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High frequency acoustic reflexes in cochlea-impaired and normal ears

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The acoustic reflex refers to the contraction of a middle ear muscle in response to sound. The contraction causes a stiffening of the middle ear system and, consequently, the flow of acoustic energy to the cochlea is impeded. By measuring the change in admittance in the auditory system during sound stimulation it is possible to indirectly monitor the middle ear muscle contractions. Such measurements provide useful information regarding the integrity of the auditory system and the location of the auditory pathology.

In subjects with normal hearing sensitivity, the acoustic reflex is typically elicited at a sensation level of between 85 and 100 dB for frequencies below 4000 Hz. In subjects with cochlear hearing loss, reflexes are often evoked at SLs of between 15 and 70 dB. As such, reflexes elicited at reduced SLs signal the presence of cochlear hearing loss, at least for frequencies below 4000 Hz. When a hearing loss is present at a frequency above 4,000 Hz then testing using the lower frequency stimuli does not successfully differentiate the pathology. To date, most research on the acoustic reflex has involved stimulus frequencies in the 250 to 4,000 Hz frequency range, mainly due to instrumentation limitations. The purpose of this study was 1) to determine if there is a difference in the SLs at which the reflex is elicited in normal hearing subjects versus subjects with high frequency cochlear hearing loss, and 2) to examine the time course of the reflex elicited by high frequency stimuli.

Acoustic reflex thresholds were obtained in 13 normal hearing subjects and eight subjects with high frequency cochlear hearing loss, using test frequencies of 1001, 4000, 6000, 8000 and 9000 Hz. The sensation level of the reflex threshold was determined by subtracting the subjects behavioral threshold from the reflex threshold at each test frequency. No differences in reflex sensation levels were found between the two groups of subjects for the four highest test frequencies. However the 1001 Hz stimulus reflex thresholds were significantly lower for the hearing impaired group than for the normal hearing group.

These preliminary results suggest that reflex testing using high frequency stimuli may not differentiate normal hearing subjects from those with high frequency cochlear hearing loss. However, in order to better assess the value of high frequency reflex testing, further studies comparing subjects with varying degrees of hearing loss are necessary.

HIGH FREQUENCY ACOUSTIC REFLEXES IN
COCHLEA-IMPAIRED AND NORMAL EARS

by

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INTRODUCTION

The involuntary contraction of a middle ear muscle in response to sound is termed "the acoustic reflex." This muscle contraction results in a change in the acoustic impedance of the ear (Geffeken, 1934). Measurement of the change in impedance or admittance (the reciprocal of impedance) during auditory stimulation of the ear thus provides an indirect method of monitoring the contraction of the middle ear muscle. Metz (1946) was the first to investigate and carefully document the effects of conductive and sensorineural hearing loss on the acoustic reflex. His findings generated a proliferation of research into the theoretical implications and practical clinical uses of acoustic reflex testing. Acoustic reflex testing is now considered a valuable tool in the differential diagnosis of auditory pathology.

Contraction of the stapedius muscle in response to an intense acoustic stimulus occurs bilaterally, even when the stimulus is delivered only to one ear (Moller, 1961). Thus, the reflex can be monitored by measuring a change in impedance in the stimulated ear (i.e. ipsilateral stimulation), or in the ear contralateral to the one that is stimulated. In humans, the acoustic reflex is attributed solely to action of the stapedius muscle (Djupesland, 1980).

The acoustic reflex acts to selectively attenuate (or reduce) sound which would ultimately reach the cochlea of the inner ear. Early studies on the acoustic reflex were often carried out using small animals as subjects. Moller (1965) observed the effects of stapedius muscle contraction on sound transmission through the middle ear of the cat. He found the greatest attenuation of sound transmitted through the middle ear at frequencies below 1000 hertz (Hz). Sound attenuation resulting from the muscle contraction decreases as frequency of the stimulus increases, with little or no effect on frequencies above 2000 Hz (Pichler & Bornschein, 1957). However, other researchers (Borg, 1972; Teig, 1973) reported that the reflex affected frequencies as high as 10 kilihertz (kHz), although the effect is not attributed solely to stapedius muscle action.

The characteristics of the acoustic reflex depend upon the parameters of the stimulus with which it is elicited, namely the intensity, duration and frequency content of the activating signal. As stimulus intensity is raised beyond the threshold of the reflex (i.e., the lowest intensity level at which a change in admittance is seen), amplitude of the reflex (i.e., magnitude of impedance or admittance change) grows until a critical intensity level is reached. Beyond this critical stimulus level there is no further increase in reflex amplitude with stimulus intensity level (Silman, Popelka & Gelfand, 1978).

Researchers investigating the threshold of the acoustic reflex as a function of stimulus duration have found that stimulus duration of one to two seconds are optimum for obtaining reflex thresholds. Extending stimulus duration beyond two seconds does not alter the reflex threshold. However, when stimulus duration is shortened below approximately 300 milliseconds (ms), the amount of sound pressure needed to obtain reflex must be increased (Woodford, Henderson, Hamernik, & Feldman, 1975).

The relationship between stimulus frequency and acoustic reflex threshold has been well documented, in both normal and pathological ears, for frequencies up to 4000 Hz (Lilly and Franzen, 1970; Reker, 1977; Metz, 1952). At these frequencies, the acoustic reflex can typically be elicited at a sensation level (i.e., level above behavioral threshold) of between 85 and 100 decibels (dBs) (Moller, 1961; Deutsch, 1972; Peterson & Liden, 1972). Popelka (1981) observed reflex threshold as a function of stimulus frequency and found that in normal hearing subjects thresholds can often be obtained at slightly lower sensation levels (SLs) at frequencies between 500 and 2000 Hz than at 250 and 4000 Hz. In subjects with hearing loss resulting from damage to the cochlea, the acoustic reflex can often be elicited at a reduced sensation level of between 15 and

60 decibel, or may be absent entirely at frequencies between 250 and 4000 Hz (Metz, 1952; Beedle & Hartford, 1973; Peterson & Liden, 1972). Reflex thresholds observed at reduced sensation levels are analogous to loudness recruitment, which is an abnormal increase in loudness with stimulus level. This phenomenon is commonly associated with cochlear hearing loss (Metz, 1952). As such, the presence of the acoustic reflex at reduced sensation levels is suggestive of cochlear hearing loss at frequencies below 4000 Hz.

Just as reduced sensation levels are indicative of cochlear hearing loss in the lower frequencies (i.e., frequencies below 4000 Hz), it might be expected that they may also signal cochlear hearing loss in the high frequencies (i.e., frequencies above 4000 Hz). This study explored this possibility by examining the acoustic reflex in both normal ears and in ears with cochlear impairments using stimulus frequencies of 1001 to 9000 Hz. The sensation level at which the reflex is elicited will be calculated by subtracting acoustic reflex threshold from the subject's behavioral threshold at each frequency. It will be determined if there is a significant difference in the sensation level at which the acoustic reflex is elicited in subjects with confirmed cochlear hearing loss above 4000 Hz versus normal hearing subjects. If reflex SLs are reduced at high frequencies in the cochlea impaired group, then this would suggest that acoustic reflex testing using high frequency stimuli could be a potential aid in the diagnosis of high frequency cochlear hearing loss.

A second purpose of this study was to examine the time course of the acoustic reflex elicited by high frequency tones. Specifically, the magnitude of the admittance change during sound stimulation and the degree and rate of reflex adaptation were observed.

REVIEW OF THE LITERATURE

The contraction of the middle ear muscle in response to sound results in a change in the acoustic impedance of the middle ear (Geffeken 1934). Metz (1946) described the effects on acoustic measurements resulting from contraction of the stapedius muscle in normal hearing subjects and in subjects with auditory pathology. Briefly, Metz observed that in normal hearing subjects, the acoustic reflex was elicited at intensity levels of between 70 and 100 decibel hearing level (dB HL). However, in subjects with conductive hearing loss the reflex could not be elicited. His study was, essentially, an attempt to devise an objective clinical measure to assist in the identification of middle ear pathology. Several years after his initial work, Metz (1952) explored further the effects of various auditory pathologies on the acoustic reflex. He observed that the acoustic reflex may be elicited at reduced sensation levels in subjects with cochlear hearing loss and loudness recruitment. It was not until sometime later, as instrumentation technology continued to advance and improve, that the clinical implications of these studies were fully realized. Over the years, acoustic reflex testing has come to be accepted as an integral part of the differential audiological test battery.

