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The effects of age on acoustic reflex adaptation

Lynn, Deborah Jean, Ph.D.

City University of New York, 1988

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Ann Arbor, MI 48106

THE EFFECTS OF AGE ON ACOUSTIC REFLEX ADAPTATION

By

Deborah J. Lynn

A dissertation submitted to the Graduate Faculty
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Supervisory Committee

The City University of New York

Abstract

THE EFFECTS OF AGE ON ACOUSTIC REFLEX ADAPTATION

by

Deborah J. Lynn

Adviser: Professor Arthur Boothroyd

In recent years, numerous studies have focused on the effects of aging on selected measurements of the acoustic reflex. It has been found that the aging process can significantly elevate the acoustic reflex threshold for broad band noise, increase the latency of the acoustic reflex response, and reduce the magnitude growth of the reflex as a function of intensity.

Although the measurement of acoustic reflex adaptation (or decay) has been used clinically in the differential diagnosis of auditory pathology, there have been no studies which have investigated how the aging process alters this measurement. It is possible that age-related changes within the auditory system could adversely affect adaptation measurements in older persons as it does with other reflex parameters. Therefore, the purpose of the present study was to investigate the effects of age and presbycusic hearing loss on the rate of reflex adaptation.

Three groups of 12 subjects each were used in this study: young normal subjects (ages 20-29), older normal hearing subjects (ages 60-69), and subjects with a mild to moderate presbycusic hearing loss (ages 60-69). Adaptation functions were measured on each subject by monitoring the contralateral reflex activity using a 220 Hz probe tone. The reflex activating stimuli consisted of tonal stimuli at .5, 1, and 2 KHz and a broad band noise presented at 10 dB and 15 dB above the subject's acoustic reflex threshold.

The rate of adaptation was calculated by using a time constant. Individual adaptation functions were fitted by the exponential equation $y = a * e^{-bt}$ and from this equation the time constant 1/b was derived. The time constant is the time in seconds taken for the admittance to decay by 63% of its maximum value. In addition to calculating the rate of adaptation for each function, the morphology of the curves were examined closely for trends. Four different curve patterns were discovered. Statistical analysis was performed on the rate and morphology data to determine group, stimulus type and sensation level effects.

It was found that the rate of reflex decay was not significantly affected by age or presbycusic hearing loss. As reported in past research, adaptation rate was found to be dependent on stimulus type and sensation level. When the taxonomy of curve patterns were analyzed, a significant age effect was discovered. The incidence of two of the four curve pattern types were significantly related to age. No significant effect of presbycusis was found. Similiar to the rate results, the morphology was dependent on the nature and level of the stimulus.

The major conclusions drawn from this study were two. First, the rate of reflex adaptation was not significantly different across the three groups studied. That is, the rate was not significantly affected by age or presbycusis. Although caution must be used in generalizing these conclusions to the clinical setting, it appears that reflex decay measurements can be used with older subjects as a diagnostic tool without making major modifications. Second, the data on the morphology of the decay curves indicated an age dependency. The basis for this age-related finding is not known. However, it appears that the reflex adaptation process may be more complex than typically assumed. Therefore, the use of a single estimate of decay rate (as commonly used in the clinical decay test) may overlook confounding detail of the adaptation function which could have diagnostic value.

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Chapter 1.

INTRODUCTION

It has long been known that acoustic stimulation presented monaurally or binaurally at sufficiently intense levels elicits a bilateral contraction of the stapedius muscle in the middle ear (Geffcken, 1934). This contraction is referred to as the acoustic reflex. Over the past 40 years, acoustic reflex activity has been measured by monitoring changes in the acoustic impedance of the middle ear transmission system (Metz, 1946 and 1951; Jepsen, 1955; Moller,1958; and Terkildsen and Nielsen, 1960). Technological advances have helped to make the measurement of acoustic impedance clinically feasible and have encouraged numerous studies dealing with the acoustic reflex and its parameters in various normal and pathological populations.

