). Although noise is often the cause of TTS, especially in work-related situations, the auditory stimuli are not always noise. The stimulus of concern in this study is organ music as a possible cause of TTS in organists.

It has been shown with laboratory animals what anatomical changes of the cochlea occur in response to acoustic stimulation (Liberman and Beil, 1979). Hair cells in the cochleas of exposed chinchillas have been found to be swollen when observed hours or days after exposure. The hair cells were found to be misshapen when observed weeks or months after exposure. This suggests that cells surviving the temporary swelling, an event related to TTS, can end up shrunken or misshapen, an event related to PTS (Liberman and Beil, 1979). The acoustic stimuli used in animal research are sometimes very intense and lengthy so that the most dramatic effects can be seen. One study used a 90-dB continuous pure tone used for 3 hours (Hunter-Duvar and Mount's, 1978). This study found bent cilia in the cochlea immediately after exposure. The anatomical changes observed in this study may suggest that similar changes are taking place when humans are exposed to strong acoustic stimuli.

Observations made about TTS include the fact that low frequency sounds do not produce as much TTS as high frequency sounds and that TTS effects are reduced when the stimulus is interrupted rather than continuous (Ward, 1973). Axelsson and Lindgren (1977) contend that TTS is small around 90-95 dB during a two-hour exposure period and increases rapidly after 95 dB. They state that the level of the sound seems to have a higher correlation with TTS than the duration of the stimulus. Duration appears to be less important in the development of TTS than intensity. In the same 1977 study, Axelsson and Lindgren stated that there are four methods of ascertaining the possible relationships between intensity and duration of sound and hearing loss. The first is to assess the relationship between sound levels and the risk the sound levels present for cochlear damage. Secondly, one can assess histologic inner ear changes after exposure. Thirdly, discovering the relationship between sound levels and permanent sensorineural hearing loss and, finally, determination of TTS after exposure to auditory stimuli. This study will concentrate on the final method mentioned with the aid of a questionnaire to the subjects.

Rationale

Gaining knowledge about the levels and durations of stimuli that cause TTS is important because it has been shown that repeated episodes of TTS may result in permanent hearing loss (Axelsson and Lindgren, 1978; Bohne, Ward and Fernandez, 1977). Research in the past has focussed on occupational noise effects on hearing (Pang-Ching, 1982). Noise is considered to be any sound that is undesirable to the listener. Organ music as an occupational sound exposure is most likely not considered to be noise by an organist. However, music, like noise, can be described by intensity, duration and spectral content, and should not be overlooked as a possible cause of hearing impairment. The term "socioacusis" was coined by Glorig (1958) to draw awareness to the fact that modern civilization presents a noise burden to the ear sufficient to cause hearing loss or sufficient enough to assist the progression of hearing loss. It seems fitting that one who produces sound for a living might suffer from "jobacusis". This would be the case with pop/rock musicians, orchestral musicians, and organists.

If organists are fond of the sound from the organ, they may allow a practice session to go on longer and more loudly than they would if it were an undesirable sound, thus, over-exposing the ears. This pattern in each practice session may repeatedly produce TTS and eventually PTS. No studies were found in a computer-assisted search concerning TTS in response to organ music; therefore, organists may have questions about safe length of practice time or about whether to wear hearing protection when practicing. Individuals exposed to pop music for 30 minutes at 100-dB SPL exhibit TTSs of 8.4 dB, 12.5 dB, 11.6 dB, 7.3 dB, and 2.7 dB at 1 k, 2 k, 3 k, 4 k, and 8 kHz respectively (Dey, 1970). Research is needed to attempt to establish values such as these with regard to the organ music levels.

Susceptibility to TTS should be addressed with regard to the type experience each subject has: enjoyable or unenjoyable. Axelsson and Lindgren (1983) contend that subjective experience effects the magnitude of the threshold shift. Larger threshold shifts were found in listeners who disliked the stimulus than those who liked the stimulus. Axelsson and Lindgren attribute the difference to compositional hormone changes and to fluid circulation in the inner ear. If this theory holds true, there may be a biological basis to advising organists not to practice for long periods of time when they are tense, upset or disturbed, or when they do not like the music they are practicing. Perhaps research could suggest that music that is disliked should only be rehearsed in short time blocks.

The specific questions asked in this study were (1) Is there a significant difference between the thresholds of hearing before and after practicing the organ for two hours?, (2) Is there a significant difference in hearing between the tense and relaxed subject, and

(3) between those who enjoy and do not enjoy themselves during practicing?

II. REVIEW OF THE LITERATURE

Temporary Threshold Shift From Music

Individual susceptibility to sound seems to vary widely, and also seems to be related to "subjective experience" (Axelsson and Lindgren, 1983). Susceptibility to TTS is thought to be affected by physiological changes in heart rate and blood pressure, and by annoyance and psychological distress. When stress is experienced,often blood pressure rises in the human body. This includes the blood pressure in the stria vascularis in the inner ear.

When comparing the puretone averages of pop musicians to classical musicians, it was found that 13% of the pop musicians had below normal hearing, while 43% of the classical musicians had below normal hearing. The pop musicians liked all of their music, giving them an overall positive experience during rehearsal or performance. The classical musicians were forced to play music that they did not like in their profession, therefore causing distress during rehearsals and performances. Swanson et al. (1987) exposed normal hearing subjects to 10 minutes of noise in one session and 10 minutes of pop music in another session. All acoustical properties and intensity levels for each stimulus were very closely matched. The threshold shift difference between subjects who liked and disliked the pop music was approximately 5 dB, with the larger shift occurring in subjects who disliked the pop music. The subjects who disliked the pop music had a 5-dB larger threshold shift in response to the music than to the noise stimulus. Subjects who liked music had a larger TTS in noise than in music, and had a larger TTS in noise than the group who disliked music. This supports Axelsson and Lindgren's theory that the magnitude of TTS is related to the individual's attitude toward the stimulus. Their theory, to restate, is that sound perceived as "pleasant" causes some hormonal changes and some changes in the fluid circulation of the inner ear. Their suggestion is that the changes possibly aid in preventing temporary swelling of haircells in the cochlea.

Axelsson and Lindgren (1983) further propose that additional factors other than the parameters of sound play a role in TTS, such as stress levels. Ten subjects with a mean age of 16.2 years were exposed to music and noise of the same parameters in their study as well. Threshold shifts of up to 9 dB were found at some frequencies in response to the noise, a stress-causing stimulus, while 5 dB was the maximum shift response to the music. The researchers believe that these results indicate a difference in TTS susceptibility due to psychological factors.

In an earlier study by Axelsson and Lindgren (1977), threshold shifts of pop music listeners and pop music musicians were compared. The audience, or listeners, had an equal TTS with the musicians even though the sound levels reaching the listeners was lower. The same amount of TTS occurred in listeners and musicians when the A-level reaching the listeners was 90 dB and the A-level reaching the musicians was 96 dB. Researchers suggest that since the musicians had been regularly exposed to the sound levels for several years that a tolerance to sound levels had developed. It was also found that TTS in the musicians recovered approximately 18 minutes faster than in listeners.

A study by Axelsson and Lindgren (1978) reconfirmed that TTS is less pronounced in pop musicians than in listeners. Equal TTS occurred in the pop musicians and listeners when exposed to 98 dB and 92 dB respectively. Sound intensity was quadrupled for the musicians yet TTS was equal. Furthermore, male listeners showed more TTS than female listeners.

The effect of discotheque music on TTS has been studied (Dey, 1970). Sound levels of the music at a discotheque were measured 30 feet from a loud speaker. Levels were found to be 110 dB typically in a discotheque where teens spend hours at a time. The sound levels and spectra were mimicked in a laboratory by matching the power of each octave of the music. Subjects in the study were 15 men ages 18-25 who were exposed to 5 minutes of music at 100-dB SPL, 30 minutes at 100-dB SPL, or to 5 or 30 minutes at 110-dB SPL. The results indicated that a TTS increase of 1.5 dB occurred per 1 dB level increase over 100-dB SPL in a 30-minute period. The TTS for 100-dB SPL in a 30-minute exposure period was 12.5 dB at 2 kHz; therefore exposure of 101 dB for 30 minutes would produce a TTS of 14 dB. The average TTS after 30 minutes at 100-dB SPL exposure was 8.4 dB, 12.5 dB, 11.6 dB, 7.3 dB and 2.7 dB at 1 k, 2 k, 3 k, 4 k, and 8 kHz respectively. Furthermore, Dey developed a damage-risk criterion for a 30 minute period of exposure to 100 dB, and to 110 dB (as in the discotheques). Amounts of TTS considered to indicate high risk for permanent hair cell damage are seen in Table I. The predicted threshold shift was calculated for a 120-dB signal after seeing the actual TTS for a 110 dB signal . This is also seen in Table I. This level was not tested by Dey, however, since it would be unethical (Dey, 1970). It is not doubted that in some discotheques, in near proximity to the speakers, people are exposed to levels nearing 120 dB. Rock band rehearsals have been found to be this intense. All of the musicians present in those rooms had "ringing" or a "feeling of fullness" in their ears for eight hours to several days (Rupp and Koch, 1969).

Table I. Temporary threshold shift in dB for three music conditions. Note that the exposure of 120 dB for two hours is a predicted shift, not an actual one (Dey, 1970).

	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
100 dB for 30 min	8.4	12.5	11.6	7.3	2.7
110 dB for 30 min	13	18	17.3	16.1	15.1
120 dB for two hours	44.9	49.9	47	43.8	35

In an octave-band analysis of rock and roll music, in a study by Rintelmann, Lindberg, and Smitley (1971), level of intensity at frequencies 63 Hz through 2 kHz was equal to 100 dB. The intensity level decreased at 4 kHz by 20 dB and decreased at 6 kHz and 8 kHz another 15 dB. When exposed to a sound with such a spectrum, subjects had a maximum TTS of 15 dB at 4 kHz.

The Chicago Symphony Orchestra members used personal dosimeters to assess the average sound exposure of 15 hours of practice weekly, the Leq A-value being 89 dB. This study by Royster, Royster and Killion (1991) revealed audiograms for the musicians that were consistent with noise-induced hearing loss (hearing losses with a worsened threshold at 4 k or 6 kHz, creating a notched shaped audiogram), however, the degree of hearing loss was very slight. The TTSs were not being measured, only hearing thresholds. Mean hearing threshold levels for these orchestral musicians proved to be lower than those for an unscreened nonindustrial noise exposed population. The notched shape of the audiograms, suggesting noise-induced hearing loss, was most pronounced for the ages 40-49, but the thresholds were no higher than the NINEP's mean hearing threshold levels (HTL). If musicians such as these do not show more hearing loss than is expected for their age, then the exposure to the sounds experienced in their occupation is considered to be very low risk for PTS.

Jatho and Hellman (1972) studied orchestral musicians and found that 24 of 65 classical musicians had sensorineural hearing loss characteristic of noise-induced hearing loss. Researchers found very high sound levels of instruments such as trumpet, bassoon, saxophone and percussion. Hearing thresholds in Jatho and Hellman's study were measured before and after a musical performance for 10 of the musicians with hearing loss: 5 males and

5 females with a mean age of 35 years (age range 26-57). The performance was 71 minutes long at varying A-levels between 87 and 93 dB. There was an intermission (duration of the intermission was not given) and 62 more minutes of playing at levels between 85 and 91 dB. The maximum mean TTS occurred at 4 kHz: 6 dB. All TTS measures were obtained within two minutes or at two minutes after playing had stopped. Researchers considered this to be the most critical time for measurement of TTS.

The sound levels of individual orchestral instruments have been measured in past studies. Folprechtova and Miksovka (1978) obtained the range of maximal levels of the following various instruments in a quiet practice room at ear-level of the musician (all A-weighted measures): violin, 84-103 dB; piccolo, 95-112 dB; cello, 84-92 dB; bass 75-83 dB; clarinet, 92-103 dB; french horn 90-106 dB; oboe 80-94 dB; trombone 85-114 dB; and xylophone 90-92 dB.

A 49 year old flutist played her own instrument alone in a quiet practice room for 40 minutes. Sound A-levels were an average of 83 dB. The TTS was 4 dB at 4 kHz and minimal at other frequencies. Another flutist, 28 years old, individually played the flute for 15 minutes at 104 dB and the piccolo for 15 minutes at 104 dB. The TTS for this subject was 14 dB at 3 kHz, 17 dB at 4 kHz, 15 dB at 6 kHz and 10 dB at 8 kHz. A 50 year old musician played the piccolo for 18 minutes at 98.4 dB (A) and TTS was 8 dB at 4 kHz. The other frequencies did not shift significantly.

Axelsson and Lindgren (1981) studied 139 classical musicians. The result was a slight hearing loss in general (below 20 dB) at least at 6 k and 8 kHz, and often at other frequencies. Females had better hearing overall, but this was attributed to the fact that all of the females in the study were younger than the males. The audiograms could be divided into 5 categories with regard to configuration. The categories were 1) high frequency sloping loss, 2) notched curve at high frequencies (the notch being from 3 k to 6 kHz), 3) a combination of notched and sloping curve at high frequencies, 4) flat loss and 5) other configurations.

The Organ

Pipe organs vary greatly in size, number of pipes, and tonal characteristics. The sound is produced by air flow controlled at the console, or keyboard. The wind chest, upon which the pipes are placed, has a set of valves that stop or allow air flow into each pipe (Strong and Plitnik, 1977). Each resonant pipe produces a different complex tone. The "stops", also called "registers", each represent a "rank", which is a set of pipes of similar construction material and therefore similar sound quality. Stops are manipulated to initiate or halt the use of a set of pipes. Certain stops allow one pipe to respond to each key, others will activate two or more sets of pipes that will respond simultaneously to one key.

The names of stops often correspond to the length of its sounding pipe. For example, the eight-foot (8') stops are standard-"pitched" stops, only producing the fundamental "pitch" or the fundamental frequency. Table II explains the overtone system

Table II. Pattern of fundamentals and overtones indicating relative frequencies and harmonic analysis of the organ (modified from Engel, 1986).

Stop in Feet	Frequency in relation to note the played	Harmonic Series			
		16'	8'	4'	2'
16'	One octave lower	1st			
10 2/3'	A perfect fourth lower				
8'	Normal pitch of note played	2d	1st		
5 1/3'	A perfect fifth higher	3rd			
4'	One octave higher	4th	2d	1st	
3 1/5'	One octave and a third higher	5th			
2 2/3'	One and a fifth octave higher	6th	3rd		
2'	Two octaves higher	8th	4th	2d	1st
1 3/5'	Two octaves and a third higher	10th	5th		
1 1/3'	Two octaves and a fifth higher	12th	6th	3rd	
1 1/7'	Two octaves and a seventh higher	14th	7th		
1'	Three octaves higher				

produced by the organ. The upper ranks, the higher pitched ones, correspond to natural overtones above a fundamental frequency (Engel, 1986).

There are four general families of pipes: the Diapasons or Principals, the Flutes or Gedackts, the String family, and the Reeds. These are divided according to timbre. The first three mentioned above are flue pipes, and the last, as the name denotes, is made up of only reed pipes.

In the literature search conducted for this study, no research using the organ as a stimulus could be located. As a result, it is unknown if, or how much, TTS is caused by the organ.