MECHANICS OF THE ACOUSTIC REFLEX

For some time it was not known if the acoustic reflex in humans solely involved contraction of the stapedius muscle or if the tensor tympani muscle was also involved. Direct electromyographic measurements of the stapedius muscle and the tensor tympani muscle were obtained on patients undergoing stapedectomies by Djupesland (1965). With electrodes placed on both middle ear muscles of the subject, electrical activity was recorded during sound stimulation of the ear contralateral to the surgically exposed ear. Results of his study indicated that during sound stimulation only the stapedius muscle contracts and not the tensor tympani muscle. Contraction of the tensor tympani muscle occurs as a startle reaction in association with other muscles of the neck and head, as well as to tactile stimulation of the outer ear and head (Djupesland, 1965). Similar findings were also reported by Jepsen (1955). By all indication then, the acoustic reflex in humans involves contraction of the stapedius muscle only. This results in a stiffening of the middle ear system and an increase in its impedance. Sound pressure reaching the fluids of the inner ear is therefore reduced by the muscle contraction.

THEORIES OF REFLEX FUNCTION

One theory attempting to explain the function of the acoustic reflex maintains that the contraction of the stapedius muscle in response to intense sounds serves to protect the inner ear from over stimulation (Wever & Lawrence, 1954). One problem with this theory is that there is a latency of approximately 10 ms between the time of onset of sound stimulation and the contraction of the stapedius muscle. Potentially damaging sound with sudden onset may reach the inner ear before the muscle contracts. The reflex does not, therefore, protect the ear from impulse noises (Tonndorf, 1976).

Simmons (1954) proposed a different explanation of acoustic reflex function. In his investigation, Simmons measured impedance changes in the ear during vocalization (single syllables consisting of "one" "two" or "three") in a patient with unilateral paralysis of the VIII nerve. Impedance changes consistent with stapedius muscle contraction were observed when the subject's vocalization was delivered to the normal ear. The onset of the reflex occurred approximately 100 ms before the vocalization and did not cease until after the vocalization had terminated. No impedance changes were recorded with contralateral stimulation of the affected ear. Simmons points out that in many animal species, in particular the bat family, the attenuation of one's own vocalizations is vital to self survival because it heightens the organism's sensitivity to environmental stimuli.

In addition to the impedance changes observed during vocalization, Simmons also found that there was a contraction of the stapedius muscle during such motor activities as head movement, chewing and swallowing. He hypothesized that "the use of the acoustic reflex contraction may help isolate novel stimuli to identify quickly whether a sound of unknown origin is from an internal physiological noise or from an environmental source."

Pichler & Bornschein (1957) proposed a similar explanation of acoustic reflex function. They based their theory on the fact that the acoustic reflex is "frequency selective," providing the greatest amount of attenuation at frequencies below 2000 Hz. Borg & Zakrisson (1974) compared the effects of a low frequency narrow band masker (presented to the contralateral ear at 85 to 100 dB) on behavioral threshold for a pulsed tone in normal hearing subjects and subjects with unilateral stapedius muscle paralysis. They found that the effect of the low frequency masker on behavioral threshold for a tone was significantly greater (i.e., the threshold was higher) in the affected ear. Also, the effect of the low frequency masker on behavioral threshold was most pronounced for the higher frequency tonal stimuli. It may be that the acoustic reflex acts to suppress low frequency sounds, thereby reducing the upward spread of masking into the high frequencies. This results in improved high frequency sound discrimination, which is particularly important in a complex listening environment (Borg & Zakrisson, 1974).

EFFECTS OF TESTING PROCEDURES

The characteristics of the acoustic reflex depend upon a number of variables. Testing procedures, for instance, may affect the intensity level of the sound at which the acoustic reflex can be elicited. A response (or impedance change) may be obtained in the stimulated ear (i.e., the ipsilateral ear) at a lower intensity level for ipsilateral stimulation than for contralateral stimulation according to early studies (Moller, 1961; Fria, LeBlanc, Kristensen & Alberti, 1975). However, Billings (1975) reported no difference in the level at which it is elicited for ipsilateral versus contralateral stimulation.

The intensity and frequency of the probe tone used to indirectly measure the reflex response also influences the acoustic reflex (Peterson & Liden, 1972; Brask, 1978). Terkildsen, Osterhammel and Nielsen (1970) observed the effects of probe tone intensity on eleven normal hearing subjects. The intensity level of the probe tone was 60 and 70 dB SL. It was found that by reducing the intensity of the probe tone from 70 to 60 dB SL, there was an elevation of reflex threshold. However, this affect was apparent only when the reflex-eliciting-stimulus did not exceed approximately 95 to 100 dB. At high stimulus intensities (greater than 100 dB) the 60 dB SL probe tone was more effective in evoking the reflex than the higher intensity probe tone.

The effects of probe tone frequency on the acoustic reflex have been well-documented, with particular focus on the pediatric population (Weatherby & Bennet, 1980; Allred, 1974). Apparently, the reflex is often absent or elevated in neonates and infants, with the traditional 220 Hz probe tone frequency. However, other studies indicate that reflex activity in infants approximates that of adults when a 660 Hz probe tone is used (Allred, 1974), although the activating stimulus is also a contributing factor.

EFFECTS OF MEASUREMENT VARIABLES

Measurement variables are also important to consider when describing the acoustic reflex. Several of the factors that have been found to influence the reflex include 1) sensitivity of the measurement unit, 2) the manner in which the admittance change is monitored (i.e., recorded or visually monitored (Gelfand, 1984), 3) the specific criterion established to decide whether or not the reflex has been elicited, and 4) the step or increment size of the activator intensity level (Gelfand & Piper, 1981). Jepson

(1963) reported that the direction of the stimulus run (increasing intensity versus decreasing intensity) affected the threshold of the acoustic reflex. He reportedly obtained lower reflex thresholds when the stimuli were presented in a descending order of intensity levels than for an ascending order. However, other researchers (Lilly & Franzen, 1970; Peterson & Liden, 1972) found no significant differences between the ascending and descending stimulus levels over repeated trials.

EFFECTS OF STIMULUS

The specific parameters of the activating stimulus are also known to effect the acoustic reflex in a number of ways. Several studies have demonstrated that there is a direct relationship between the intensity level of the stimulus used to evoke the response and the amplitude of the reflex. Amplitude of the reflex is as the magnitude of the admittance or impedance change, resulting from the stapedius muscle contraction. Research shows that the amplitude of the reflex grows with stimulus intensity of a certain level. Peterson & Liden (1972) report that this level is approximately 10 to 15 dB above the reflex threshold, while other researchers, Dallos (1964), have found that the reflex continues to grow as a function of stimulus intensity level as high as 30 dB SL.

Woodford et al. (1975) studies the effects of stimulus duration on the acoustic reflex threshold in ten normal hearing subjects and five subjects with cochlear hearing loss. Reflex thresholds were obtained using stimulus frequencies of octave intervals between 500 and 4000 HZ and stimulus durations of 10, 20, 50, 100, 200 and 500 ms. The sound pressure level needed to elicit a minimal response was found to be as much as 30 dB higher with a 10 ms duration stimulus, as compared to a 500 ms duration stimulus. The steepness of the threshold versus duration function depended in part on the sex of the subject, the presence of cochlear hearing loss and the frequency of the reflex activator. A steeper gradient of the function was observed with males versus females and with cochlear impaired versus normal subjects. It was also found that the higher frequency stimuli of short duration resulted in the highest reflex thresholds. Threshold of the acoustic reflex was less frequency dependent at longer stimulus durations. These findings are similar to those of Barry and Resnick (1976), and Wright (1972).