Acoustic reflex testing has gained widespread appeal as a clinical tool for several reasons. First, acoustic reflex measurements provide valuable information regarding the status of the middle ear (Metz, 1952; Liden, Harford and Hallen, 1974), the cochlea (Peterson and Liden, 1972; Beedle and Harford, 1973), the auditory nerve (Anderson, Barr and Wedenberg, 1969; Jerger, Burney, Maudlin, and Crump, 1974; Silman, Popelka, and Gelfand, 1978), the brainstem (Greisen and Rasmussen, 1970; Jerger and Jerger, 1974; 1975), and the facial nerve (Klockhoff, 1962). Second, acoustic reflex measurement is a physiologically-based objective technique. As a consequence, acoustic reflex testing has been used to predict hearing loss in infants, uncooperative adults and difficult-to-test populations (Jerger et al., 1974; Niemeyer and Sesterhenn, 1974; Popelka, Margolis and Wiley, 1976; Silman and Gelfand, 1979). Third, acoustic reflex testing is an essentially noninvasive, easy to administer procedure that can provide corroborative information to compare to behavioral audiologic findings.

There are several parameters of acoustic reflex activity that are commonly used clinically. The first is the acoustic reflex threshold. The threshold can be defined as the lowest sound intensity which produces a measureable change in acoustic impedance or, its recriprocal, admittance (Gelfand, 1984). The threshold is typically expressed in terms of the level (dB HL or dB SPL) of the activating stimulus.

A second measurement is acoustic reflex magnitude which refers to the size of the reflex response elicited by a stimulus at a specific intensity level (Silman and Gelfand, 1982). The magnitude is typically quantified in units of impedance (or admittance) relative to the resting or baseline value. The reflex magnitude changes with the intensity level of the activating stimulus. Thus, the magnitude is small at threshold and increases monotonically with intensity level within a certain range above threshold. The plot of the magnitude with increased activator intensity is referred to as the acoustic reflex growth function (Silman, 1984).

Two other measures which describe the temporal aspects of the reflex response are acoustic reflex latency and acoustic reflex adaptation. Reflex latency is generally defined as the time between the onset of the activating stimulus and the first detectable impedance change. Acoustic reflex adaptation is defined as the decrease in the reflex response (quantified by the admittance change from baseline) during ongoing stimulation. The rate at which the magnitude of immittance change decreases over time can be used to infer the relaxation or decay of the reflex response.

Early studies concentrated primarily on the above reflex parameters in normal hearing and hearing impaired subjects (Silman and Gelfand, 1982). More recently, investigations have focused on the effects of age on various acoustic reflex parameters for two reasons. First, because the acoustic reflex measurement is a relatively objective technique it is not plagued by the effects of decision criteria and cognitive and attentional factors as is the case with psychoacoustic research with aged listeners. Second, the acoustic reflex parameters are used clinically in the diagnosis of auditory pathology. Therefore, knowledge of the effects of age on these measures is crucial.

Current literature indicates that aging has been associated with significantly elevated acoustic reflex threshold for broad band noise (Silman, 1979; Gelfand and Piper, 1981), reduced rate of growth of the acoustic reflex magnitude (Wilson, 1981) and increased latencies of the reflex response (Bosatra, Russolo, and Silverman, 1984). Of great importance is the fact that these studies have shown that age effects are apparent even when there is normal hearing acuity. For example, using a strict audiometric definition of normal hearing, Silman (1979) and later Gelfand and Piper (1981) found that the reflex threshold for broad band noise (BBN) stimuli were elevated in their old normal hearing group compared to their young normal hearing group. In view of these results, Silman suggested that the elevation in acoustic reflex thresholds for broadband noise may reflect age-related sensory degeneration that is not substantial enough to cause hearing loss as measured by traditional pure tone testing. Aging effects have also been found on the growth function of the reflex response with intensity. In fact, Gelfand and Piper (1981) have pointed out that it is most likely the loss of the low-level "tail" of the acoustic reflex growth function that results in the elevation with aging in the BBN threshold. Finally, studies on acoustic reflex latency have found significant age effects when results are compared between young and old normal hearing groups. Thus, it is clear from the literature that aging has an effect of several acoustic reflex parameters even in the presence of normal hearing acuity.