Flue pipes have a sharp metal or wooden edge at the mouth of the pipe while reeds have a flexible metal tongue at the foot of the pipe (Engel, 1986). The Diapason or Principal family is made up of those pipes with most characteristic, or fundamental, tone of the organ, and also those with the fewest harmonics. These pipes are open and cylindrical. The Flute or Gedackt family are described as less "aggressive" than the Principals. Flute pipes are generally wide in diameter and are cylindrical or conical in shape. They are fuller in tone than the Gedackts. Open flutes have a strong first overtone and are much like the orchestral flute. Gedackts are covered at the top of the pipe to produce a tone one octave lover than an open pipe of the same length. Gedackts are a duller sound and have a stronger second overtone . Partially stopped or covered flutes emphasize oddpartials and have few harmonics of the spectrum. The string family resembles the sound of stringed orchestral instruments. The pipes producing this sound are very narrow in diameter and are the smallest pipes of the organ. The string pipe harmonics have a greater amplitude than that of the fundamental frequency (Strong and Plitnik, 1977).

Reed pipes are also called lingual pipes. The tone of the reed pipe is produced by the vibration of a reed moved by a stream of air through the pipe. Reed pipes are decribed as having a nasal timbre, but their quality can vary greatly. The shape and length of the pipe and the metal reed will determine the tone quality.

III. METHODOLOGY

Subjects

Subjects were 10 volunteer organists who responded to an advertisement concerning research on organists. The mean age of the subjects was 42.3 years (range 23-54 years). There were 6 males and 4 females. The mean number of years playing the organ was 20.5 years (range 4-37 years).

Procedures

Each subject had a pre-exposure hearing test in a portable testing booth. Air conduction thresholds were obtained and bone conduction was obtained to rule out any conductive components. An otoscopic exam was completed on each subject. When subjects inquired about expected TTS amounts before the study began, they were informed that no former studies of this type could be located and so the expectations were unknown. A two-hour sesssion simulating a typical practice session was played by each subject immediately after the hearing tests. The session was divided into four stop combinations of 30 minutes each on the organ (see Appendix A for the stops present on the instrument used, and Appendix B for the stop combinations used). Each subject played a quiet registration, a full registration without reed pipes, a solo/accompaniment combination, and a full registration with reed pipes, respectively, for 30 minutes in each combination. The quiet registration consisted of two Gedackts, two partially covered Flutes, and two open Flutes. The full without Reeds registration used all of the pipes except the Reeds and one of the open Flutes. The solo/melody with accompaniment registration included many Flute and Gedackt pipes and a tremulant, which is a special device for steadying the tone of the organ. The full with Reeds registration consisted of the same combination as full without Reeds, but added two reed pipes. There was a 5 minute rest period for subjects after one hour of playing . The sessions for the study were to be as closely simulated to a normal practice session for each organist as possible, thus the reasoning behind the stop combinations for 30 minutes each.

Five minutes of each registration was recorded on cassette tape for every subject. Sound measurement levels were taken throughout the session.

When two hours of playing was completed, hearing was retested in the same test booth. Post-exposure testing began within one minute after playing had ceased and all thresholds were obtained within 5 minutes. Testing began with the highest frequency tested (8 kHz) and finishing with the lowest (0.250 kHz) because TTS effects were expected to be more visible at higher frequencies. Each subject then answered a questionnaire (see Appendix C). The summary of answers to the questionnaire are seen in the results section.

Sound levels that were taken throughout the sessions were done with a sound level meter (SLM) that was positioned at head level of each subject. The SLM was positioned on a stand behind the subject, putting the microphone of the SLM beside the subject's ear. The microphone of the SLM was approximately 30 cm from each subject's ear.

Lowest and highest sound levels were recorded for each stop combination as well as the equivalent level for 30 minutes into the session, one hour into the session, one and a half hours into it, and a total two hour equivalent level. Therefore, the 30 minute average included only the quiet registration of the organ, the one hour average included quiet registration and the full without Reeds, and the one and a half hour average included quiet registration, full without Reeds, and solo with accompaniment combination. The two hour total equivalent level included all four stop combinations: quiet, full without Reeds, solo with accompaniment, and full with Reeds.

Instrumentation

Sessions took place in an organ studio measuring 36 x 15 x 14 feet. The organ was a two manual Gabriel Kney limited, built in 1978, measuring 4 x 14 x 13 feet. The organ was located at one end of the room. This particular organ contains 21 ranks (approximately 1000 pipes).

Room and booth ambient noise measures were taken with a B & K sound level meter (model 2203, serial 112973). Audiometric testing was done in a double-walled, portable Eckoustic audiometer booth (serial number 63034). Ambient noise levels are found in Appendix D.

A portable Beltone audiometer (model 110) was used for hearing testing (serial number 10D 264) with TDH 50P earphones (serial numbers 813717 and 840289). The bone oscillator used in the testing was a Radio Ear B-71 (serial number 44209). Complete calibration of the audiometer was performed before and after the study, and a biological check on calibration was made before and after each subject. The complete testing of all subjects lasted a period of approximately 3 weeks.

Music was recorded on a cassette tape with a SONY stereo casette recorder (model WM-DGC) and a SONY microphone (model ECM-929LT, serial SAD 35). A RION sound level meter was used for all sound measures during the sessions (model NA-21, serial 00690024). The sound level meter was calibrated before and after each session. An Leq attachment (model EQ-05, serial 000600125) was used for the measurement of equivalent levels over each 30-minute interval of each session.

A spectrum of each registration of organ music was obtained by a Nicolet Scientific UA-500A Ubiquitous Spectrum Analyzer (serial number 348666). The spectrum analyzer contained a built-in 604 Monitor Oscilloscope. Input to the spectrum analyzer was fed from the output of an HD casette tape player (model CS-F12, serial number 8011009). Analysis range was 10 kHz with a 50-millisecond time window; 1024 samples were summed during each time window. This spectrum analysis is a relative measure of the actual intensity levels played during practice sessions. The spectrum was plotted logarithmically.

IV. RESULTS

Sound Levels and Spectra

The sound levels measured during the sessions are presented in Table III. No A-weighted level was less than 65 dB or greater than 90 dB for any of the two hour sessions. Spectrum analysis (see Appendix F) revealed that most energy for every organ registration was at frequencies below 1 kHz. The envelope for the spectrum at the frequencies below 1 kHz often peaked around 500-750 Hz.

All sound levels taken during the sessions were A-weighted. Mean sound level for all the quiet registrations, which was a 30 minute equivelant level, was 77.1 dB. Mean equivalent level overall for 1 hour of the sessions (quiet registration and full without Reeds) was 84.3 dB. Mean equivalent level for the 1.5 hour mark into the session (quiet registration, full without Reeds, and solo with accompaniment registration) was 79.3 dB. The overall mean equivalent level for complete sessions (including the full with Reeds registration) was 85.5 dB.

At very high frequencies the relative sound levels were low. During the quiet registration of the session, the least amount of energy is present above 4 kHz. At low frequencies, energy appeared to be ever-present during any of the registrations. During the full with reeds, full without reeds, and solo with accompaniment registrations, the spectrum has many peaks at the frequencies above 1 kHz, however, the energy at the low frequencies still dominate.

Table III. Smallest (S) and largest (L) A-weighted sound levels for each thirty minute stop combination played with on-going equivalent levels taken at each thirty minute interval.

Subject	Quiet Registration			Full without Reeds			Solo with Accompaniment			Full with Reeds		
	S	L	30 min	S	L	1 hour	S	L	1.5 hour	S	L	2 hour
1	70	78	76	76	87	85.9	75	80	79	77	90	83.3
2	70	77	76.8	77	86	85.2	74	81	79.7	79	87	85.2
3	70	77	76.3	75	86	82.7	73	80	77.8	78	87	85.9
4	73	80	77.2	78	86	84.9	71	80	77.9	78	88	85.7
5	69	80	79	78	86	85	71	81	80.4	79	88	87
6	71	79	78.5	77	86	84.7	69	81	79.9	77	86	84.6
7	66	80	77.5	76	87	86.8	77	81	80.1	80	88	86.9
8	70	79	77.1	75	86	83.6	66	82	79.2	76	88	85.7
9	70	78	77	77	87	81	68	81	79	79	87	85
10	65	79	76	77	88	84	76	81	80	77	89	86
Averages	69.4	79	77.1	76.6	86.5	84.4	72	80.8	79.3	78	87.8	85.5

The resultant frequency spectra obviously depend upon the music selected by the organist. These organists did not play the same music. In general, the spectrum from each organ registration tended to be broad with little detail through approximately 750 Hz. Less intense sounds from 1 kHz-10 kHz had jagged peaks that decreased in intensity as frequency increased. The higher frequencies reveal much more detail than the lower frequencies.

Hearing Sensitivity and Temporary Threshold Shifts

A statistical analysis done with a treatment-by-subject design for all ears tested in the study revealed no significant threshold shift ($p=0.05$). No significant TTS occurred at any frequency tested (see Appendix E for statistical calculations).Table IV displays the mean threshold shift at each frequency for all right ears, all left ears, and then for all ears.

The largest shifts occurred at 2 k, 4 k, 6 k, and 8 kHz for all ears. There is a noticeable mean shift in right ears at 4 k and 6 kHz. For the left ears that shift is smaller. The largest shift of 15 dB occurred three times, all in different subjects. This occured at 250 Hz, 4 kHz and 6 kHz. All of these threshold shifts were in males and all in the right ear.

Fifty percent of the subjects have normal or better than expected hearing for their age according to the Hearing Conservation Branch of the U.S. Army Environmental Hygiene Agency (Miller, 1985). Four of the subjects have a noise-notch with levels falling below expected hearing levels for their age, three of these at 6 kHz

Table IV. Mean threshold shift for right ears, left ears, and all ears at all frequencies tested (in dB).

Test Frequency	Right Ears	Left Ears	Mean overall shift for all ears
0.250 k Hz	2.5	1.0	1.75
0.500 k Hz	1.0	2.0	1.5
1 k Hz	0.5	0.0	0.25
2 k Hz	2.5	2.0	2.25
3 kHz	0.5	1.5	1.0
4 k Hz	3.0	1.5	2.25
6 k Hz	3.5	1.0	2.25
8 k Hz	2.5	2.0	2.25

and one of these at 4 kHz. One of the subjects with a notch at 6 kHz also has a low frequency hearing loss in one ear. One subject has a flat, moderate sensorineural hearing loss. In twelve of the twenty ears tested (83.3%) thresholds were within normal limits during the pretesting. Normal limits are defined as any hearing level better than 25 dB. However, in ten of the twenty ears tested, a noise notch existed. The noise notch was usually very slight. Eight of the ten noise notches were at 6 kHz. One subject had a flat, moderate sensorineural hearing loss with a peak at 4 kHz into the normal limits.

Questionnaire Answers

The mean number of years playing the organ regularly amongst the subjects was 20.5 years (range 4-37 years). The subjects currently practice a mean of 10 hours a week (range 2-18 hours). Ninety percent of the subjects currently exercise three times weekly. All of the subjects liked the music they played during the sessions; all subjects chose their own music. Eighty percent of the subjects were relaxed for the duration of the session while 20% were tense while practicing. Seventy percent of the subjects perceived the session at a comfortable loudness and 30% perceived the full registration as "a little too loud". One of the three subjects that perceived part of the session as too loud had one of the largest TTSs in the study: 15 dB at 4 kHz. All of the subjects enjoy playing the organ very much in general. No subject had an unusual noise exposure history; organ music was their chief exposure.

V. DISCUSSION

The results of this study are in agreement with Axelsson and Lindgren's (1977) theory that levels of 90-95 dB cause only a small amount of TTS. In this study the exposure levels in this study were not as high as 90 dB continuously and yet some small amount of TTS occurred, although the amounts were statistically insignificant. Perhaps if the music levels of an organ session did reach an average of 90 dB or more over a two hour period, some significant amount of TTS would be present.

Carter et al. (1982) stated that TTS tends to occur one-half octave above the frequency at which the energy in the spectrum of the stimulus predominates. However small the TTSs in the results of this study may be, the shifts were never one-half octave above the "predominate" frequency, which in this study was approximately 750 Hz. The largest TTSs in this study were at 2 k, 4 k, 6 k, and 8 kHz, never at 1 kHz. Carter's contention that most PTS is at 4 kHz in musicians no matter what the spectrum of sound is also inconsistent with the results of this study. Half of the ears tested, as mentioned earlier, had a pretest notch, 80% of which were at 6 k Hz, the others were at 4 kHz. These notched audiograms were of slight distinction, but they definitely present a pattern to consider. A third statement by Carter suggested that TTS was a poor indicator of PTS. It can be speculated in this study that the insignificant amount of TTS is directly correlated to the fairly good hearing of these musicians who have experienced exposure to music for many years, some for over 30 years. The musicians in this study have small amounts of PTS, and a pattern can be seen developing in the shape of the audiograms of a dip at 6 kHz. Some studies contend that TTS is a poor indicator of (PTS); according to Carter, the majority of TTS occurs one-half octave above the predominating frequency of the stimulus while PTS tends to occur around 4 kHz, regardless of the spectrum of sound (Carter et al., 1982). The findings of this study are in disagreement because the majority of PTS found in this study was at 6 kHz. Although the amount of TTS is small at 6kHz each time an organist practices, repeated episodes would seemingly cause an eventual PTS at that frequency, as seen in 50 % of the ears tested. Although the mean TTS of 2.25 dB is not considered significant at the p=0.05 level, it is nonetheless a contributing shift that, occurring repeatedly, may have cumulative effects resulting in PTS. On the other hand, these subjects may possibly be resistant to TTS since they are regularly exposed to the stimulus. An element of resistance for organists could also be the fact that they find the stimulus a pleasant experience. More research is needed to draw definite conclusions about this stimulus as an inducer of hearing loss.

Ward (1973) reported that low frequency stimuli were less likely to cause TTS. In the same study, Ward also stated that an interrupted stimuli as opposed to a continuous one was less likely to cause TTS. The organ music in this study was interrupted and the dominate frequency was usually 500-750 Hz. These factors may have reduced the risk of TTS to the organists, seemingly supporting Ward's statements.

The type of experience each subject has during an acoustic stimulus was addressed by Axelsson and Lindgren (1983). They contended that a negative experience increases TTS and a positive one prevents the occurence of TTS. All of the musicians participating in this study liked the music played during the sessions, and TTS was very small; however, agreement cannot be confirmed on this point since there was no comparison group of musicians who disliked the music. In the same way, 90% of these subjects exercise regularly and can be considered to be in good health. This factor may have reduced the effects of sound exposure also, but there is no way to know for sure without a comparison group of organists who do not exercise.

One subject admitted to being tense during the session, which would make the experience less pleasurable than those who were relaxed. This subject had threshold shifts of 10 dB at 2 kHz, 5 dB at 3 k and 6 kHz, and 10 dB at 8 kHz. Other subjects had shifts this large as well, so Axelsson and Lindgren's (1983) theory cannot be supported by this study. None of the subjects expressed any discomfort in response to the levels of the instrument, although three subjects felt that the session was a little loud at times. Two of these three subjects, both male, were ones with a TTS at some frequency of 15 dB, and the third of these subjects had 10 dB shifts at 6 k and 8 kHz. One of these subjects had TTS in four different frequencies and the other two at five different frequencies. Other subjects who perceived the sessions as comfortable had shifts of 5 or 10 dB at two and three different frequencies. The levels of the sessions are not thought to be loud enough in general to cause 15 dB shifts, therefore these individual cases may be attributed to individual susceptibility.