Adaptation

Studies show that adaptation of the acoustic reflex, which is the decrease in the magnitude of the reflex during sound stimulation is dependent upon activator frequency. The reflex adapts more rapidly to high frequency tones (above 1500 Hz) than to the low frequency tones (below

1500 Hz) (Cartwright & Lilly, 1976; Wilson, Steckler, Jones & Margolis, 1978).

Wilson, McCullough and Lilly (1984) investigated acoustic reflex adaption as a function of stimulus frequency in 35 normal hearing subjects using stimuli consisting of pure tones (250 through 6000 Hz) and broad band noise. Each stimulus was presented for 31 seconds at an intensity level of 10 dB above the reflex threshold, while admittance changes were recorded in the contralateral ear. At 500 and 1000 Hz the reflex adaptation was minimal. However, rapid reflex adaptation occurred during sound stimulation with the higher frequency pure tones and with the broad band noise. In addition, whereas adaptation of the low frequency tones tended to increase linearly during sound stimulation, the same did not hold true for the higher frequency stimuli. Instead, adaptation occurred more rapidly during the first 10 seconds of stimulation and declined steadily thereafter. It was also noted that the time after onset of stimulation at which the admittance change (from baseline) was greatest was inversely related to stimulus frequency. That is, the higher the activating stimulus frequency, the earlier the point of maximum admittance change.

Effects of Stimulus Frequency on Reflex Threshold

The specific effects of stimulus frequency on the acoustic reflex have been studied by a number of researchers (Peterson & Liden, 1972; Barry & Resnick, 1976). Studies indicate that the width of the noise band used to elicit the acoustic reflex influences the reflex response (Flottorp, Djupesland & Winther, 1971). Margolis, Dubno and Wilson (1980) sought to replicate an earlier study by Flottorp et al (1971) which suggested that a critical band phenomenon may exist for the acoustic reflex. To further investigate this possibility, they obtained reflex thresholds using stimuli having center frequencies of between 250 and 4000 Hz, with various sized band widths surrounding these center frequencies. They found that reflex thresholds remained relatively constant for band widths of less than 700 Hz. As the noise bands were widened beyond 700 Hz, threshold of the reflex dropped. It was also noted that the critical band for the acoustic reflex widened as a function of increased center frequency. These results were in good agreement with those of Flottorp et al. (1971).

The effects of stimulus frequency on the acoustic reflex are dependent in part on the integrity of the auditory system. In ears with normal hearing the intensity level at which the reflex can be elicited with pure tone stimuli is generally between 85 and 100 dB SPL (sound pressue level) (Metz, 1946, 1952; Moller, 1961; Peterson & Liden, 1972). Some studies report that in normal ears thresholds for pure tone stimuli are lowest when the frequency of the activator is between 500 and 2000 Hz. Outside this frequency range acoustic reflex thresholds are observed at higher intensity levels (Beattie & Leamy, 1975; Anderson & Wedenberg, 1968). Wilson (1981) obtained reflex thresholds on 18 normal hearing subjects using pure tone stimulus frequencies of 250 to 6000 Hz. Mean reflex thresholds were 104.3 dB at 250 Hz, 89.8 dB at 1000 Hz, and 97.7 dB at 6000 Hz. These levels are similar to those obtained by Wilson and McBride (1978). Reflex measurements were also obtained in 50 normal hearing adults by Neimeyer and Sesterhenn (1974) at stimulus frequencies from 125 to 8000 Hz. Thresholds obtained paralleled the threshold of audibility curve for pure tone stimuli delivered by air conduction. Greater sound pressure levels were thus needed to elicit the reflex at frequencies below 1000 Hz and above 4000 Hz.

When a hearing loss of cochlear origin is present, the sensation level at which the threshold is observed is reduced at the affected frequencies. For instance, if a hearing loss is present in the 2000 to 4000 Hz frequency range, then reflex thresholds in dB SPL obtained will be reduced within this frequency range in comparison to those elicited at other unaffected frequencies. One explanation of this phenomenon is based on the hypothesis that the intensity level at which the acoustic reflex is elicited is governed by the loudness of the activating stimulus (Metz, 1952; Jepsen, 1963). In ears with cochlear damage, loudness grows at an abnormally rapid rate at the affected frequencies. The "abnormal increase in loudness" described by Metz (1952) is termed "loudness recruitment." When recruitment is present, reflexes are elicited at lower than normal sensation levels. There is general agreement that acoustic reflex thresholds observed at sensation levels of 70 dB or less suggest the presence of cochlear hearing loss (Metz, 1952; Popelka, 1981).

While some researchers (e.g. Jerger, 1970) reported a one-to-one inverse relationship between the degree of hearing loss and the sensation level at which the acoustic reflex is elicited, more recent investigation suggests that the reflex is observed at a fairly constant level, as long as the loss does not exceed 50 to 55 dB (Popelka, 1981; Gelfand, Piper & Silman, 1983). Silman and Gelfand (1981) obtained acoustic reflex thresholds on 278 subjects with varying degrees of cochlear impairment, using stimulus frequencies of 500, 1000 and 2000 Hz. While reflex thresholds remained constant for hearing losses less than 50 dB, they were elevated in the ears with hearing loss greater than 60 dB and absent entirely in ears with severe cochlear hearing loss.

As part of the differential audiological test battery, acoustic reflex threshold testing is typically performed using stimulus frequencies of 250, 500, 1000, 2000 and 4000 Hz. Some studies advocate the exclusion of 4000 Hz based on the large proportion of absent reflexes at this stimulus frequency, even in normal hearing subjects (Jerger, Jerger & Mauldin, 1972). It is possible that failure to elicit a reflex at 4000 Hz is due to output limitations of conventional equipment. The fact that frequencies above 4000 Hz are not commonly used as reflex activators can also be attributed, at least in part, to instrumentation restrictions. Most impedance systems in use today are hard wired to produce pure tones within a determined range of frequencies. This restriction limits, to a certain degree, the diagnostic capabilities of the acoustic reflex test.

When there is a cochlear hearing loss at frequencies outside of the 250 to 4000 Hz frequency range, reflex threshold testing using tonal stimuli within the traditional frequency limits does not successfully identify the auditory pathology. The reason for this is that with cochlear hearing loss, the sensation level at which the acoustic reflex is elicited is reduced only at the affected frequencies. As such, acoustic reflex testing using stimuli below 4000 Hz is ineffective in detecting high frequency cochlear hearing loss.

Ironically, high frequencies are usually the first to be affected by damage to the cochlea, due in part to the structure of the inner ear (Tonndorf, 1976). That is, the base of the cochlea (where high frequencies are analyzed) is more susceptible to acoustic trauma than the apex of the cochlea. Typically, an individual with noise induced hearing loss will exhibit a maximum loss between 4000 and 6000 Hz, with smaller losses below and above this range. Moreover, it is not uncommon to observe normal hearing sensitivity in the low to mid-frequency range, with an abrupt drop in hearing in the high frequencies in subjects with noise-induced cochlear hearing loss. Because the first signs of noise-induced hearing loss are generally apparent at frequencies above those which contribute most to the understanding of speech (approximately 300 to 3000 Hz), the hearing loss often goes undetected until the loss has spread into the mid-frequencies. Thus, once these mid-frequencies are affected there may already be considerable permanent high-frequency hearing loss. In many cases the high-frequency hearing loss can be prevented by early detection (Burns, 1973).

High frequency cochlear hearing loss may also be caused by ototoxic drugs. The aminoglycoside antibiotics are a group of drugs known to have ototoxic effects which can result in permanent inner ear damage (Brummett & Fox, 1982). As with hearing loss caused by excessive noise exposure, the loss of hearing sensitivity resulting from the aminoglycoside antibiotics typically begins at the base of the cochlea and progresses toward the apex. High frequencies are affected first, followed by the middle and lower frequencies. According to Brummet et al. (1982) "there is evidence the early functional losses at very high frequencies may be reversible if drug administration is stopped." He points out that the hearing loss produced by these drugs could be avoided by routine testing at high frequencies. Hearing testing using high-frequency stimuli would then signal that a switch to a different drug or a change in dosage is needed in order to avoid further damage. Brummet et al. explains that "even if the patient's hearing loss for high-frequency sound is not reversed, prompt change of therapy will probably spare the patient's hearing for the important speech communication frequencies between 300 and 3000 Hz."