While the characteristics of acoustic reflex adaptation have been well established in young normal adults (Wilson, McCullough, and Lilly, 1984), there have been no studies which have investigated acoustic reflex adaptation as a function of age. Information on the possible relation of age to acoustic reflex adaptation characteristics has both theoretical and clinical significance. The age effects (or lack of effects) on acoustic reflex adaptation characteristics may lead to a better understanding of the underlying physiologic changes of the auditory system associated with aging. As mentioned above, several parameters of the acoustic reflex are known to be affected by age. If age effects are not found for reflex adaptation, then reflex adaptation phenomenon may reflect processes that are different from those proposed for other reflex measures.

Futhermore, acoustic reflex adaptation (or decay) measurements have been used routinely in clinical practice to infer the integrity of the eighth nerve. It has been found that subjects with retrocochlear lesions exhibit a faster rate of acoustic reflex adaptation compared to subjects with normal auditory systems or with cochlear pathology (Anderson, Barr, and Wedenberg, 1969; 1970). Despite the widespread clinical use of reflex decay measurement, there is a paucity of research concerning the effects of certain variables, such as age or degree of cochlear loss, on reflex adaptation characteristics. Age-related changes within the auditory system may alter the acoustic reflex adaptation characteristics and, in turn, may lessen the effectiveness of adaptation as a clinical tool.

The present study examined the reflex adaptation phenomenon in young normal hearing, older normal hearing and presbycusic subjects using three tonal stimuli (.5, 1, 2 kHz) and broad band noise presented at two sensation levels (10 dB and 15 dB) above the acoustic reflex threshold. The study was designed to test the following hypotheses:

(1) There are significant age effects on the rate of acoustic reflex adaptation.

(2) There are significant presbycusic effects on the rate of acoustic reflex adaptation.

(3) Age and presbycusic effects on the rate of reflex adaptation are different for different stimuli.

(4) Age and presbycusic effects on the rate of reflex adaptation are different for different sensation levels.

Chapter 2.

REVIEW OF THE LITERATURE

BACKGROUND INFORMATION ON THE ACOUSTIC REFLEX

Acoustic stimulation presented monaurally or binaurally at sufficiently intense levels elicits a bilateral contraction of the stapedius muscle in the middle ear. This contraction is known as the acoustic reflex. The existence and properties of the acoustic reflex depend on the structure and function of the middle ear system, the cochlea, the acoustic nerve, the facial nerve, and the pathways of the brainstem.

Anatomical Aspects of the Middle Ear Muscles

It has long been established that there are two middle ear muscles; the stapedius muscle innervated by the facial nerve (N VII) and the tensor tympani muscle innervated by the trigeminal nerve (N V) (Politzer, 1861). Early research on the anatomy of the middle ear muscles was conducted with animals and showed that in the cat and the rabbit, both the tensor tympani and the stapedius muscles contract to acoustic stimuli (Lorenz de No, 1935; Wersall, 1958). In humans, however, the acoustic reflex involves primarily the stapedius muscle

(Jepsen, 1955; Saloman and Starr, 1936) unless the acoustic stimulation is intense enough to produce the startle reaction (Djupesland, 1964).

The tendon of the stapedius emerges from a bony canal in the posterior wall of the tympani cavity and inserts at the neck of the stapes (Dallos, 1973). Upon contraction, the stapedius pulls the head of the stapes in a posterior direction, stiffens the ossicular chain and, in most cases, causes outward movement of the eardrum (Feldman, 1975).

Neurological Correlates of the Acoustic Reflex

Although the anatomy of the middle ear muscles has long been established, the neural organization of the acoustic reflex arc is not yet completely known. One view is that the stapedius-muscle reflex arc is essentially a chain of four neurons: (1) a primary auditory neuron in the VIII nerve (the afferent or sensory neuron), which transmits impulses from the cochlear hair cells to the cochlear nucleus; (2) a second-order neuron from the ventral cochlear nucleus to the medial superior olive; (3) the interneuron from the superior olivary complex to the ipsilateral and contralateral facial motor nucleus; and (4) the efferent facial motor neuron to the stapedius muscle (Borg, 1974). Borg (1973) and Courville (1966) found evidence to suggest that there are other indirect pathways involving complex chains in the lateral zone of the reticular formation. Research now indicates that the direct and indirect neural pathways of the ipsilateral and contralateral acoustic reflex are highly complex (Moller, 1984).