As in Axelsson and Lindgren's 1978 study in which male listeners exhibited more TTS than females, male subjects showed more TTS than females did. That is, a TTS occurred at more frequencies for every male than for any female. Additionally, there were three occurrences of a 15 dB shift. All of these were in male organists, reestablishing the tendency that males may be more susceptible to TTS than females. In another study, Axelsson and Lindgren (1981) found that females had overall better hearing amongst 139 classical musicians. This was attributed to a younger mean age among women used in their study. Overall better hearing was also established in the females in this study, but cannot be attributed to younger age since the mean age for females was 47 years and the mean age for males was 39 years.

The results of hearing sensitivity are similar to Axelsson and Lindgren's (1981) findings in 139 classical musicians: 50% had normal hearing for their age with the exception of slight hearing loss at 6 kHz. The subject with a flat moderate hearing loss had the least occurrence of TTS, being only at 6 kHz. All other subjects had shifts at at least two frequencies and some had shifts at up to five different frequencies. This might suggest that the subject with hearing loss is somewhat protected from a certain amount of TTS.

The frequency analysis of rock and roll music reveals a slightly broader spectrum than that obtained from organ music. Rock and roll music has high intensity energy through 2 kHz, whereas the organ's spectrum peaked in intensity at 500 Hz (for most stop combinations) then began to decrease in intensity, usually dropping sharply around 1 kHz. After a sharp drop of approximately 20 dB from 500 Hz to 1 kHz, the intensity drop per octave decreased greatly for any registration played. For quiet registrations, the decrease from 2 k to 10 kHz was at a rate of approximately 4 dB per octave. For the full without Reeds combinations, frequencies from 2 k to 10 kHz had nearly constant energy. This was also true for the full with Reeds combinations. The solo with accompaniment registrations dropped about 10 dB between 1 k and 2 kHz, then only dropped about 2-3 dB per octave for the remainder of the spectrum. The maximum TTS for the rock music spectrum, a more broad one when compared to organ music, was at 4 kHz. The maximum TTS for organ music spectrum, a spectrum with a low frequency emphasis, was 2.25 dB occuring at four different frequncies: 2 k, 4 k, 6 k, and 8 kHz. This may suggest that for any sound loud enough to cause TTS, the maximum TTS will most likely occur around 4k Hz whether other frequencies are affected or not, and regardless of the spectrum.

Royster, Royster and Killion (1991) revealed audiograms of Chicago Symphony Orchestra members that had the same pattern as 50% of the ears in this study: a slight noise notch at 4k or 6 kHz usually within normal limits of hearing. The notch in the audiograms in this study cannot be attributed to age because none of the subjects were particularly elderly; the oldest age was 54. The pattern in the audiograms could possibly be attributed to a mean of 20.5 years of exposure to organ music. Fifty percent of the musicians in this study, like those in Royster, Royster, and Killion's study, have fairly good hearing, in general, with the exception of one frequency: 6 kHz. Thus, the exposure to organ music cannot be considered high risk for TTS. There is some degree of low risk involved since some TTS and PTS are present in these organists; however it is not considered to be a statistically significant risk, even at 6 kHz.

Although noise-induced permanent threshold shift is a phenomenon which gets worse with more and more exposure to the stimulus (Carter, 1982), chances are that an occupation as an organist is not high risk for it. According to Dey's 1970 damage-risk criterion, none of the levels played by the organists for two hours are intense enough to cause permanent damage to coclear hair cells in just one two-hour session. There is one exception in Dey's criterion: the hair cells at the location corresponding to 6 kHz in the cochlea. Dey's criterion for PTS at 6 kHz was 2.7 dB of TTS, although he was using a different stimulus. Two subjects in this study had a 10-dB TTS at 6 kHz and others had a 5 dB shift (the overall mean shift at 6 kHz in this study was 2.25 dB). These individual shifts would be considered significant TTS by Dey. The relatively small degree of hearing loss found in the organists in this study, considering their regular exposure to music for anywhere from 4 to 30 years, confirms the overall low risk for PTS involved.

Since all of the subjects perceived the stimulus as pleasurable in this study, further research could be useful with a comparison group that finds the stimulus unpleasureable. A two hour practice session is normal for organists, as all the subjects agreed, but further research with longer practice sessions or sessions with higher SPLs could help to predict at what point practicing the organ becomes high risk for TTS. A high risk practice session for TTS would not be realistic however, since it would probably require using a full registration for the full practice to see the effects of a significant TTS, something that organists would be unlikely to do.

VI. CONCLUSION

No TTS that occurred in this study was statistically significant at the $p=0.05$ level. Maximum overall TTSs were 2.25 dB at 2 k, 4 k, 6 k, and 8 kHz.

The only occurrence of TTS in this study that seemed to be related to the PTS of the subjects is at 6 kHz. This is because 50% of the ears tested in this study had a noise notch at 6 kHz. The same amounts of TTS occurred at other frequencies, so TTS was not found to be a good predictor of PTS.

There were not enough subjects who were tense or uncomfortable in this study to discover if a relationship exists between a stressful or tense experience and TTS. Ninety percent of the subjects in this study were relaxed during the sessions and enjoyed themselves. All of the subjects had insignificant TTS, though, so perhaps support can be offered to the contention that a pleasurable acoustic experience, as opposed to an unenjoyable one, can aid in resisting TTS.

The results of this study can confirm that a two hour practice session on the organ is a safe period of time to rehearse with regard to sound exposure.

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APPENDICES

Appendix A

GABRIEL KNEY STUDIO ORGAN STOPS

Couplers: Swell to Great
Great to Pedal
Swell to Pedal

Great:	Swell:	Pedal:
Rohrgedeckt 8'	Holzgedeckt 8'	Subbass 16'
Principal 4'	Rohrfloete 4'	Gemshorn 8'
Offenfloete 4'	Nasat 2 2/3'	Choralbass 4'
Blockfloete 2'	Spitzprincipal 2'	Mixture III (2')
Mixture III (1 1/3')	Terz 1 3/5'	Dulzian 16'
Regal 8'	Octave 1'	
Tremulant	Tremulant	

Appendix B

STOP COMBINATIONS

1. Quiet Registration
   Swell: Holzgedeckt 8'
   Rohrfloete 4'
   Great: Rohrgedkt 8'
   Blockfloete2'
   Pedal: Subbass 16'
   Gemshorn 8'
2. Full without Reeds
   Swell: All swell stops except Tremulant and Terz1 3/5. Use of Octave 1' for only 15 minutes of this 30 minutes.

   Great: All stops except Tremulant and Regal 8'

   Pedal : All except Dulzian 16'
   Couplers: Swell to Great
   Great to Pedal
3. Solo/Melody with Accompaniment

   Swell: All stops except Octave 1' and Tremulant
   Great: Rohgedeckt 8'
   Offenfloete 4'
   Pedal: Subbass 16'
   Gemshorn 8'
4. Full with Reeds

   Same as Full without Reeds, but add Dulzian 16' and Regal 8'

Appendix C

QUESTIONNIARE TO SUBJECTS

1. How long have you been playing the organ (in number of years)?
2. How often and how long do you practice?
3. When playing the organ today, were you tense or relaxed?
4. Did you like or dislike the music you played during the practice session today?
5. Did you perceive today's practice session as
   a) too loud
   b) comfortably loud
   c) not very loud at all?
6. Do you exercise, and if so, how often?
7. Do you enjoy playing the organ in general?

Appendix D

AMBIENT NOISE LEVELS (in dB) IN

TEST ROOM AND IN PORTABLE TEST BOOTH

	ROOM	BOOTH
Linear		
A-weighted	49	28
C-weighted	62	60
Flat	67	65

External Filter (in Hz)	Front of Room	Beside Organ	Back of Room	Booth
31.5	53	62	54	56
63	50	53	46	43
125	56	49	46	29
250	49	43	40	26
500	48	40	40	13
1000	47	42	42	14
2000	40	38	40	11
4000	43	32	23	14
8000	24	23	23	14
16,000	16	17	16	16

Appendix E

TREATMENT-BY-SUBJECT STATISTICAL DESIGN FOR ALL EARS TESTED

Step 1. List all data collected by amount of TTS for each subject at each frequency.

Subject	0.250 k Hz	0.500 k Hz	1 k Hz	2 k Hz	3 k Hz	4 k Hz	6 k Hz	8 k Hz	sums
1	0	15	0	5	0	5	0	0	25
2	0	0	0	0	0	0	15	0	15
3	20	0	5	5	0	5	0	5	40
4	0	5	0	0	5	0	5	0	15
5	0	5	0	0	5	15	5	0	25
6	0	0	0	15	10	5	5	20	55
7	5	5	0	5	0	5	0	0	20
8	5	0	0	0	0	0	15	5	25
9	5	0	0	5	0	0	10	10	30
10	0	0	0	10	10	10	0	10	40
sums	35	30	5	45	30	45	55	50	

Step 2. Add the scores in each treatment (frequency) to get the sum for each treatment. This is seen in the table in step 1.

Step 3. Square each number in the table in step 1 and add the squared values together.

$$0^2 + 15^2 + 0^2 + 5^2 + \text{..........} = 3175$$

Step 4. Add the sums for each treatment for a total of the entire table.

$$35 + 30 + 5 + 45 + 30 + 45 + 55 + 50 = 295$$

Step 5. Square step 4 total and divide by the total number of measures recorded. This number is called the correction term.

$$\frac{295^2}{80} = 1087.81$$

Step 6. Computation of the total sum of square (SS_t): subtract the correction term (step 5) from the sum of the squared values obtained in step 3.

$$SS_t = 3175 - 295 = 2880$$

Step 7. Add the scores recorded for each subject to get the sums for each subject. These values can be seen in step 1.

Step 8. Square all the sums obtained in Step 7, and add the squares.

$$25^2 + 15^2 + 40^2 + 15^2 + \text{........} = 9850$$

Step 9. Divide the value obtained in step 8 by the number of scores that were added to get each of the sums in step 7.

$$\frac{9850}{8} = 1231.25$$

Step 10. Computation of the sum of squares for subjects (SS_{sub}): subtract the correction term from the value obtained in step 9.

$$SS_{sub} = 1231.25 - 1087.81 = 143.44$$

Step 11. Square each of the values obtained in step 2, and add the squares.

$$35^2 + 30^2 + 5^2 + 45^2 + 30^2 + 45^2 + 55^2 + 50^2 = 12625$$

Step 12. Computation of the sum of squares for treatments (SS_{treat}): subtract the correction term from the value of step 11.

$$SS_{treat} = 1262 - 1087.81 = 174.69$$

Step 13. Computation of the error-term sum of squares (SS_{error}): subtract the SS_{sub} and the SS_{treat} from step 12 from the SS_t.

$$SS_{error} = 2880 - 143.44 - 174.69 = 2561.87$$

Step 14. All computations based directly on the data have been completed. However, since the test of significance (F ratio) is a ratio of the mean squares, these values are also computed. The degrees of freedom (df) are determined as follows.

$$\text{df } SS_t = 80 - 1 = 79$$
$$\text{df } SS_{sub} = 10-1 = 9$$
$$\text{df } SS_{treat} = 8-1 = 7$$
$$\text{df } SS_{error} = 79 - 9 - 7 = 63$$

Step 15. The mean squares are then computed as SS/df.

$$ms_t = \text{not needed}$$
$$ms_{sub} = \text{not needed}$$
$$ms_{treat} = \frac{\text{step 12}}{df} = \frac{174.69}{7} = 24.96$$
$$ms_{error} = \frac{\text{step 13}}{df} = \frac{2561.87}{63} = 40.66$$

Step 16. The test of significance (F) is equal to ms_{treat}/ms_{error}.

$$\frac{ms_{treat}}{ms_{error}} = \frac{24.96}{40.66} = .64$$

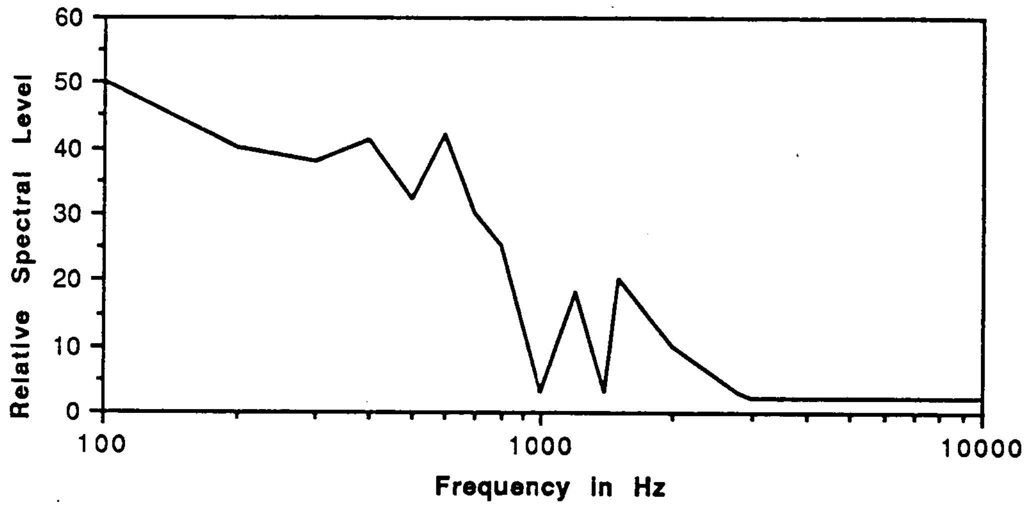
Tabled analysis.

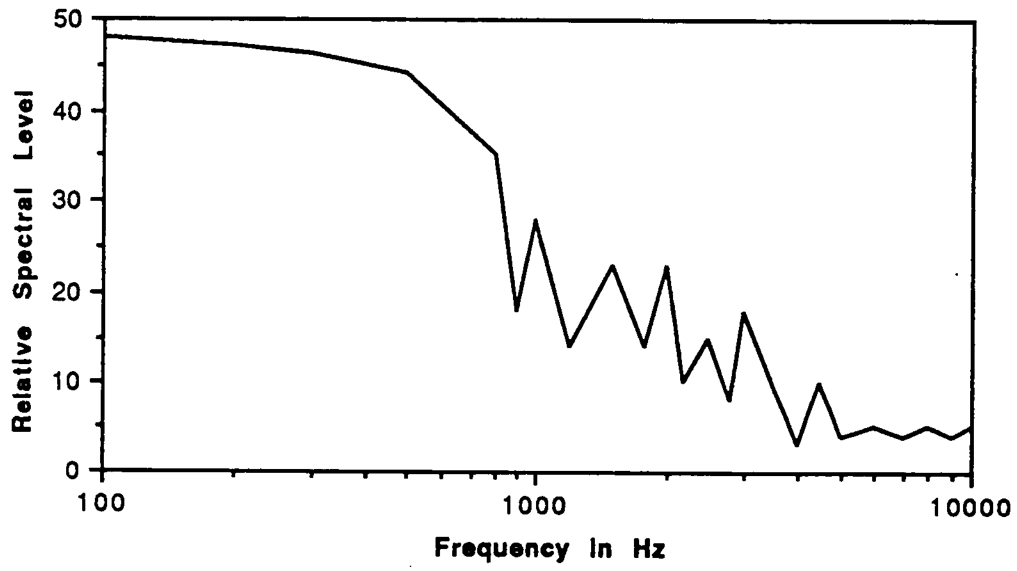
Source	SS	df	ms	F	p
Total	2880	79	---	---	---
Subjects	143.44	9	---	---	---
Treatments	174.69	7	24.96	.64	---
Error	2561.87	63	40.66	---	---

Since the .64 F value is not significant at any alpha level, the amount of threshold shift experienced by any subject at any frequency is not a significant amount.