METHODS

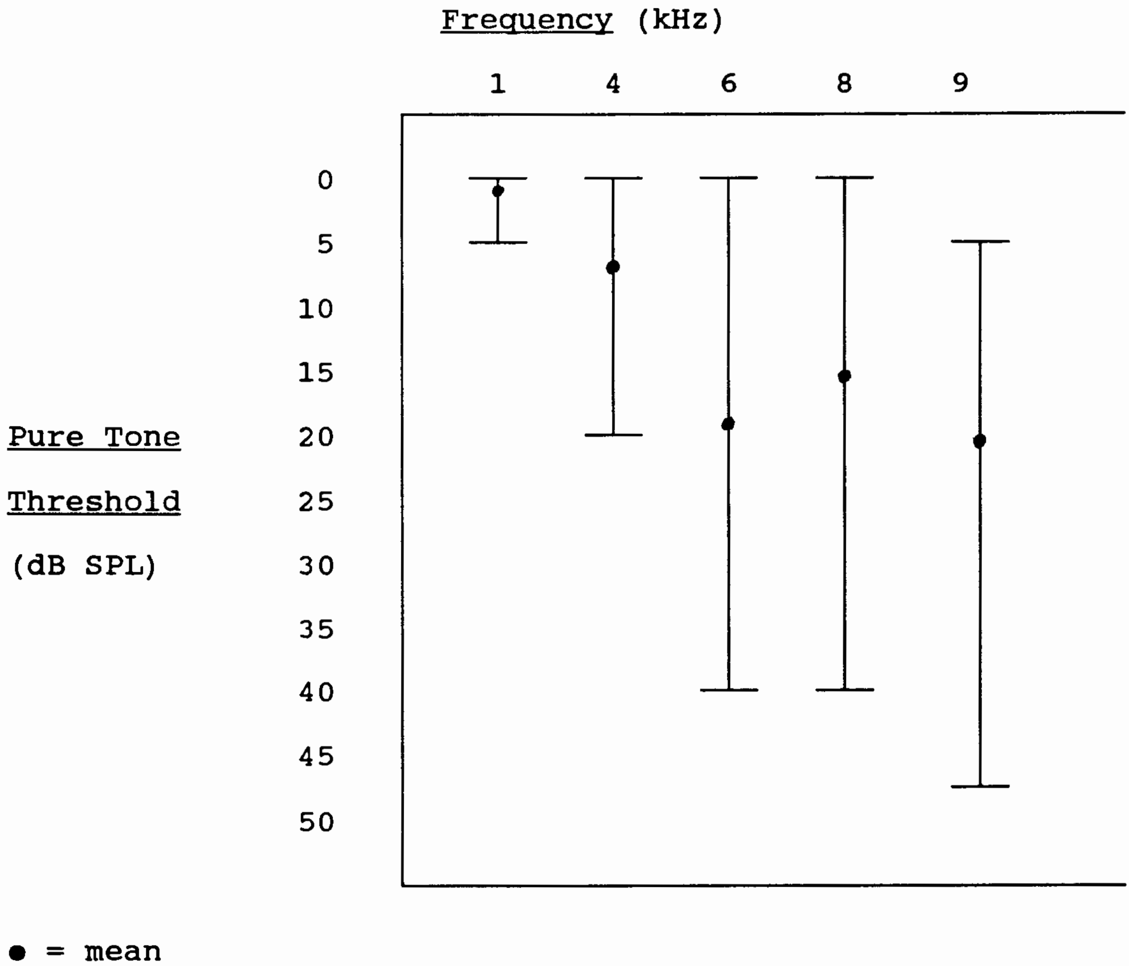
SUBJECTS

Two groups of listeners served as subjects. One group consisted of 16 normal hearing subjects; the other group consisted of 8 subjects with high frequency cochlear hearing loss. All subjects were between 30 and 50 years of age and were selected from a pool of volunteers at Portland State University. Criteria for selection of subjects included 1) no history of middle ear pathology, and 2) normal middle ear pressure, defined as a tympanogram peak at ± 50 deca pascals (daPa) of air pressure. All subjects were examined otoscopically to ensure that each had healthy, unoccluded ear canals.

Subjects included in the normal hearing group all demonstrated behavioral thresholds of 20 dB or lower (ANSI, 1969) at octave test frequencies from .25 to 9 kHz. Subjects in the high frequency cochlear hearing loss group demonstrated pure tone thresholds of 20 dB or lower at test frequencies below 40000 Hz, and a hearing loss within the range of 20 to 45 dB at or above 4000 Hz. An audiogram depicting mean thresholds and ranges of thresholds for subjects in this group is presented in Table I.

TABLE I

MEAN PURE TONE THRESHOLDS AND RANGES OF THRESHOLDS
AT THE FIVE TEST FREQUENCIES FOR THE
EIGHT SUBJECTS WITH HIGH
FREQUENCY HEARING LOSS



The presence of cochlear hearing loss was determined by patient history and a recent audiological evaluation indicating air-bone gaps no greater than 10 dB at any test frequency. Those with cochlear hearing losses exceeding 65 dB at frequencies of 4000 Hz or higher were excluded from the study, due to the fact that the acoustic reflex is typically absent when the cochlear hearing loss is this severe (Popelka, 1981).

PROCEDURES

Behavioral thresholds were obtained for all subjects at test frequencies of .25, .5, 1, 4, 6, 8 and 9 kHz. Test tones between .25 and 8 kHz, delivered through TDH 49 earphones, were generated by a standard audiometer (Amplaid 209) calibrated to the ANSI 1969 standards. The 9000 Hz stimuli were generated by the Virtual 310 Immitance Measurement System and delivered through a TDH 49 earphone. Behavioral hearing thresholds were obtained for both ears, using the Hugheson Westlake (1944) Threshold Determination Procedure. Calibration of the Virtual 310 Immitance System, to be used for reflex measurements was performed before testing each subject. Sound pressure levels produced by the Virtual were measured by means of the Bruel & Kjoer Precision Sound Level Meter, in order to ensure proper output intensity levels.

Next, a tympanogram was obtained in the test ear of the subject by means of the Virtual 310 Immittance Measurement System interfaced with a MacIntosh Computer. The probe tone frequency was 220 Hz. The probe was inserted into the ear canal, a hermetic seal was obtained and admittance changes in the canal were monitored as air pressure was swept from

-300 to +300 daPa. Middle ear pressure was taken as the pressure point of maximum admittance on the tympanogram.

Prior to reflex testing, air pressure in the canal of the test ear was automatically set by the Virtual to the point of maximum compliance determined from the tympanogram. Next, acoustic reflex testing was performed with the probe in the test ear and the tonal stimuli delivered to the contralateral ear. That is, admittance changes were monitored in the test ear (using a 220 Hz probe tone) during sound stimulation of the contralateral ear. Pure tones were delivered to the contralateral ear through a TDH 40 earphone housed in a MX 41 AR cushion. Each tone was presented for a duration of one second, with a five second silent interval between presentations. The frequency of the tone was varied parametrically in ascending order, from 1001 to 9000 Hz. At a given frequency the intensity of the tonal stimulus was raised in 5 dB increments, from 75 dB SPL to 115 dB SPL. Threshold of the acoustic reflex was taken as the lowest intensity level at which there was a decrease in admittance of .02 mmho (millimhos) or more below baseline. The same procedure was then conducted with the headset reversed, to test for reflexes in the opposite ear.

RESULTS

Representative individual data obtained from a normal hearing subject (MM) at the five test frequencies is presented in Appendix A. Each graph depicts the change in acoustic admittance (in millimhos) as a function of time in seconds. The parameter is stimulus level in dB SPL, indicated by the number to the right of each tracing. Data for stimulus frequencies of 1001, 4000, 6000, 8000 and 9000 Hz are shown in panels a, b, c, d and e, respectively.