Methods for Observing the Acoustic Reflex

Early investigators used direct observation of the tendons of the middle ear muscles to study acoustic reflex activity in animals and in humans (Wever and Lawrence, 1954). Luscher (1930) was the first to report observations of the stapedius muscles viewed through large tympanic membrane perforations in humans. Later researchers also observed reflex activity directly through tympanic membrance perforations and during middle ear surgery (Lindsay, Kolerak and Perlman, 1936; Potter, 1938; Perlman, 1938).

As technology advanced, it was possible to record electromyographic (EMG) action potentials by placing an electrode on the stapedius tendon (Perlman and Case, 1939). Of course, similiar to the direct observation method, the electromyographic technique was only performed in humans who had perforations of the tympanic membrane or who underwent middle ear surgery (Perlman and Case, 1939; Salomon and Starr, 1936). Both of these methods were unsuitable for routine clinical use in human subjects with normal ears (McPherson and Thompson, 1977).

Geffcken (1934) first discovered that contraction of the middle ear muscles resulted in a change in the ear's acoustic impedance (Moller, 1984). Subsequently, Metz in 1946 developed the first mechanical impedance bridge which allowed for a noninvasive method of monitoring acoustic reflex activity. His acoustic impedance bridge was cumbersome, and his method required complex mathematical calculations. As a result, researchers pursued the development of other devices (Moller, 1958, 1961; Klockhoff and Anderson, 1960; Zwislocki, 1963). The electro-acoustic bridge, developed by Terkildsen and Nielsen in 1960, represented a significant improvement over the mechanical impedance bridge and it is now commonly used for both clinical and research purposes (Feldman, 1975).

The electro-acoustic method for measuring the impedance of the ear involves sealing the ear canal with a probe assembly which consists of a sound source and a microphone. A probe tone, usually 220 Hz, is delivered by the sound source and the sound pressure in the sealed ear canal is recorded by the microphone. Upon contraction of the stapedius muscle, the impedance of the normal ear changes, and in turn the sound pressure level within the ear canal changes. The microphone records the sound pressure level so that the activity can be reflected on a meter or in graphic form. The available clinical meters differ in design but most generally operate in the way described here.

For the past 15 years, the clinical accessibility of the electroacoustic meter has encouraged numerous studies dealing with the acoustic reflex and its parameters in various normal and pathological populations. Recently, several investigations of the acoustic reflex parameters have focused on the effects of age.

AGE EFFECTS ON THE AUDITORY SYSTEM

Neurological Changes that Accompany Aging

It is well understood that changes occur in all sensory systems with advancing age. Numerous studies have documented age-associated changes in auditory structure and function at all levels from the conductive mechanism to the cortex. Structural alterations with age have been reported for the pinna, ear canal and middle ear (Schow, Christensen, Hutchinson, and Nerbionne, 1978). Numerous studies have described changes of the cochlear nerve with aging (Schow et al, 1978). Schuknecht (1955) has shown deterioration of basal hair cells and supporting structures (sensory presbycusis); reduction in the number of neurons (neural presbycusis); atrophy of the stria vascularis (metabolic presbycusis); and a deterioration in the function of cochlear mechanics (mechanical presbycusis). Kirkae, Sato, and Shitara (1964) found atrophy of neural structures in the ventral cochlear nuclei, the superior olivary complex, and more central nucleus through the auditory nervous system, including the cortex. Given the known neurophysiologic changes that accompany aging, it is not suprising that auditory functioning declines in older subjects.