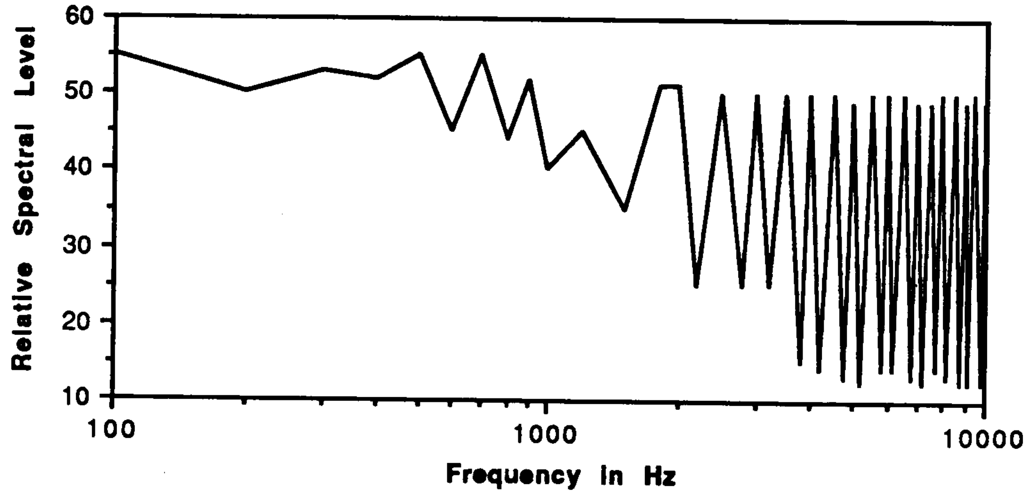
Appendix F

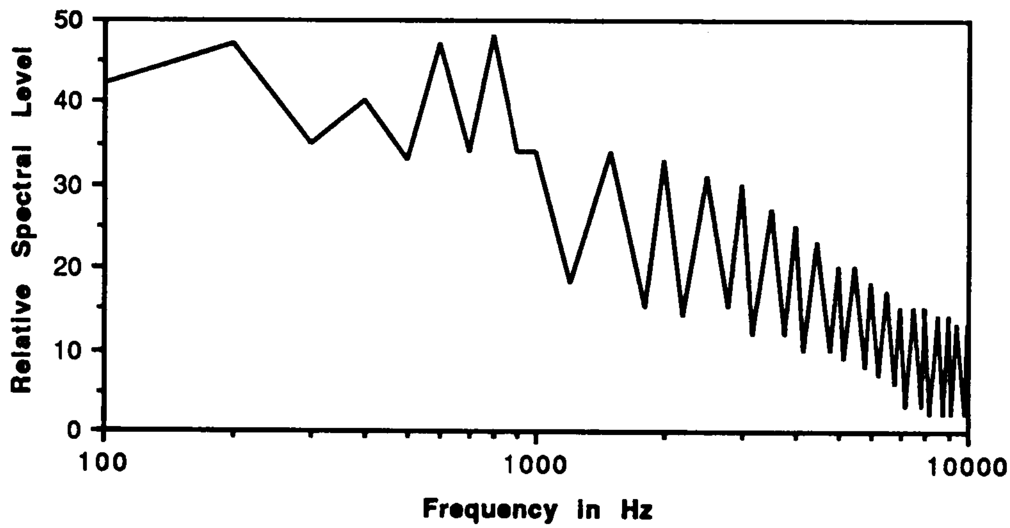
RELATIVE SPECTRAL LEVELS FOR ORGAN IN FOUR REGISTRATIONS



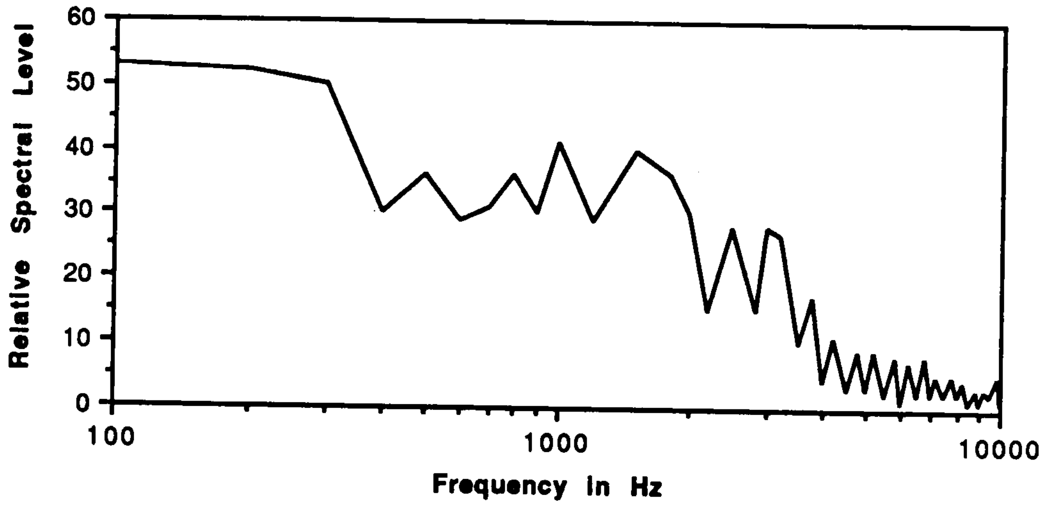


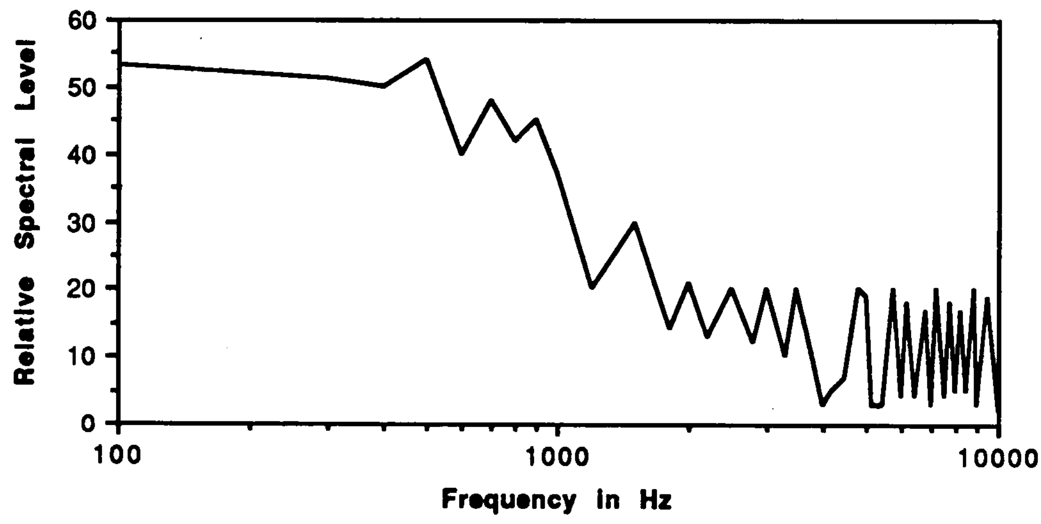
Figures 1. Two examples of the relative spectral level of organ in quiet registration.



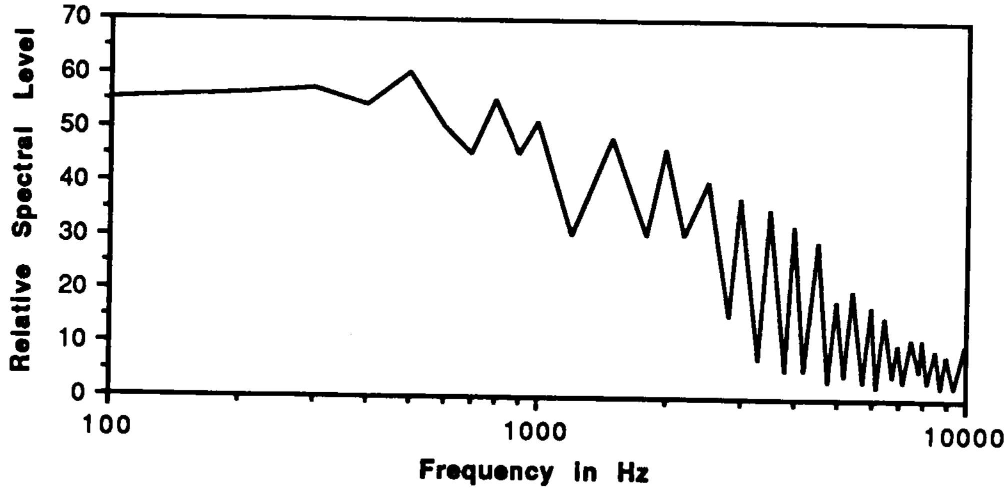


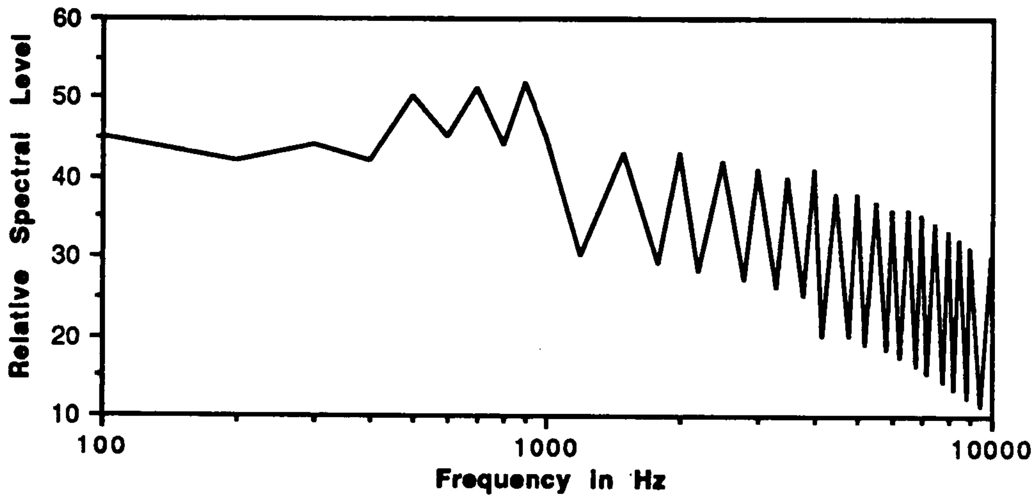
Figures 2. Two examples of relative spectral level of organ in full registration without Reeds.





Figures 3. Two examples of relative spectral level of organ in solo with accompaniment registration.

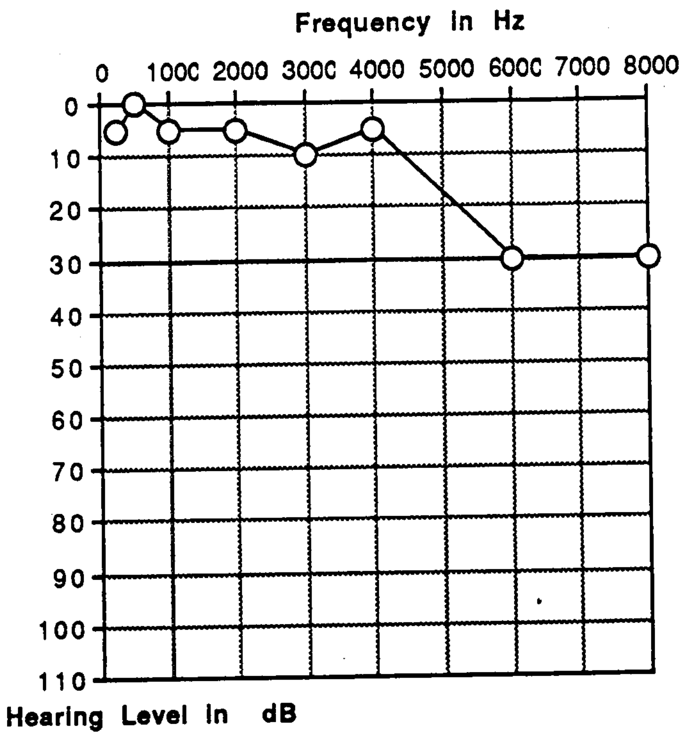


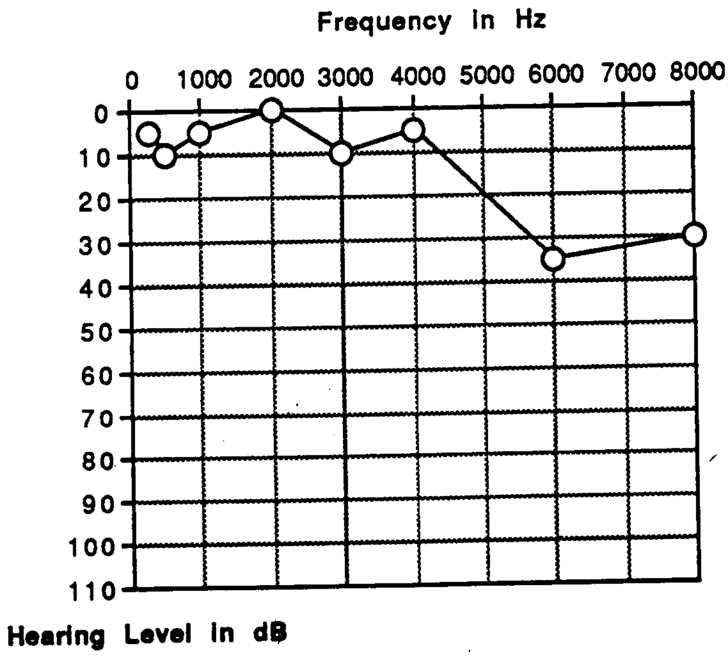


Figures 4. Two examples of relative spectral level of organ in full registration with Reeds.