With the 1001 Hz stimulus frequency, admittance remains unchanged over the 1.4 second duration of the 80 dB SPL stimulus. However, when the stimulus level is raised to 85 dB SPL, admittance decreases by up to .03 mmho over the duration of the stimulus. The decrement in admittance increases from .03 to .18 mmho as the level of the tone is raised from 85 to 115 db SPL. Threshold of the acoustic reflex in this case is taken as 85 dB SPL, or the lowest level at which the reflex is elicited. It should be noted that reflex adaptation, which describes the decrease in the magnitude of the admittance change during sound stimulation, is minimal with the 1001 Hz reflex-activator signal. In other words, the change in acoustic admittance associated with a reflex response is sustained and in some cases increases over the duration of the stimulus presentation. Minimal reflex adaptation with 1000 Hz stimuli has been reported in other studies (e.g., Wilson et al., 1978).

When a 4000 Hz tone is used as the stimulus, the reduction in admittance increases from .04 to .1 mmho as the level of the tone is raised from 90 to 115 dB SPL. At each stimulus level the reflex appears to adapt to approximately one-half its initial magnitude and to sustain this level until the stimulus is terminated. At stimulus offset, the admittance rapidly returns to the baseline value.

With a 6000 Hz tone, no change in admittance occurs until the stimulus level reached 95 dB SPL. The magnitude of the admittance change grows from .04 mmhos at 95 dB to .08 mmhos at 115 dB. It can be observed that the point of maximum reduction in admittance occurs later in time for the 6000 Hz tone than for the 4000 Hz tone. This is particularly evident at the lower stimulus intensity levels.

With a 8000 Hz tonal stimulus, the magnitude of the admittance change is considerably less than that observed with the lower frequency tones. The amount of reduction in admittance increases slightly from .02 to .04 mmho as the intensity of the tone is raised from 95 to 115 dB SPL. Rapid reflex adaptation occurs within the first .06 ms of the reflex response at all the intensity levels. At 9000 Hz no admittance change is apparent at the stimulus level of 110 dB SPL. However, a change of .05 mmho is seen at 115 dB

SPL. Reflex adaptation is quite pronounced with the 9000 Hz stimulus, as demonstrated by the rapid recover to the original baseline admittance level within .04 seconds. Increased rate of reflex recovery with increasing stimulus frequency was found to be characteristic of normal hearing subjects in this study.

Appendix A thus illustrates that the magnitude of the admittance change appears to be directly related to sound pressure level of the stimulus and inversely related to the stimulus frequency. Other researchers have noted similar relationships (Wilson et al., 1978), although stimulus frequencies above 4000 Hz were not utilized. It should also be noted that reflex adaptation tends to occur most rapidly with the highest frequency stimuli. Rapid reflex decay in response to high-frequency stimuli has been previously reported by Johansson, Kylin and Langfy (1967) and Tietze (1969).

Appendix B depicts the change in admittance as a function of stimulus intensity level obtained for subject MM. The magnitude of the admittance change in each intensity level was taken as the greatest absolute drop in admittance from the baseline admittance value. Baseline was taken as the median admittance value between the lowest and highest data points during the .04 seconds prior to stimulus presentation. The plot illustrates that at each test frequency, the magnitude of the admittance change increases with stimulus intensity level to a certain point, after which little or no further admittance change occurs with an increase in intensity level. Similar observations were reported by Silman, Popelka & Gelfand (1978). It should also be noted that the slope of the admittance versus intensity level function is inversely related to the stimulus frequency. The steepest reflex growth function occurred with the 1001 HZ stimulus and the curves tended to flatten as the frequency of the tone increased. This relationship was apparent for the majority of the ears tested and is consistent with the findings of other research (Peterson & Liden, 1972).

The presence and absence of reflex activity at the five test frequencies was recorded for both groups of subjects. Acoustic reflexes were elicited at all five test frequencies in only two subjects (three ears). Most subjects in the normal hearing group did not demonstrate reflexes at the highest test frequencies. In fact, an example of the admittance versus intensity curves for a more typical normal hearing subject is presented in Appendix C. The reflex is present at 1001 and 4000 Hz. At the higher test frequencies, a reflex could not be elicited at or below a stimulus presentation level of 115 dB SPL. Table I (page 22) summarizes the number of ears for which acoustic reflexes were elicited at the five test frequencies. Decreased reflex activity in normal hearing subjects at higher test frequencies, specifically at 4000 and 6000 Hz, has also been reported by Popelka (1981).

Appendix D depicts the raw data and the admittance versus intensity curves for one typical ear with sensori-neural impairment. Reflexes are present at 1001 and 4000 Hz and are absent at the three highest frequencies. Reflexes were absent (i.e., could not be elicited at or below 115 dB SPL) in all 13 ears tested at 9000 Hz in this group. Reflexes were present in three ears at 8000 Hz, and in six ears at 6000 Hz. They were elicited in all 13 ears with the 4000 and 1001 Hz tonal stimuli. The presence of the acoustic reflex for this group at each test frequency is presented in Table II.

TABLE II

NUMBER OF EARS FOR WHICH ACOUSTIC REFLEXES WERE ELICITED AT THE FIVE TEST FREQUENCIES

(Frequency, kHz)	1	4	6	8	9	Total # ears
Normal	23	19	12	9	3	23
Sensori-neural	13	13	6	3	0	13

For both groups of subjects, the reflex was elicited most often with the 1001 Hz stimulus and least often with the 9000 Hz stimulus.

Sensation level of the acoustic reflex was calculated for each ear in which a reflex was elicited. This was done by subtracting the subject's behavioral threshold from the acoustic reflex threshold at each test frequency by means of a Casio HS-7 High-Power Solar Cell calculator. A plot of mean acoustic reflex thresholds for both groups of subjects is presented in Appendix E. In the normal hearing group, the mean reflex thresholds were 89.4, 90.7, 89.5, 93.0, and 83.8 dB SL at 1, 4, 6, 8 and 9 KHz respectively. In the group with high frequency hearing loss, mean reflex thresholds were 84.7, 86.8, 80.3, and 80.5 at 1, 4, 6, and 8 kHz respectively.

Sensation level values of the two groups of subjects were compared at 1001, 4000, 6000 and 8000 Hz by means of the Mann-Whitney U Test. The test was not performed at 9000 Hz because no reflexes were elicited in the hearing impaired group at this test frequency. Acoustic reflex thresholds were significantly lower for the hearing impaired group than for the normal hearing group with the 1001 Hz stimulus ($p<.01$) No significant differences in threshold levels were observed between the two groups with the higher frequency tonal stimuli at the .01 level.

DISCUSSION

Acoustic reflexes were measured in two groups of subjects, one with normal hearing and one with high frequency cochlear hearing loss. Pure tones at frequencies of 1001, 4000, 8000 and 9000 Hz were presented to the test ear while admittance changes were monitored in the opposite ear. At each frequency the intensity of the tone was raised from 75 to 115 dB, in 5 dB increments.

No significant differences in reflex thresholds were found between the two groups at stimulus frequencies of 4000, 6000 and 8000 Hz. Therefore, it would appear that high frequency reflex thresholds did not distinguish the hearing impaired subjects from the subjects with normal hearing sensitivity. As such, this would seem to suggest that reflex testing using high frequency stimuli is not diagnostic of cochlear hearing loss. However, the lack of difference between the two groups may have been due to the fact that at the higher frequencies reflexes could not be elicited in many ears, even at the highest stimulus intensity level (115 dB SPL). In fact, at 9000 Hz reflexes were not elicited in any of the 13 ears with cochlear hearing losses. The sample sizes thus may have been too small at the high frequencies to show significant differences between the groups.

Failure to elicit reflexes with the high frequency stimuli could be due to a number of factors. It may be that the highest intensity level at which the tones were presented (115 dB SPL) was not sufficient to elicit an observable response. This would not be surprising, given that hearing sensitivity is poorest (i.e., thresholds are highest) in the high frequencies (Popelka, 1981). With higher presentation levels, a change in admittance might have been observed. Secondly, the rapid rate of reflex adaptation seen in the high frequencies (see Appendix A) could have resulted in an inability to record a reflex response. That is, a reflex response might have decayed too quickly to be detected and recorded. Thirdly, it is possible that certain limitations within the testing equipment precluded the recording of reflex activity. In order to observe a change in admittance resulting from a reflex response, it is desirable to set the ear canal pressure to the point of peak admittance (called peak pressure), as determined by the tympanogram. When peak pressure is set, air pressure is the same on both sides of the eardrum. With this pressure setting, contraction of the stapedius muscle causes a maximal change in impedance of the middle ear and this change can be most easily detected and monitored (Ruth, Tucci & Nilo, 1982). During reflex testing, a pressure setting in the ear canal that is more negative or positive than peak pressure results in a stiffening of the middle ear system. This can greatly minimize the change in admittance or impedance associated with the reflex. Furthermore, peak pressure can change during testing. Variations in middle ear pressure are known to occur due to swallowing and the absorption of air in the middle ear cavity (Margolis & Shanks, 1985). To obtain peak pressure, canal pressure must be re-adjusted periodically. In fact, this is done clinically with manual admittance measurement instruments. However, with the Virtual 310 Immittance Meter used in this study, peak pressure is automatically set to a fixed value which is maintained throughout the testing of acoustic reflexes. As such, the ear canal pressure may not have been optimal for observing a change in admittance. Reflexes might, therefore, have been obscured.