Auditory Manifestations of Aging

Age-related sensorineural hearing loss, or presbycusis, is common among the older population. Most often the loss occurs gradually for the high frequencies and increases with advancing age. Presbycusic subjects tend to perform as a highly heterogeneous group on various audiological measures, probably reflecting the diverse nature of the underlying physiological changes that may occur. Tests of loudness recruitment, short increment sensitivity and tone decay do not show consistent results among presbycusic subjects (Harbert, Young, and Menduke, 1966; Goetzinger, Prout, Dicks, and Embrey, 1961). Aging appears to have an effect on frequency analysis abilities as measured by difference limens for frequency, psychophysical tuning curves and loudness summation (Marshall, 1982). There is substantial evidence to indicate that age-related difficulties occur in lateralization and masking level difference experiments (Herman, Warrens, and Wagener, 1977; Warren, Wagener, and Herman, 1978). Speech discrimination abilities, even under the most ideal conditions, are known to deteriorate with aging (Jerger, 1973).

Although the bulk of psychoacoustic literature with aged listeners indicate that aging has a detrimental effect on auditory processing, most psychoacoustic studies with the elderly have not controlled for hearing acuity. In addition, the results of these studies have been characteristized by poor control of methodological variables such as ear canal collapse, large test-retest variability, decision criteria, learning effects, and cognitive and attentional factors (Marshall, 1982).

Because of the need for a more objective technique for measuring auditory function in aging subjects, investigators have turned to physiological measures, such as acoustic reflex testing, to assess aging effects on the auditory system. Several parameters of the acoustic reflex have been shown to be affected by aging. These include the acoustic reflex threshold, the latency of the acoustic reflex, and acoustic reflex magnitude and growth.

AGE EFFECTS ON ACOUSTIC REFLEX PARAMETERS

Acoustic Reflex Thresholds to Tonal Stimuli and Aging

The acoustic reflex threshold has been defined as the lowest sound intensity which produces a measureable change in acoustic impedance (Gelfand, 1984). In the past, the studies on the acoustic reflex threshold with aging have turned up some conflicting findings. Early studies indicated that the acoustic reflex thresholds for tonal activators actually decreased with aging. For example, Jepsen (1963) investigated tonal acoustic reflex thresholds using subjects ranging in age from 10 to 80 years. He found that while the threshold of hearing increased with age (presbycusis), the stapedial reflex threshold decreased. One problem with Jepsen's conclusion was that he expressed the acoustic reflex threshold in sensation level (SL), or the dB above hearing threshold level (or in dB SL). When the data are expressed in dB SPL, the age effect tends to be neglible. This study points out how the reflex threshold could differ depending on the way in which the threshold is defined.

Jerger, Hayes, Anthony and Maudlin (1978) retrospectively analyzed clinical acoustic reflex threshold findings on 214 normal hearing subjects across six decades (age 0-59). The criterion for normal hearing was </= 20 dB at frequencies 500 Hz to 4000 Hz. It was shown that the acoustic reflex thresholds for pure tones below 4000 Hz, systematically decreased with age. The effect of age on mean acoustic reflex threshold for broad-band noise was neglible in their study (i.e. the mean acoustic reflex threshold for BBN remained +/- 2dB across all decades). It is interesting to note that the findings of Jerger's study in 1978 directly contradicted the findings on acoustic reflex thresholds from an earlier study conducted by the Jerger, Jerger and Maudlin (1972). That is, in the 1972 study, Jerger et al found no changes in acoustic reflex thresholds for tonal stimuli as a function of age.

More recent studies have failed to show significant changes in the acoustic reflex threshold for tonal stimuli (500 Hz, 1000 Hz, and 2000 Hz) with aging (Silman, 1979; Thompson, Sills, Recke, and Bui, 1980; Gelfand and Piper, 1981). For example, Silman (1979) investigated the effect of age on the acoustic reflex thresholds in a group of 20 young normal hearing adults (age 21-36) and 20 normal hearing elderly (age 60-79). In this study, normal hearing was defined as pure tone thresholds </= 20 dB at frequencies 500 Hz to 4000 Hz. Silman found that the mean reflex thresholds for the tonal signals, expressed in dB SPL, did not differ significantly between the two test groups. These results are in close agreement with previously published data (Margolis and Popelka, 1975; Margolis and Fox, 1977; and Popelka, et al, 1976).