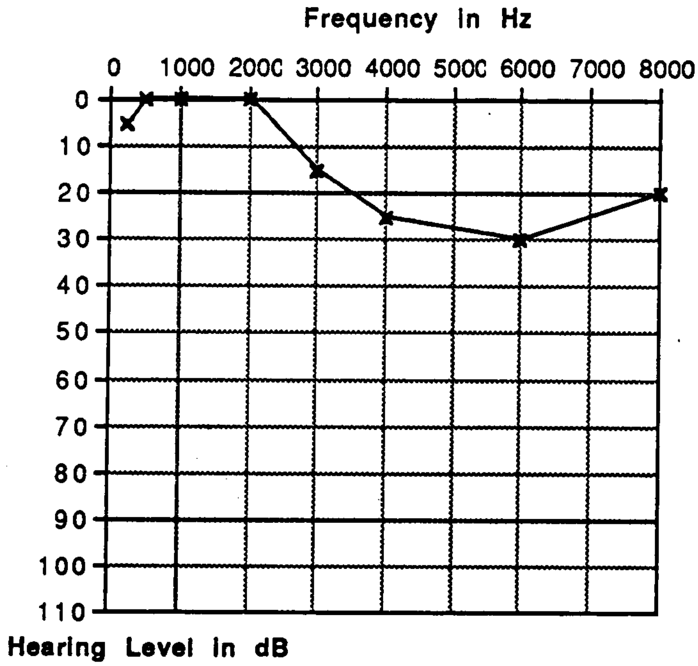
APPENDIX G

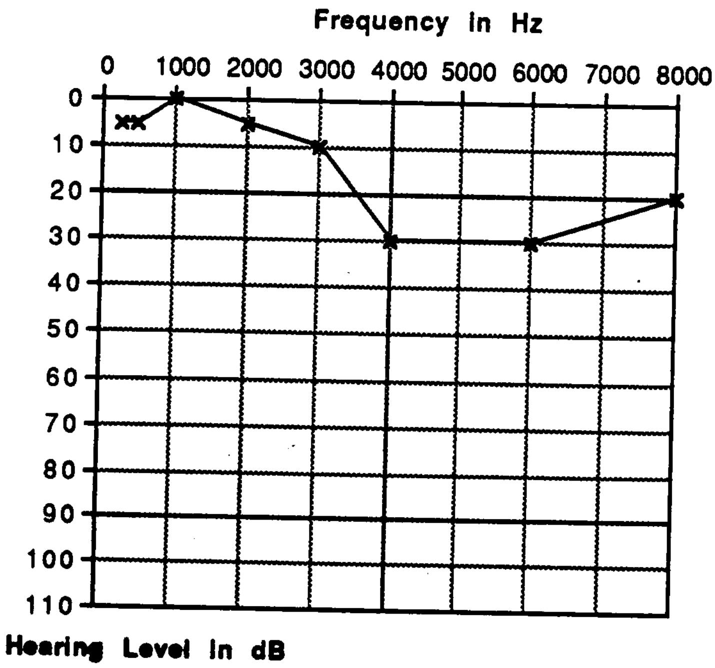
PRE AND POSTTEST SUBJECT AUDIOGRAMS



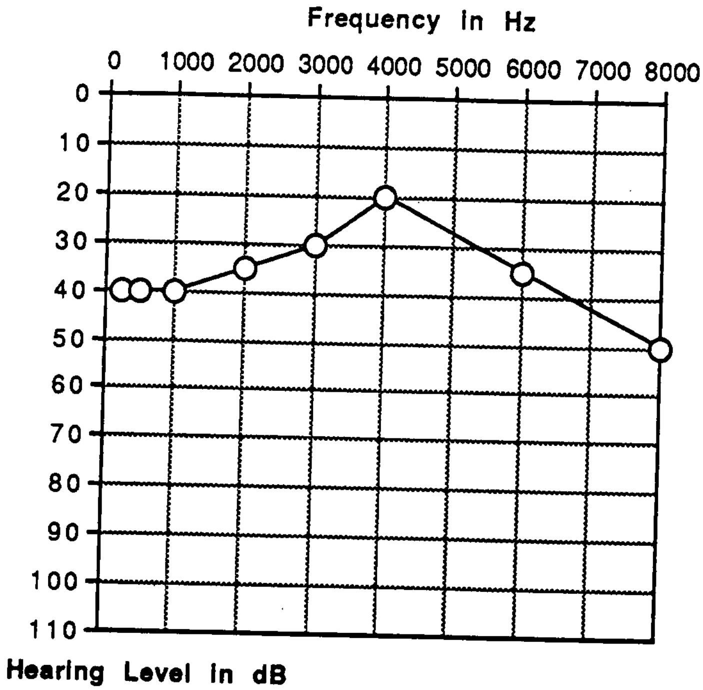


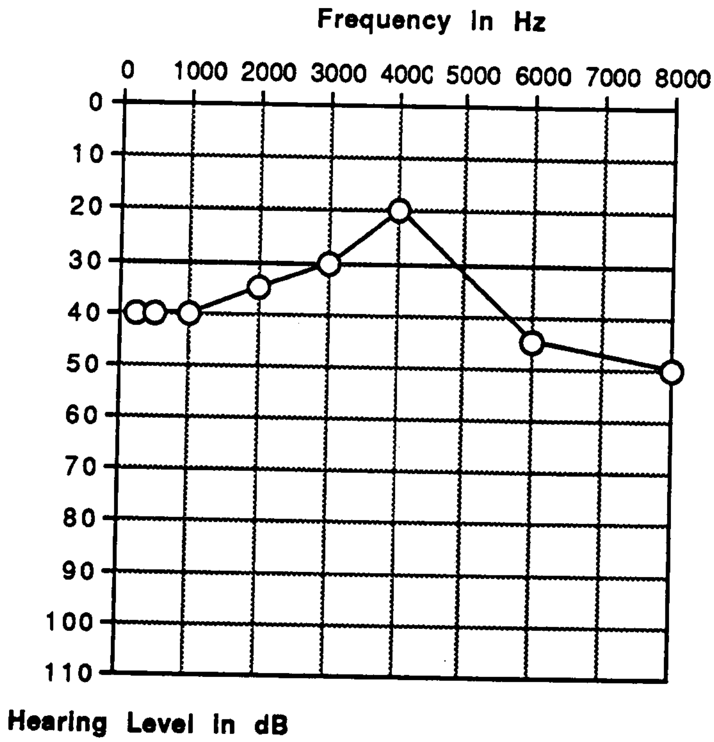
Figures 5. Pre (top) and post-exposure audiograms: subject 1, right ear.



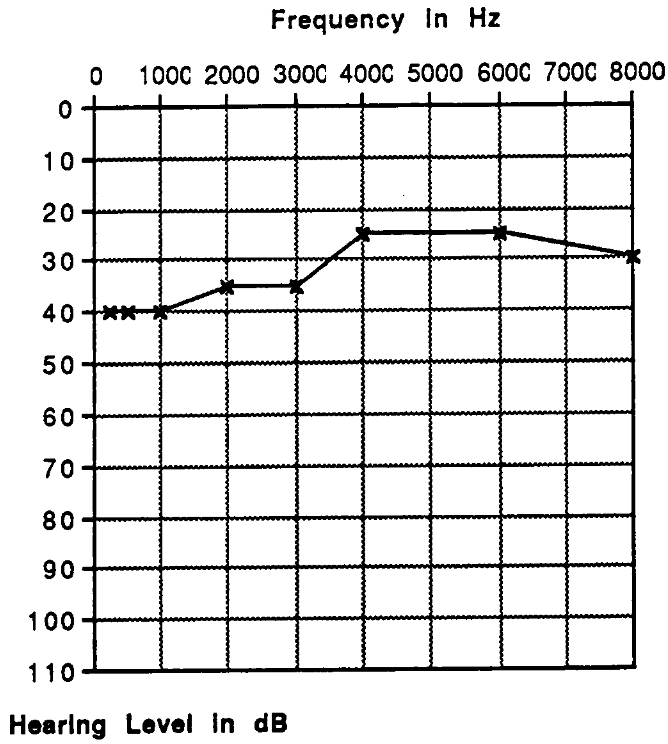


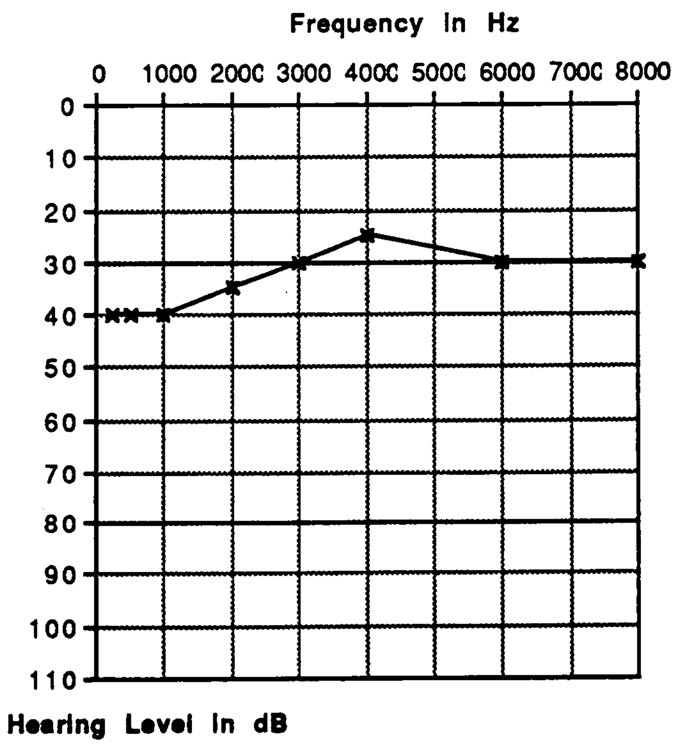
Figures 6. Pre (top) and post-exposure audiograms: subject 1, left ear.



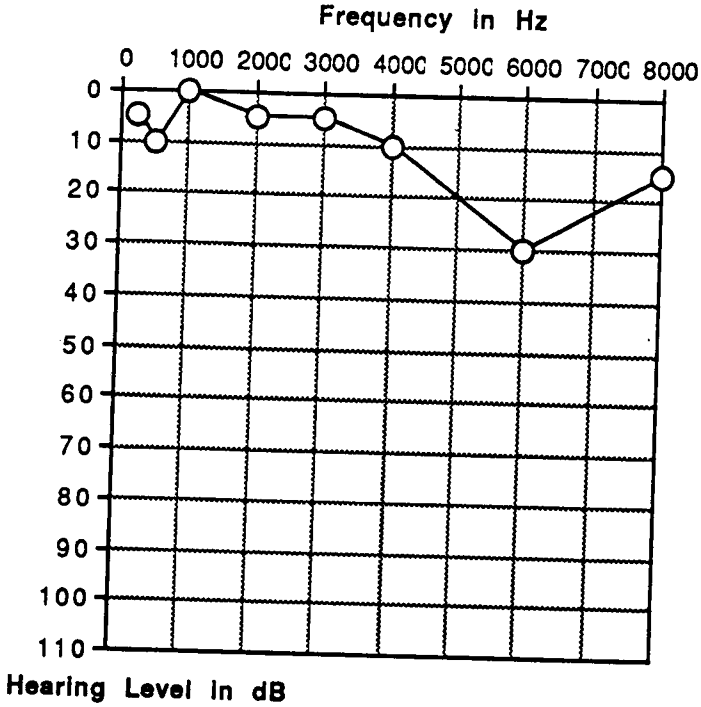


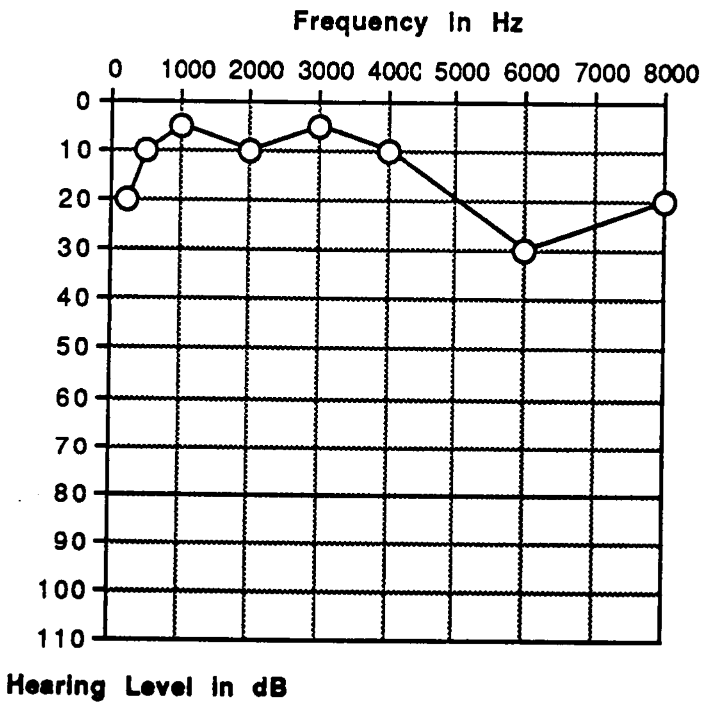
Figures 7. Pre (top) and post-exposure audiograms: subject 2, right ear.



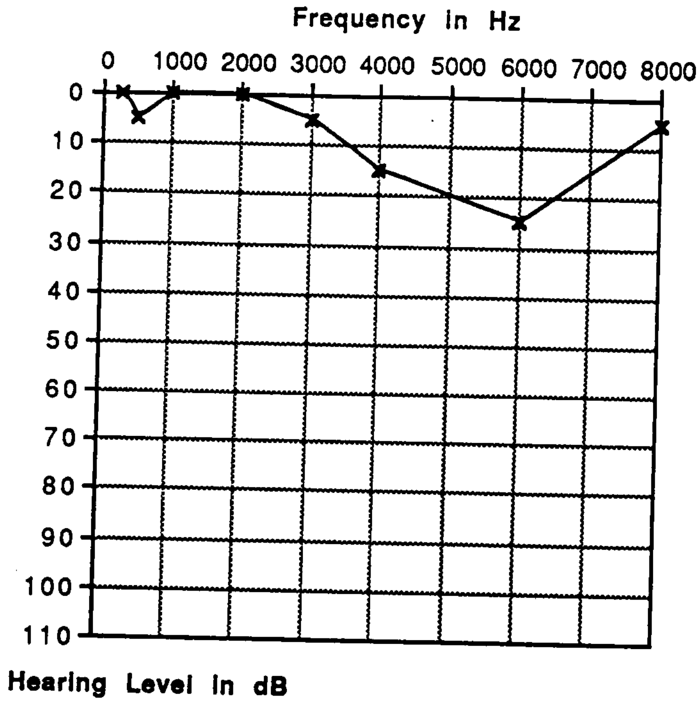


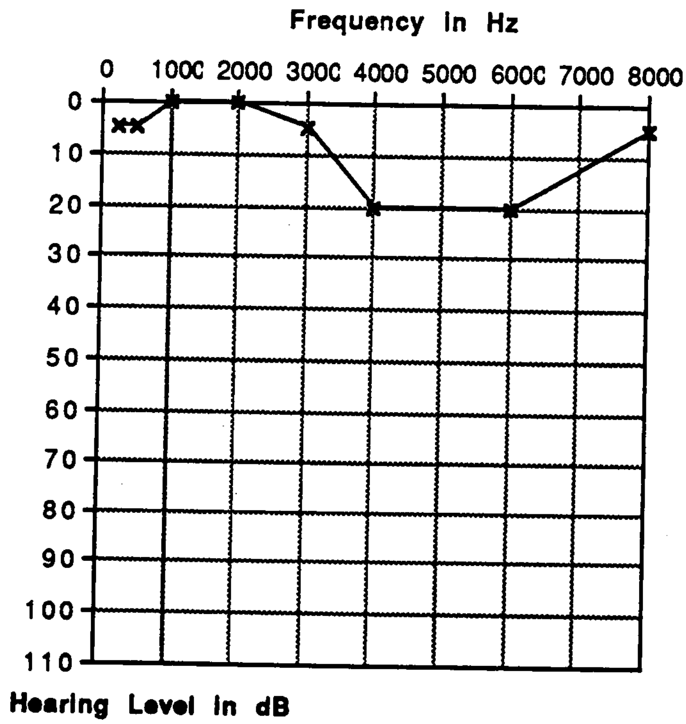
Figures 8. Pre (top) and post-exposure audiograms: subject 2, left ear.