Lastly, the varying degrees of hearing loss present in the group of subjects with cochlear impairment may have contributed to the high proporation of absent reflexes in the high frequencies. This would not be improbable, considering that at any one test frequency behavioral hearing thresholds in this group ranged from 0 to 45 dB.

Although no difference between the two groups was apparent for the high frequency stimuli, a significant difference in the intensity level at which the reflex was elicited was found for the lowest test frequency. At 1001 Hz, reflex thresholds (in dB SL) were lower for the subjects with high frequency sensori-neural hearing loss than for the normal hearing subjects. The difference in threshold levels between the groups is somewhat surprising, given that behavioral thresholds at 1000 Hz were within normal limits for all subjects in the study. As such, acoustic reflex thresholds would not be expected to vary considerably between the two groups. It is possible that the disparity seen with the 1001 Hz stimulus is due to the difference in the size of the two groups (one group contained 16 subjects, the other contained 8). The relatively small number of subjects in the hearing impaired group might have resulted in a greater difference at this test frequency than would have been found if the "n" had been larger.

To better assess the value and effectiveness of high frequency reflex testing in the identification of high frequency cochlear hearing loss, further research is necessary. Follow-up studies should involve the use of higher stimulus intensity levels, as it is possible that reflexes would be present at higher intensity levels than those typically used in reflex testing with lower frequency stimuli. In addition, the degree of hearing loss in the subjects with cochlear impairment needs to be closely matched at each of the test frequencies. Lastly, a system should be implemented whereby peak pressure in the ear canal is strictly maintained throughout acoustic reflex testing.

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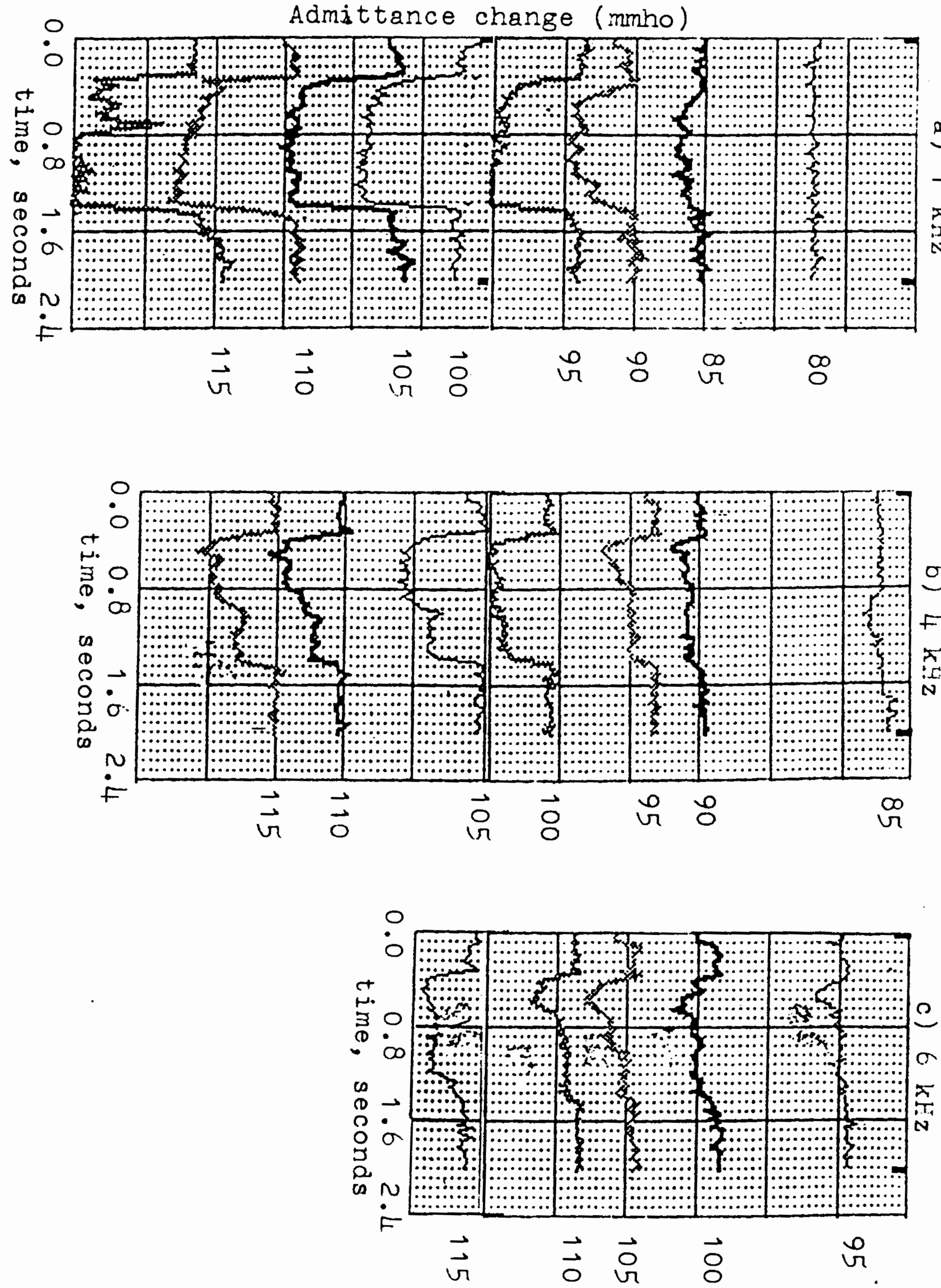
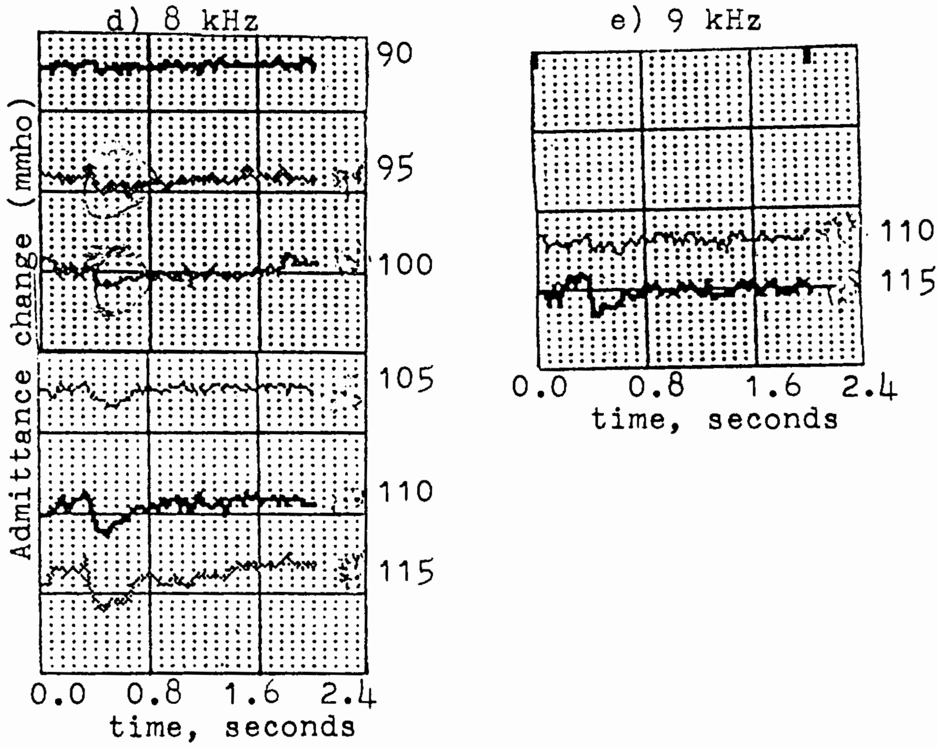
APPENDIX A

ACOUSTIC REFLEX TEST

RAW DATA PRINT OUTS

Acoustic reflex plots for a normal hearing subject (MM). 1.001, 4, 6, 8 and 9 kHz stimuli shown in panels a, b, c, d and e, respectively. The ordinate represents admittance, in mmhos, .10 mmhos per division. The abscissa is time, in seconds. Intensity level of the tonal stimulus, in dB SPL, is displayed to the right of each tracing.