Gelfand and Piper (1981) replicated Silman's study but employed a stricter criterion for subject selection. Unlike other studies on aging effects on acoustic reflex threshold, all subjects in their study had normal hearing sensitivity extending up to 8000 Hz. They found no statistically significant difference for tonal acoustic reflex thresholds for 500 Hz, 1000 Hz or 2000 Hz between the young and old groups.

In summary, there is a concensus among the majority of studies, especially when conducted under laboratory conditions, that age does not affect the acoustic reflex thresholds for tonal acitivators of 500 Hz, 1000 Hz and 2000 Hz. The differences between the early findings by Jerger et al (1978) and the findings of Silman (1979), Thompson et al (1980) and Gelfand and Piper (1981) can be explained by differences in the methods used in the experiments (e.g. use of 5 dB vs. 2 dB activator steps and visual monitoring methods vs. graphic display methods).

Acoustic Reflex Thresholds for Noise Stimuli and Aging

The acoustic reflex threshold for broad band noise (BBN) activators is approximately 18 dB lower than the acoustic reflex thresholds for tonal activators in young normal hearing subjects (Deustch, 1972; Djupesland, Flottorp, and Winther, 1967; Margolis and Popelka, 1975). The threshold difference between tonal stimuli and noise stimuli has been associated with a critical band phenomenon (Flottorp, Djupesland and Winther, 1971). In cases of sensorineural hearing loss, the acoustic reflex threshold difference between BBN and tonal signals is reduced, because of an elevation of acoustic reflex threshold for broad band noise. The reduced tonal-BBN acoustic reflex threshold difference in hearing-impaired subjects has been related to an abnormally wide critical bandwidth that can occur with cochlear involvement (Jerger et al, 1974).

Handler and Margolis (1977) were the first researchers to statistically demonstrate an elevated acoustic reflex threshold for BBN activators (i.e. a reduced tonal-BBN acoustic reflex threshold difference) for elderly subjects. Subsequently, other researchers (Silman, 1979; Gelfand and Piper, 1981 and Wilson, 1981) reported similiar findings. For example, in the study by Silman (1979), the young subjects' acoustic reflex threshold to BBN was approximately 20 dB lower than their tonal thresholds, whereas for the elderly subjects, the average BBN acoustic reflex threshold was only 10 dB lower than their tonal thresholds. Therefore, a 10 dB difference was noted between BBN reflex thresholds for the young and old. It should be pointed out here that the manner in which the acoustic reflex is monitored and defined has been shown to result in differences in broad band noise thresholds across studies (Gelfand, 1984). For example, early researchers used visual monitoring methods and used an activator step size of 5 dB. Silverman (1982) demonstrated that these methods can obsure the finding of an age effect on BBN reflex thresholds.

Gelfand and Piper (1981) avoided the problem of hearing sensitivity effects (a criticism lodged by Jerger in 1979 regarding Silman's study) by closely matching the auditory thresholds of the young and old subjects. The results of this study were in close agreement with Silman (1979). More specifically, the mean acoustic reflex threshold for BBN was 76.2 dB (S.D. 6.5dB) for the young subjects and 84.2 dB (S.D. 7.9dB) for the elderly subjects. Thus, an 8 dB difference was noted between the young and old groups. A later study by Wilson (1981) further verified the reduced tonal-BBN acoustic reflex difference in older subjects.

It is apparent from the above-mentioned studies that age affects the acoustic reflex threshold for BBN activators even in the presence of normal hearing acuity. A hypothesis proposed by Silman (1979) provides a possible explanation for the elevation of BBN reflex threshold in older subjects. He hypothesized that when diffuse, mild deterioration of the outer hair cells occurs, the effect on acoustic reflex threshold parallels that found in subjects with mild sensorineural hearing loss. That is, in subjects with mild sensorineural hearing loss, the acoustic reflex threshold to BBN are affected due to the widening of the critical band. Whereas, the acoustic reflex threshold for tonal signals remains unaltered for hearing losses up to approximately 50-55 dB; for hearing losses greater than this the tonal ARTs tend to increase as the loss increases (Gelfand, Piper, and Silman, 1983; Keith, 1979; Popelka, 1981; Silman and Gelfand, 1979).