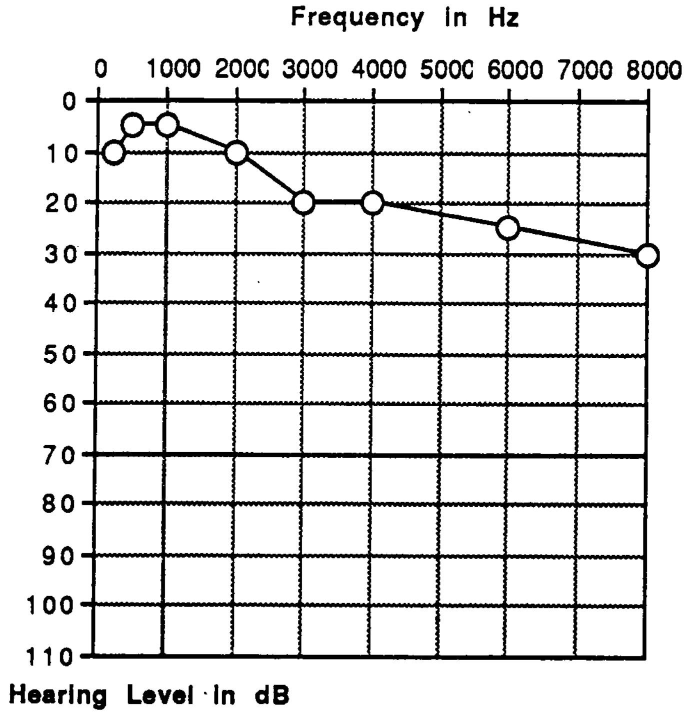


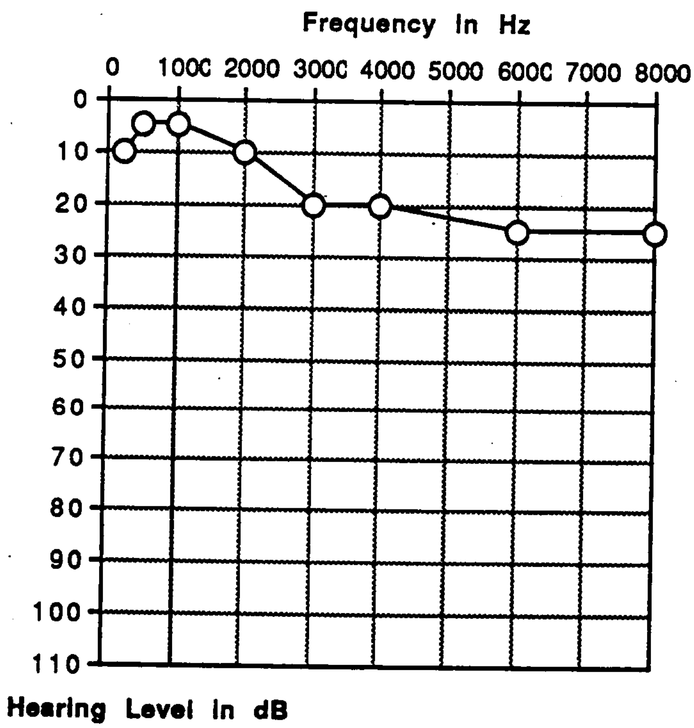
Figures 9. Pre (top) and post-exposure audiograms: subject 3, right ear.



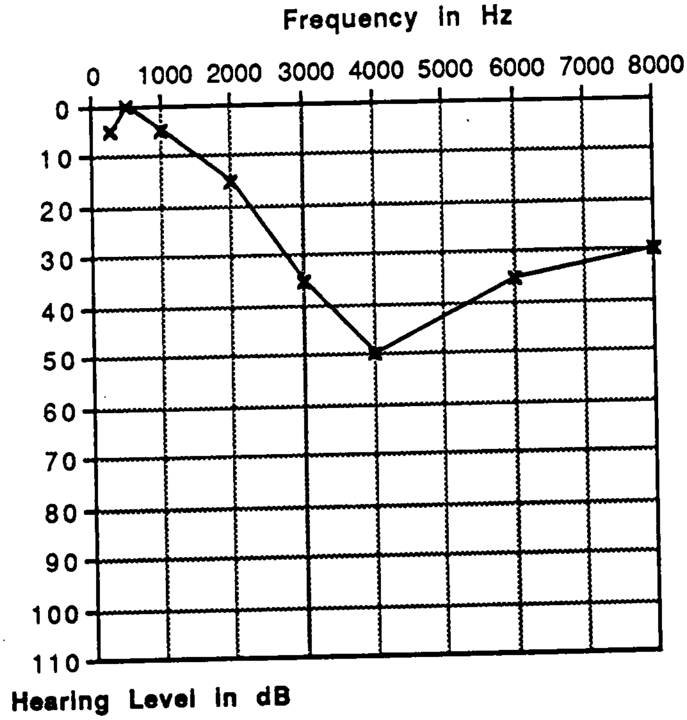


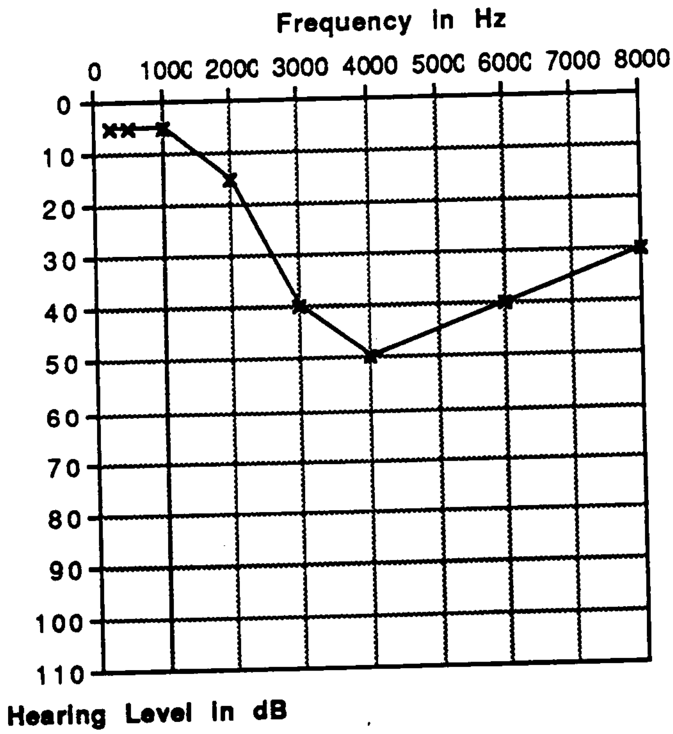
Figures 10. Pre (top) and post-exposure audiograms: subject 3, left ear.



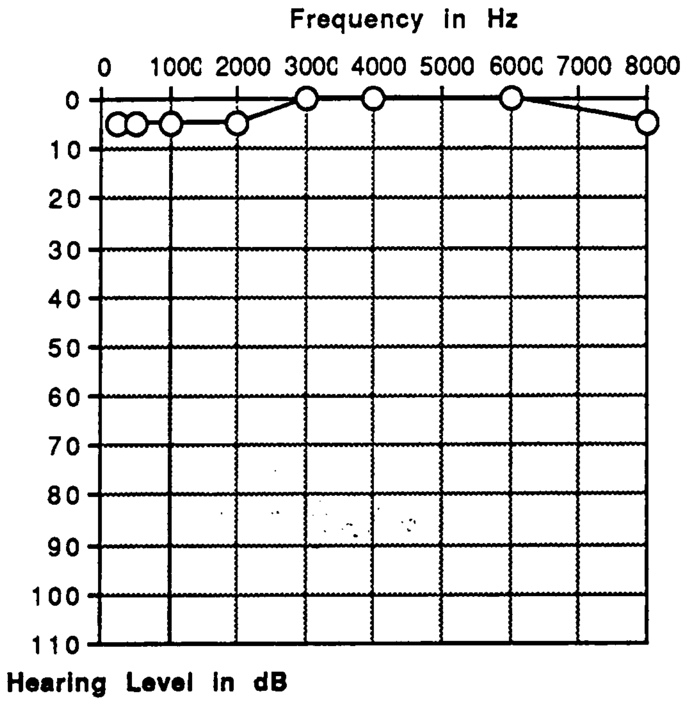


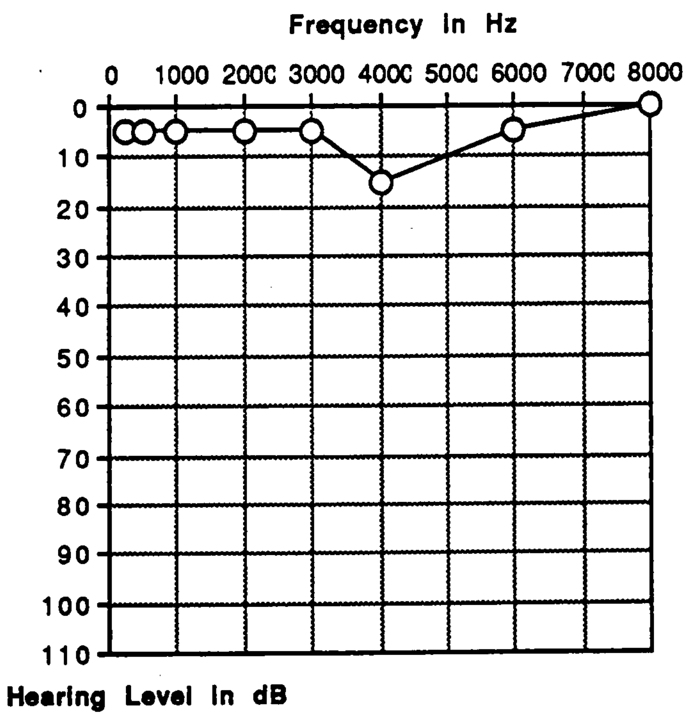
Figures 11. Pre (top) and pos-exposure audiograms: subject 4, right ear.



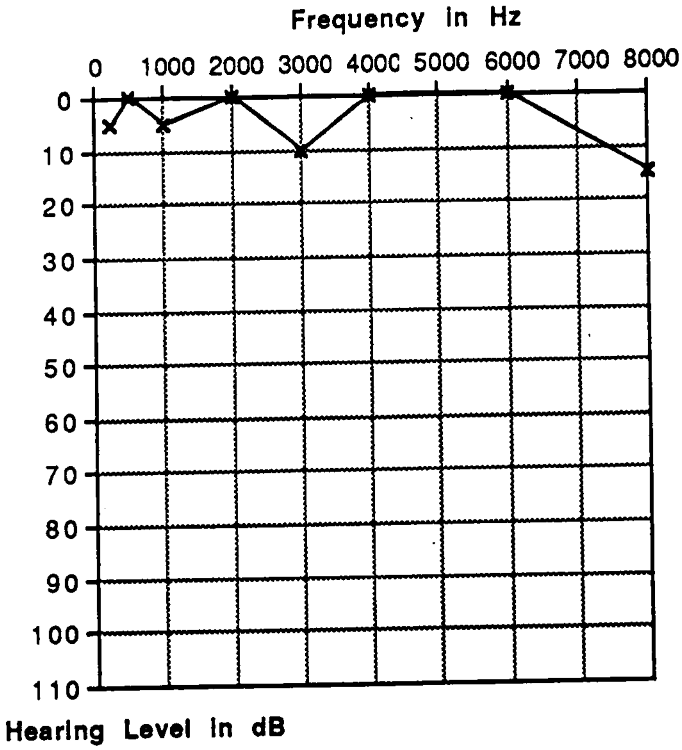


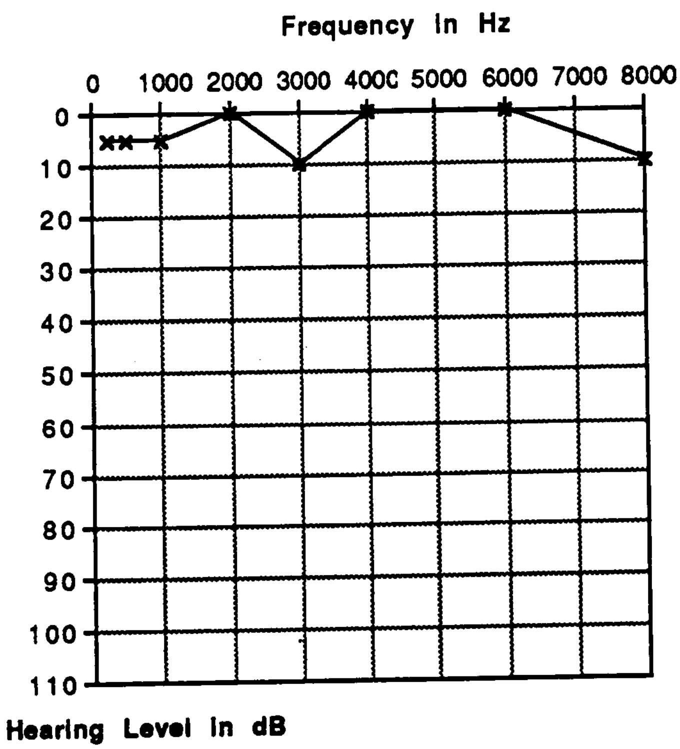
Figures 12. Pre (top) and post-exposure audiograms: subject 4, left ear.



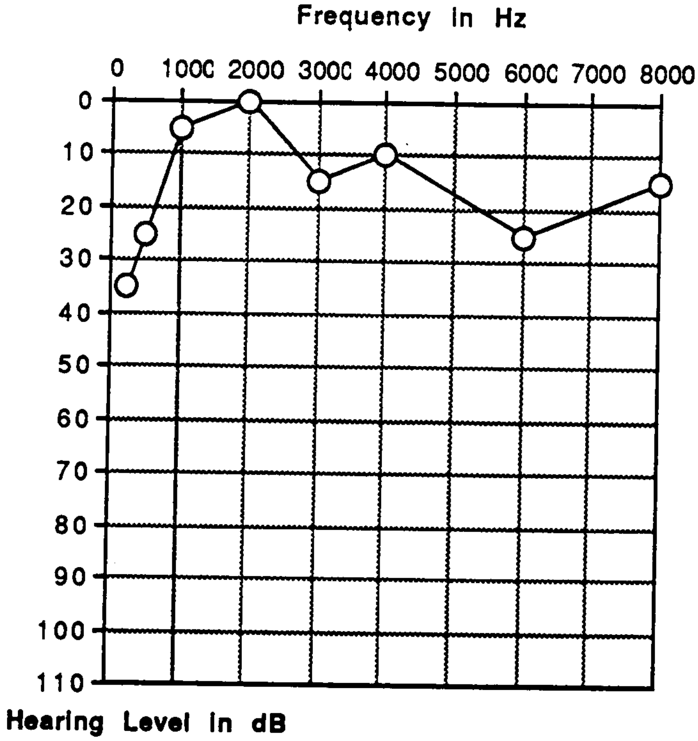


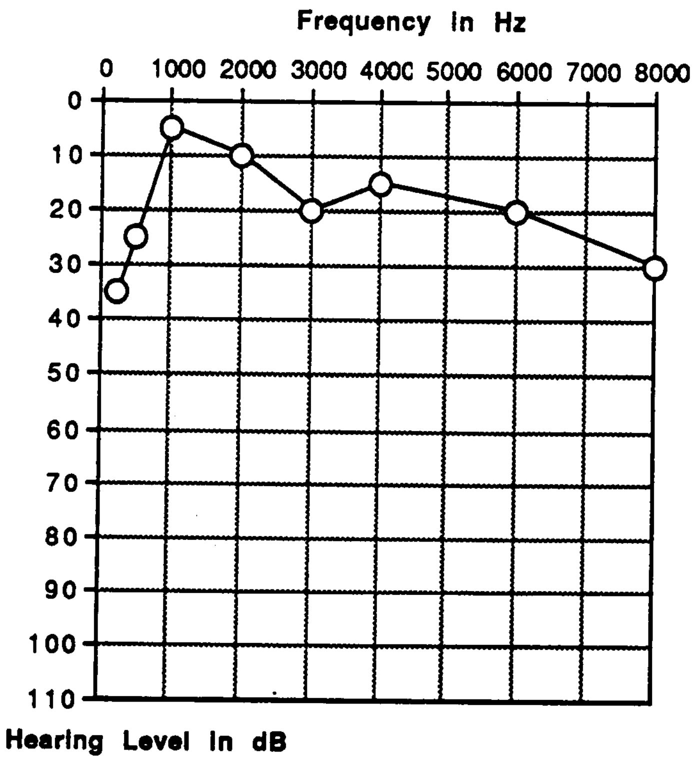
Figures 13. Pre (top) and post-exposure audiograms: subject 5, right ear.