Admittance change (mmho)
a) 1 kHz
b) 4 kHz
c) 6 kHz
0.0 0.8 1.6 2.4
time, seconds
80
85
90
95
100
105
110
115

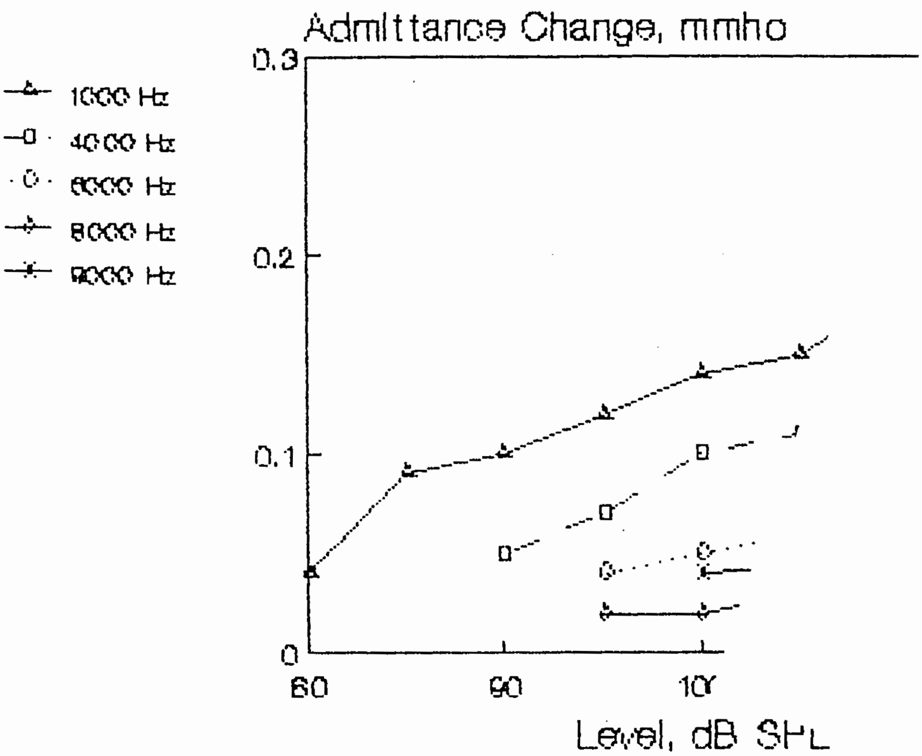

d) 8 kHz
90
95
100
105
110
115
Admittance change (mmho)
0.0
0.8
1.6
2.4
time, seconds
e) 9 kHz
110
115
0.0
0.8
1.6
2.4
time, seconds

APPENDIX B

ACOUSTIC REFLEX TEST PLOTTED FOR

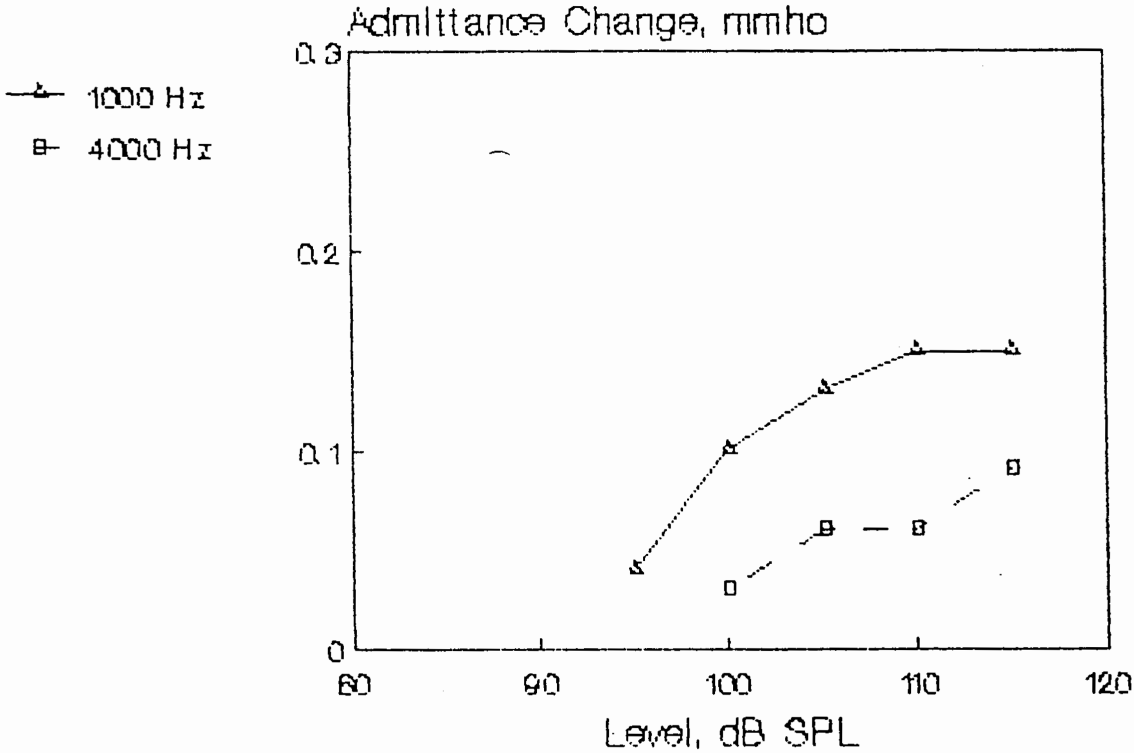
MAXIMUM ADMITTANCE CHANGE

Maximum change in admittance is plotted as a function of stimulus level in dB SPL for normal hearing subject (MM). The parameter of the reflex growth function is frequency of the sinusoidal stimulus.


Admittance Change, mmho
0.3
0.2
0.1
0
1000 Hz
4000 Hz
6000 Hz
8000 Hz
9000 Hz
60
90
10Y
Level, dB SPL