Silman (1979) pointed out that the elevated noise reflex thresholds in elderly subjects may reflect age-related sensory degeneration that is not substantial enough to result in hearing loss as measured by traditional pure tone testing. Silverman, Silman, and Miller (1983) further speculated that complex signals such as BBN may detect slight diffuse disorders associated with aging before simple signals like pure tones.

Acoustic Reflex Latency and Aging

Acoustic reflex latency is defined as the time between stimulus onset and the first measureable impedance change (Bosatra et al., 1984). Acoustic reflex latency has been shown to increase with several types of pathology including brainstem impairments (Bosatra, Russolo, and Poli, 1975), and acoustic tumors (Strasser, 1975; Clemis and Sarno, 1980; Mangham, Lindeman, and Dawson, 1980). Although there are limited data available, studies on acoustic reflex latency with various ages suggest that latency (measured in msec) increases with age (Spence, 1982; Bosatra et al, 1984).

Bosatra et al (1984) reported acoustic reflex latency results for 120 subjects with normal hearing (thresholds </= 10 dB at 500 Hz, 1000 Hz and 2000 Hz). The subjects were divided into decade groups from 20-29 to 70-79 years of age. Acoustic reflex latency results for contralateral stimulation were measured at levels of 10, 20, and 30 dB above the acoustic reflex threshold for 500, 1000, 2000 Hz and broad band noise. They found that the mean acoustic reflex latencies for tonal and broad-band noise activators were not significantly different across decades up to 50-59 years. However, the mean acoustic reflex latency increased approximately 30 msec for all activators in the 60-69 and 70-79 year old groups. Spence (1982) also found that acoustic reflex latency increased for subjects over the age of 60 years. The differences noted between young and old subjects for these studies were not tested statistically so that it is not clear whether there is a true age effect on the acoustic reflex latency.

Acoustic Reflex Magnitude and Aging

Acoustic reflex magnitude is generally defined as the amount of impedance change resulting from stapedius muscle contraction (Silman, 1984). The magnitude is quantified in impedance units relative to the baseline (or resting) impedance. With increases in the intensity of the activating stimulus, the magnitude of the reflex response increases monotonically within a certain range above acoustic reflex threshold. The plot of magnitude with stimulus intensity is referred to as the acoustic reflex growth function. In the magnitude growth studies to be described, the magnitude is measured at the plateau of the reflex response during the first 1000 msec of stimulation. Later in this study, this measurement will be referred to as the peak magnitude as opposed to the magnitude during prolonged stimulation.

Age effects on the acoustic reflex magnitude growth are well documented in the literature. Thompsen et al., (1980) were the first investigators to publish a detailed study on the effect of age on acoustic reflex growth function. This study included 30 subjects with normal hearing (<20 dB at frequencies 250 Hz to 4000 Hz) ranging in age from 20 to 79 years (N=5 per decade). The stimuli consisted of pure tones of 500, 1000 and 2000 Hz and white noise high-passed filtered at 1000 Hz. The admittance change from baseline was measured for each subject as a function of intensity level to obtain a magnitude growth function for each stimulus. Their results indicated that the rate of growth in amplitude of the admittance change decreased linearly with increase in age decade. The linear decrease with age was most pronounced for broad band noise.

The results of Thompson et al. were confirmed by Silman and Gelfand (1981) who found decreased growth of the acoustic reflex magnitude with intensity level in their elderly subjects compared to their young subjects. Acoustic reflex growth functions ~~were~~ obtained for 14 ears from 8 normal hearing subjects aged 61-76 years and 16 ears from 9 subjects with sensorineural hearing loss aged 60-84 years. The growth functions for the two elderly subject groups were then compared to growth functions for 26 ears from 13 normal hearing subjects (ages 9 to 28 years) obtained from a previous study (Silman, Popelka, and Gelfand, 1978). The criterion for normal hearing for old and young normal hearing groups was </= 20dB for frequencies 250 Hz-4000 Hz. The degree of sensorineural hearing loss for the remaining old group ranged from mild to severe across the frequency range.