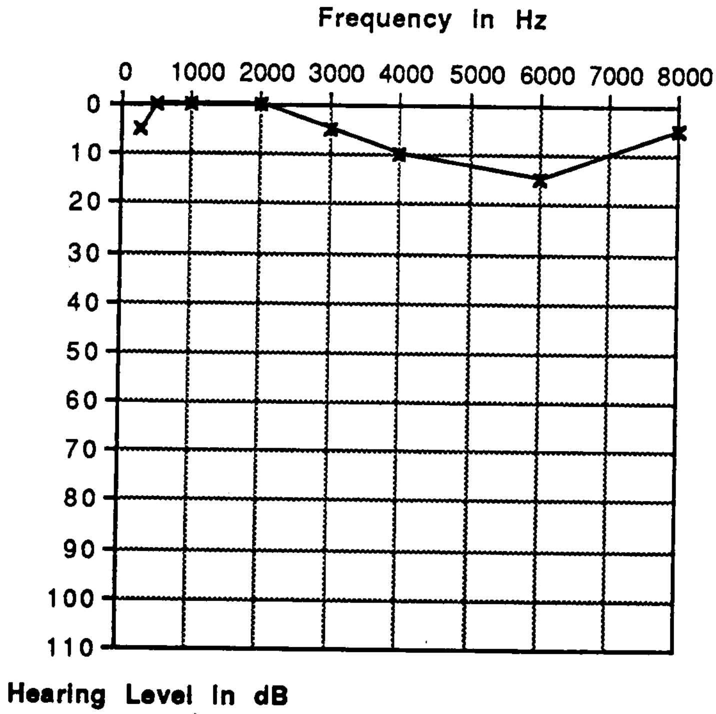


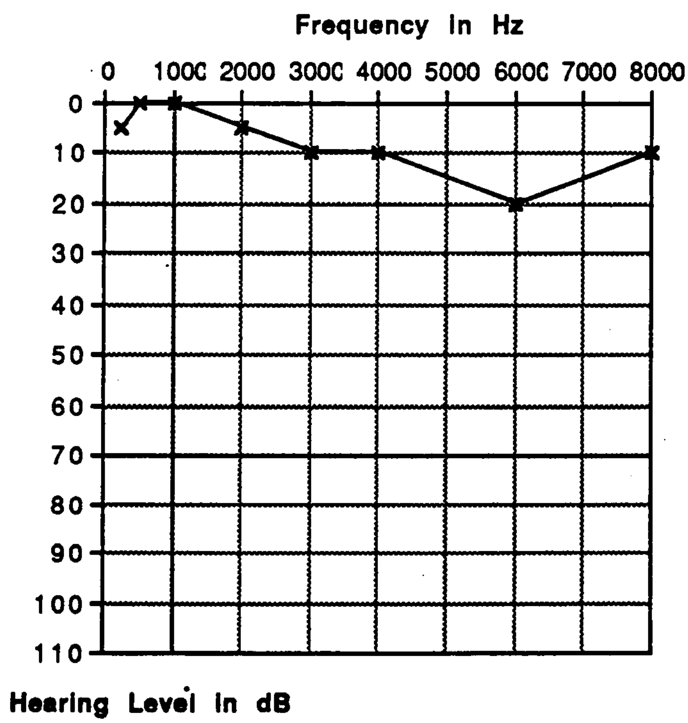
Figures 14. Pre (top) and post-exposure audiograms: subject 5, left ear.



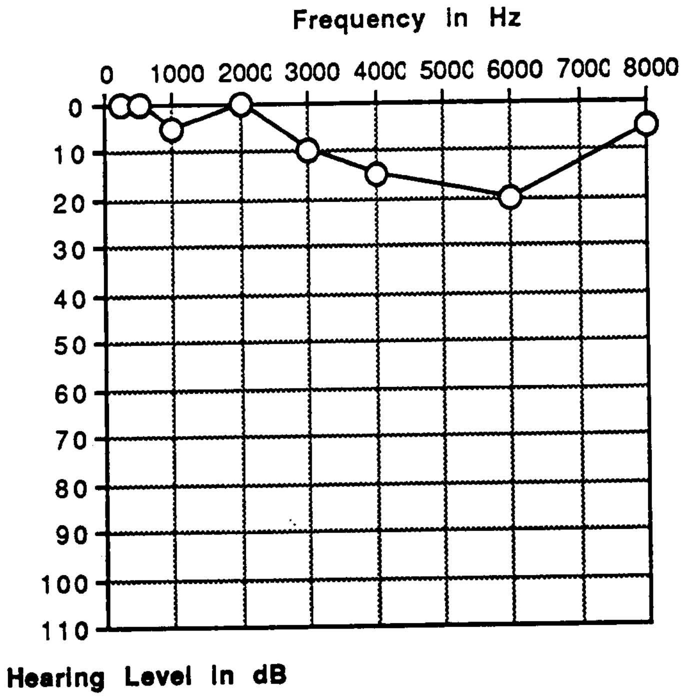


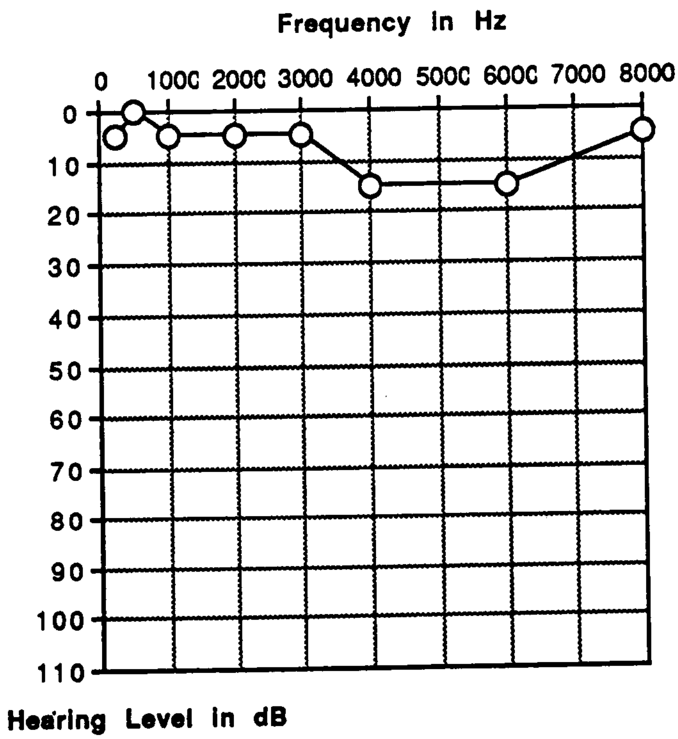
Figures 15. Pre (top) and post-exposure audiograms: subject 6, right ear.



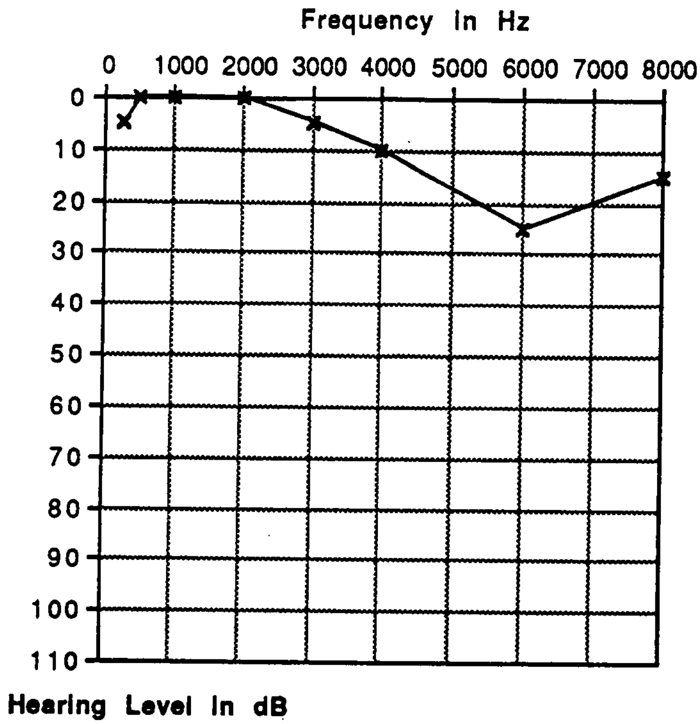


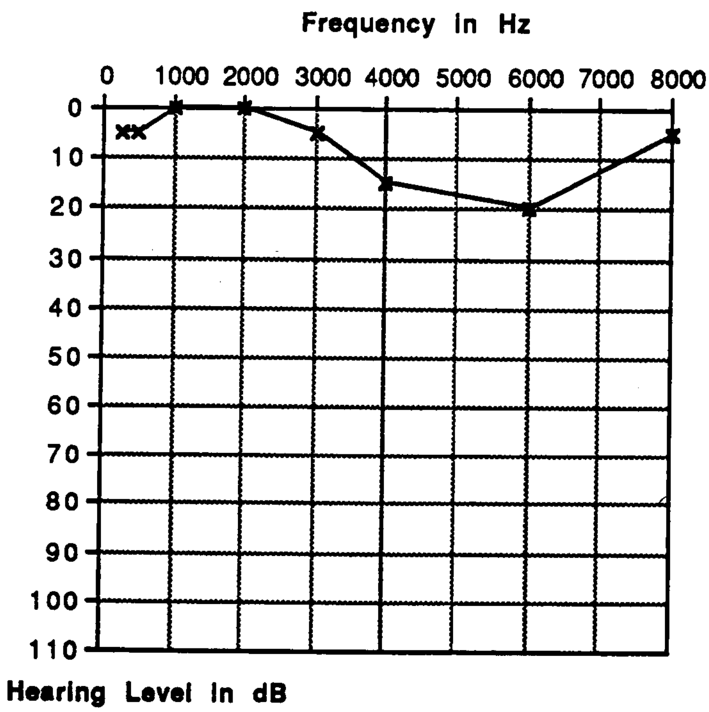
Figures 16. Pre (top)and post-exposure audiograms: subject 6, left ear.



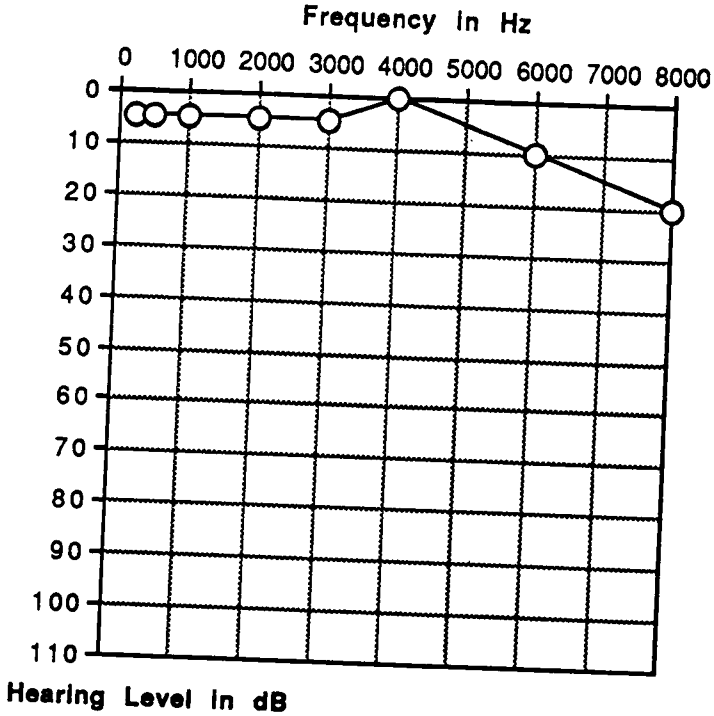


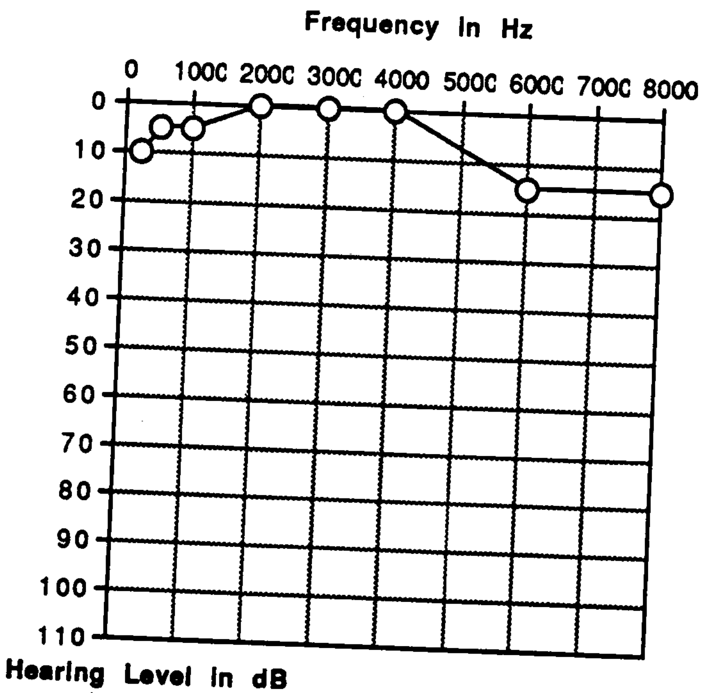
Figures 17. Pre (top) and post-exposure audiograms: subject 7, right ear.



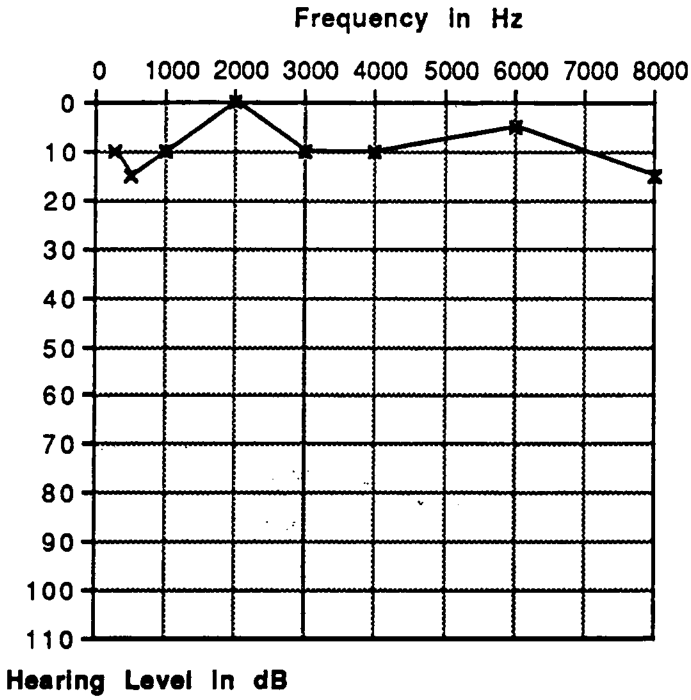


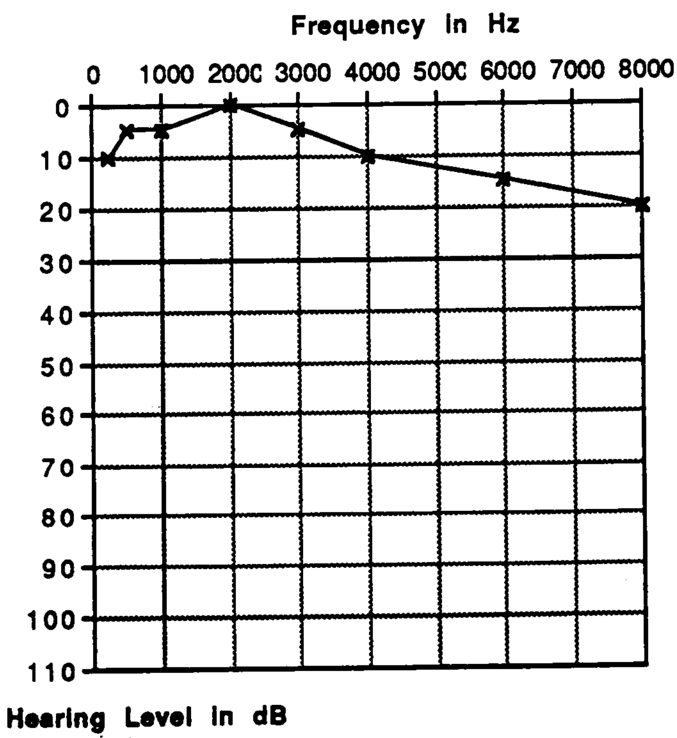
Figures 18. Pre (top) and post-exposure audiograms: subject 7, left ear.