APPENDIX C

ACOUSTIC REFLEX TEST PLOTTED FOR GROWTH IN A TYPICAL NORMAL HEARING SUBJECT

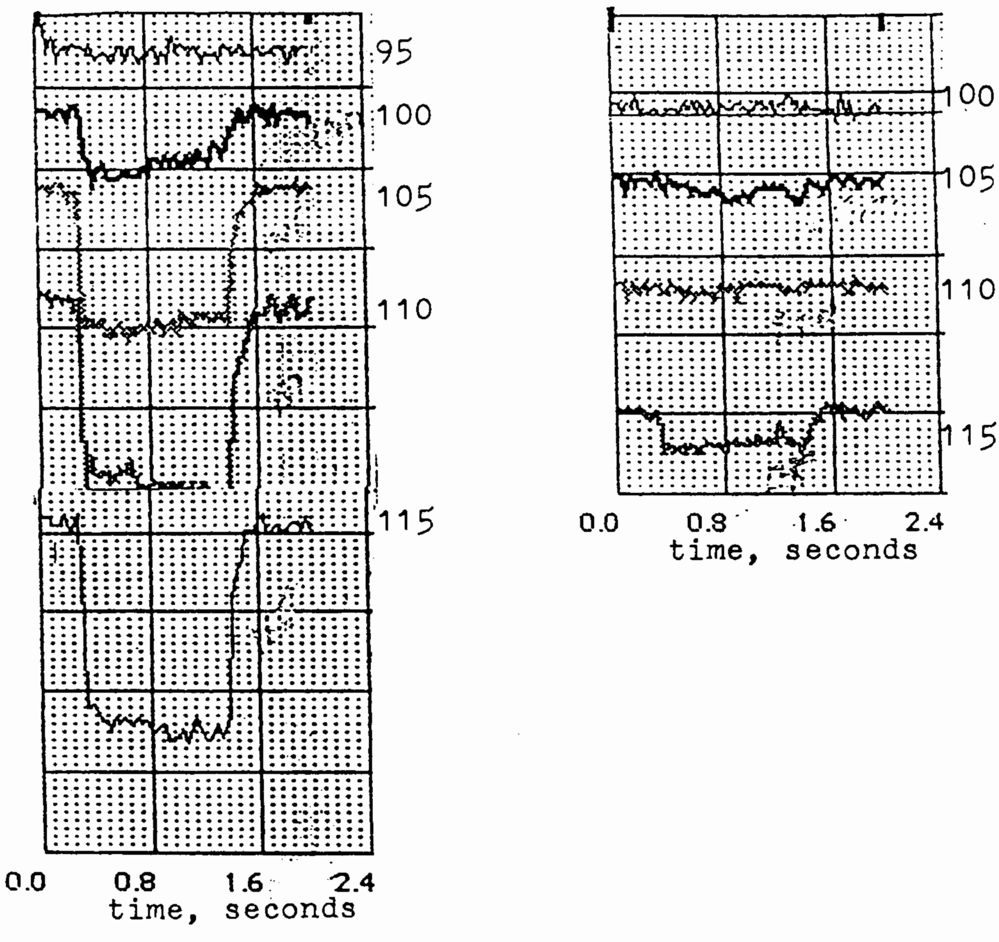

Admittance Change, mmho
1000 Hz
4000 Hz
0.3
0.2
0.1
0
80
90
100
110
120
Level, dB SPL

Subject: EK

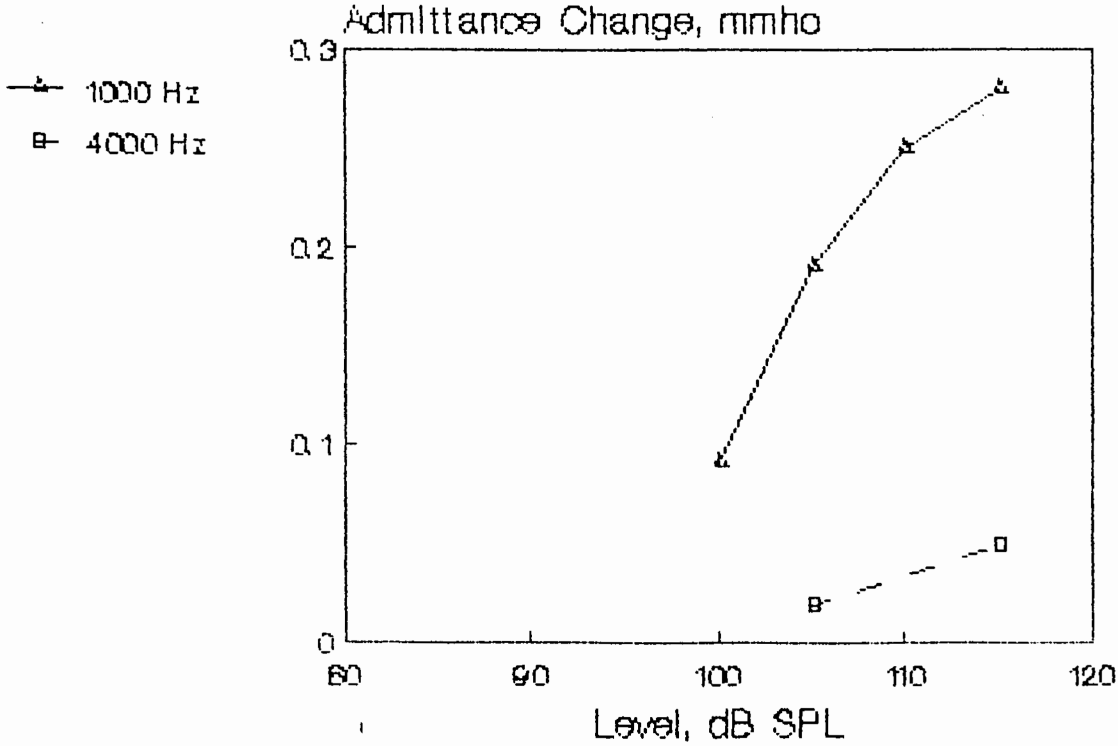
APPENDIX D

ACOUSTIC REFLEX PLOT AND REFLEX GROWTH FUNCTION FOR TYPICAL SUBJECT WITH COCHLEAR HEARING LOSS

(a)

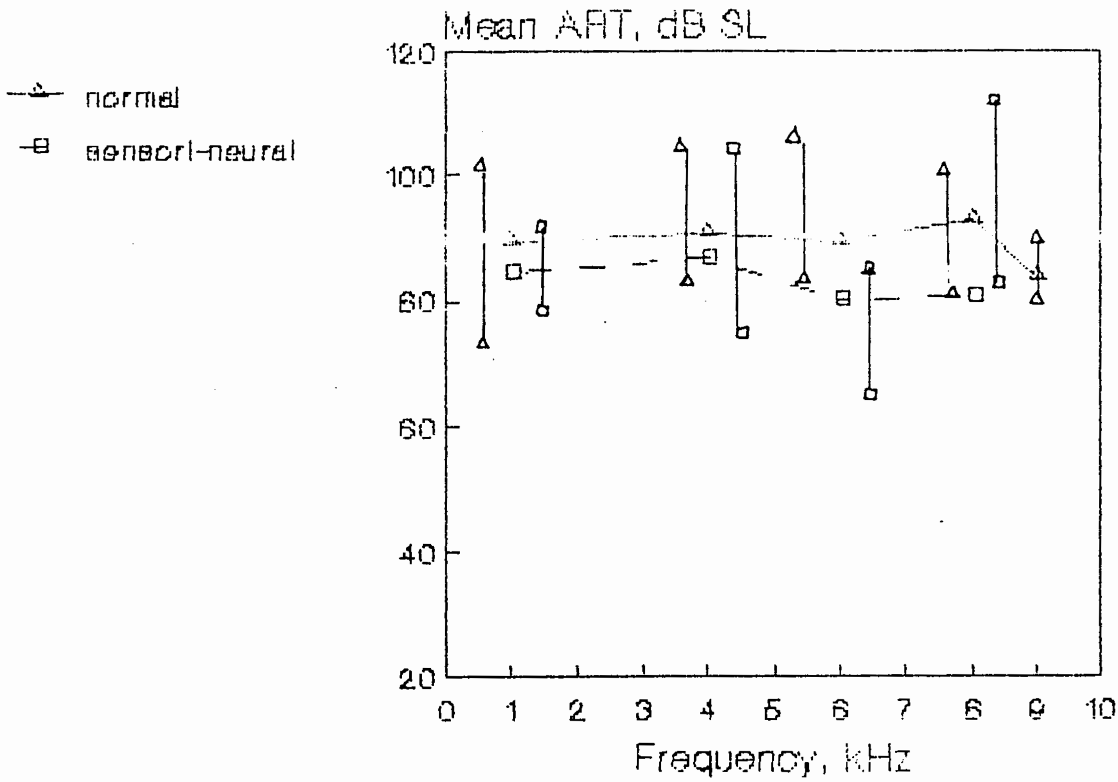

95
100
105
110
115
0.0
0.8
1.6
2.4
time, seconds
100
105
110
115
0.0
0.8
1.6
2.4
time, seconds

(b)


Admittance Change, mmho
1000 Hz
4000 Hz
0.3
0.2
0.1
0
80
90
100
110
120
Level, dB SPL

APPENDIX E

MEAN ACOUSTIC REFLEX TEST THRESHOLDS PLOTTED IN dB SL AS A FUNCTION OF FREQUENCY



Ranges of thresholds are indicated by bars.