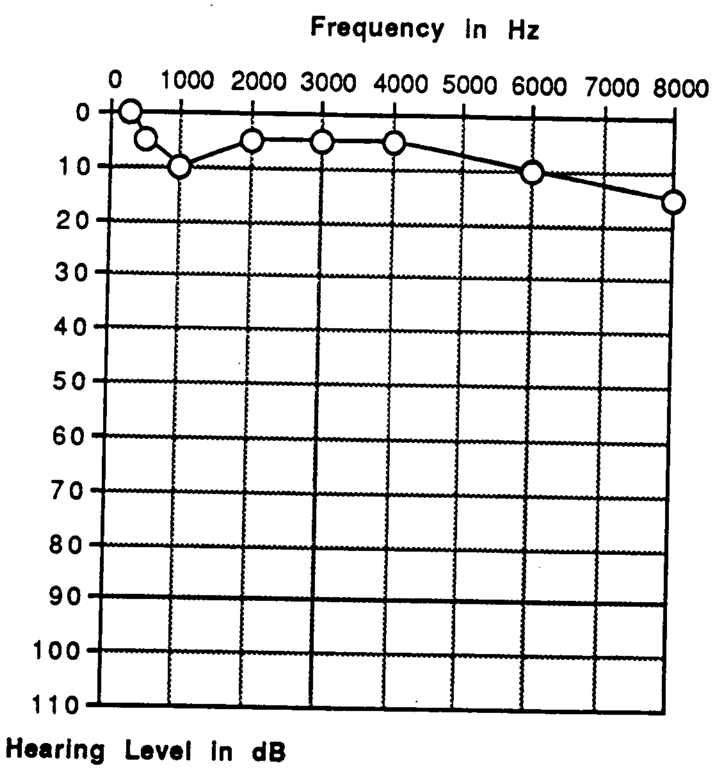


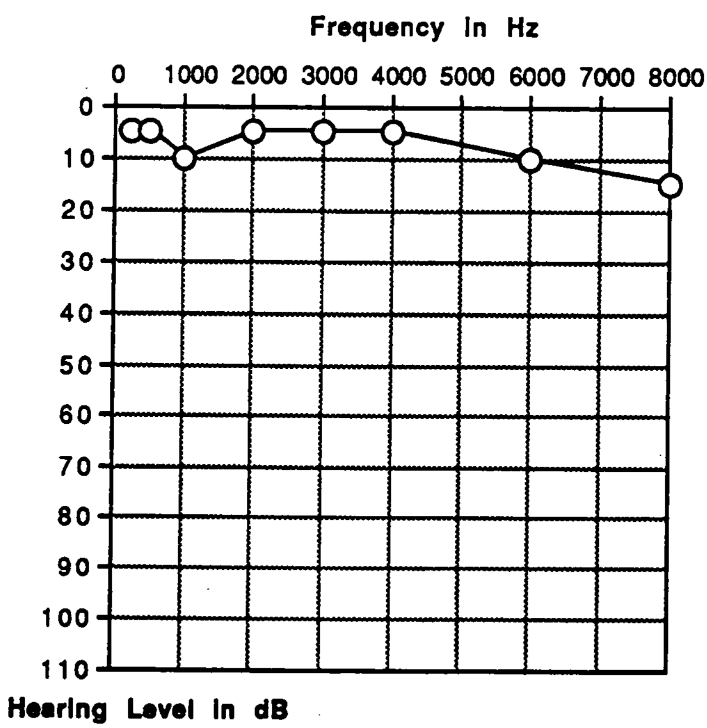
Figures 19. Pre (top) and post exposure audiograms: subject 8, right ear.



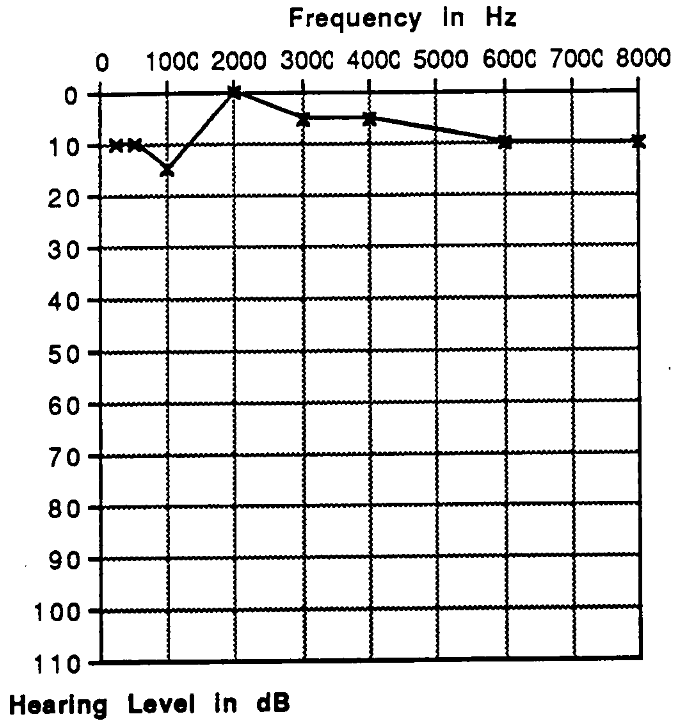


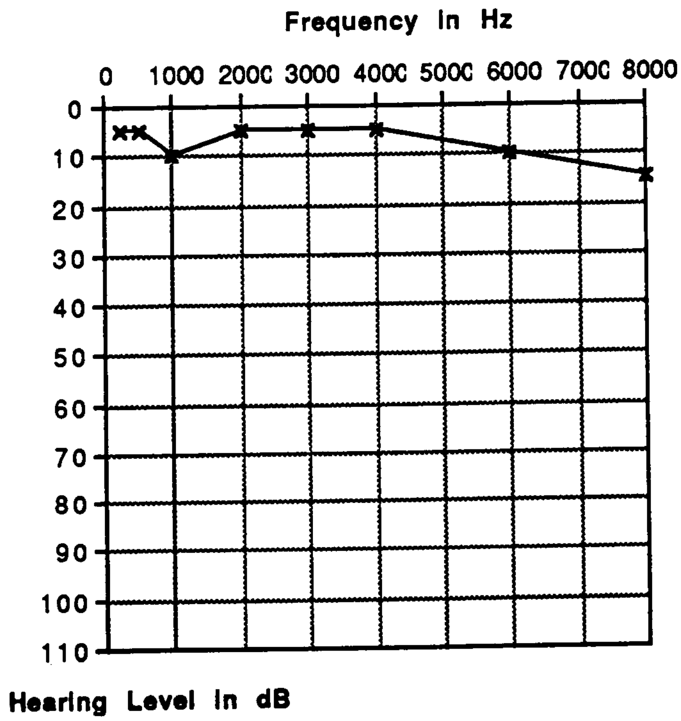
Figures 20. Pre (top) and post-exposure audiograms: subject 8, left ear.



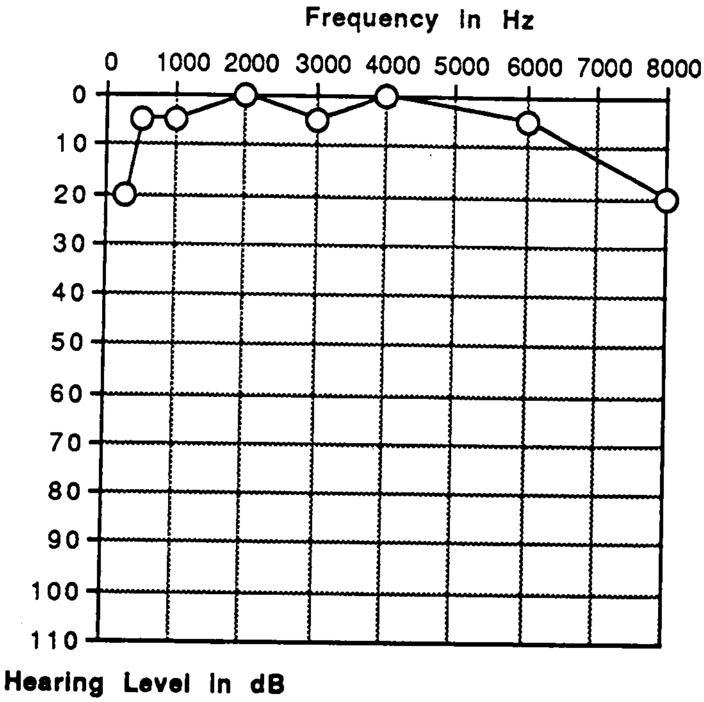


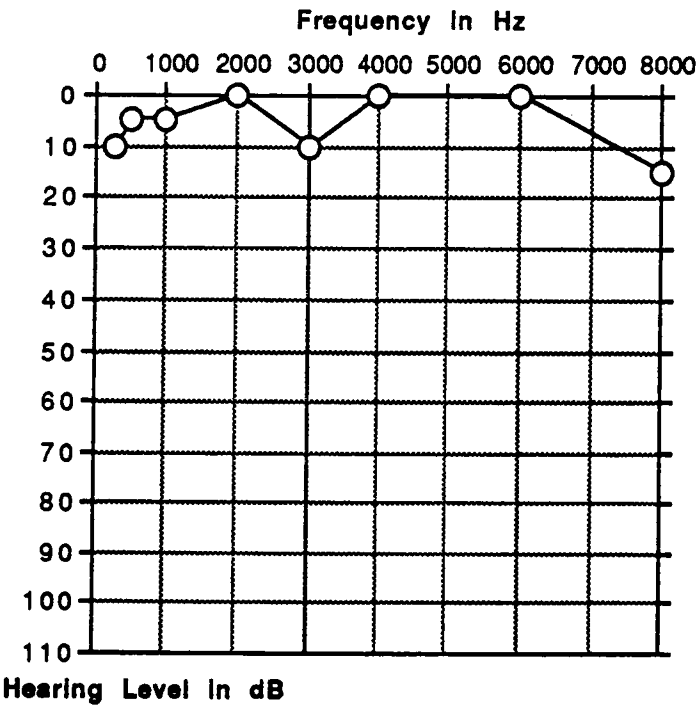
Figures 21. Pre (top) and post-exposure audiograms: subject 9, right ear.



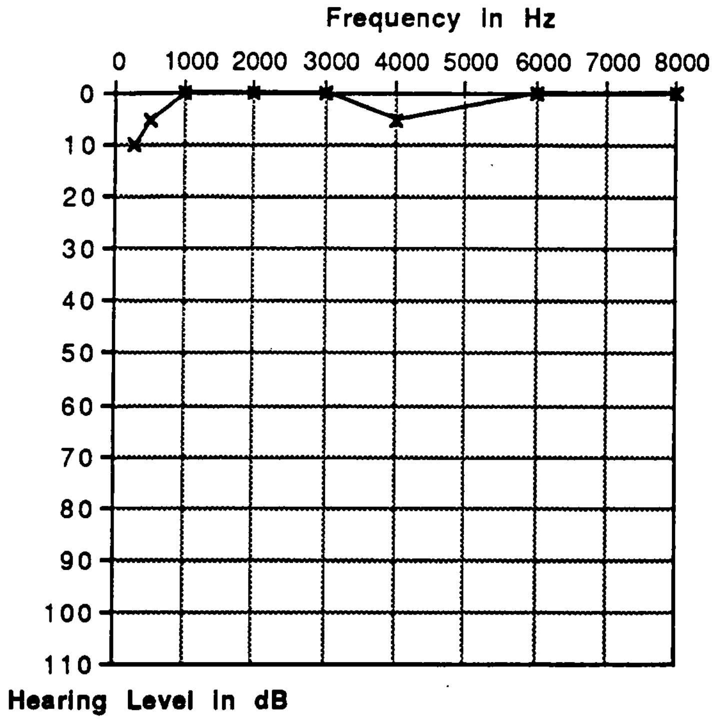


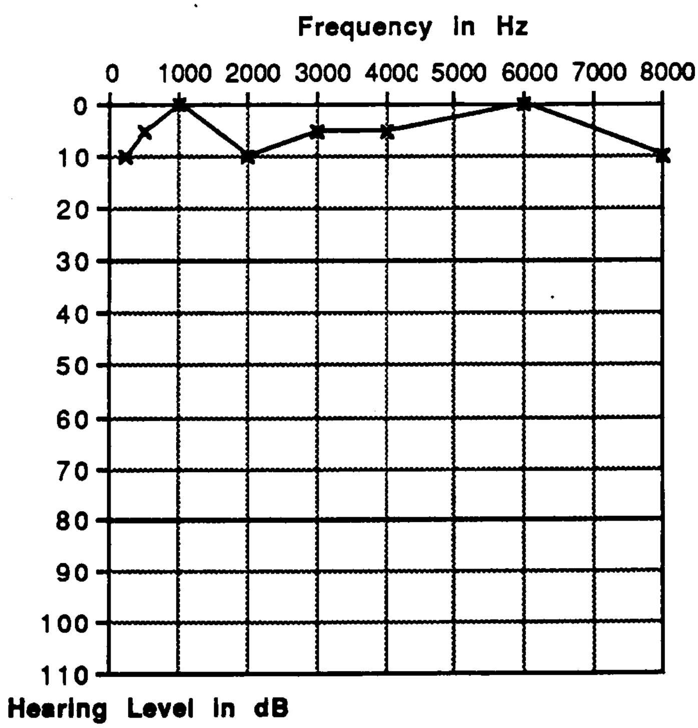
Figures 22. Pre (top) and post-exposure audiograms: subject 9, left ear.





Figures 23. Pre (top) and post-exposure audiograms: subject 10, right ear.





Figures 24. Pre (top) and post-exposure audiograms: subject 10, left ear.

VITA

Laura Elise Brock was born in Knoxville, Tennessee on September 16, 1967. She was raised in Knoxville and attended high school there, graduating in June, 1985. She received a B.A. in Psychology with a minor in American Sign Language from Maryville College in Maryville, Tennessee in May, 1989. She received an M.A. in Audiology from the University of Tennessee, Knoxville, in December, 1991. Future plans include completing a Clinical Fellowship Year in the southeast region of the United States, practicing Audiology in a medical setting, and pursueing a doctral degree in Audiology.