The study by Silman and Gelfand revealed at least two important aspects about magnitude growth in the elderly. First, statistical analysis of the acoustic reflex magnitude data of two elderly groups (normal hearing and hearing-impaired) showed no significant hearing loss effect for tonal stimuli when the data were expressed as dB re acoustic reflex threshold. This finding is similar to those reported in an earlier study by Silman et al (1978), who showed that the mean growth functions for tonal signals in young subjects were not significantly altered by cochlear hearing loss. For the broad band noise stimuli, an analysis of variance showed a significant difference in magnitude between the two elderly groups. The magnitude growth in the hearing loss elderly group was reduced compared to the normal hearing elderly group.

Second, comparison of the ARGF for the two elderly groups with those of Silman et al. (1978) showed that the mean reflex magnitude was substantially smaller in the elderly than for their young counterparts. However, a statistical test was not performed between the two sets of data to determine if the magnitude differences between the young and old groups were statistically signficant.

In a later study by Wilson, Shanks, and Velde (1981), reflex magnitude growth functions were measured on two age groups (one group of subjects < 30 years of age and one group of subjects >50 years of age). Both groups had normal hearing sensitivity from 500 Hz to 4000 Hz. It was found that the magnitude of the acoustic reflex was substantially smaller for the old group than for the young group. These investigators also reported large variability in the reflex magnitude data for both groups.

It is evident from the reflex growth studies mentioned above that aging has an effect on the growth of the reflex magnitude with intensity. Similiar to the other reflex parameters, the age effect was noted in subjects with normal hearing sensitivity. Wilson suggests that the magnitude differences between the young and old may reflect "a general decrease in the efficiency of neurophysiological activity throughout the acoustic reflex arc " (Wilson et al, 1981, p.412).

ACOUSTIC REFLEX ADAPTATION: BACKGROUND INFORMATION

Another acoustic reflex phenomenon that is used as a clinical tool is acoustic reflex adaptation. Acoustic reflex adaptation, or decay, is defined as the decrease in reflex magnitude during prolonged acoustic stimulation (Wilson, Shanks, and Lilly, 1984). Figure 1 illustrates an idealized reflex adaptation function. The percentage of the maximum reflex response is shown on the ordinate and time (in seconds) is shown on the abscissa.

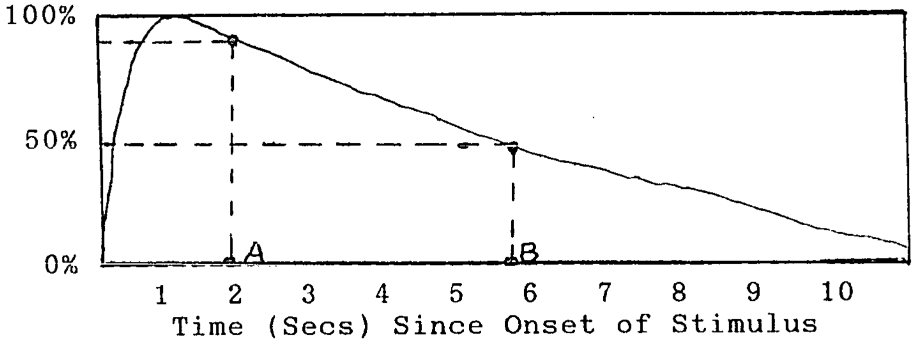


Figure 1. Percentage of Maximum Reflex Response

Two parameters are typically used to describe the reflex adaptation function. The time of onset of adaptation (denoted by A on the graph) is the time at which the reflex magnitude decreases to 90% of the maximum reflex magnitude after stimulus onset. The half-life (denoted by B on the graph) is the time measured from stimulus onset at which the reflex magnitude decreases to 50% of the maximum reflex magnitude. The half-life is typically used as an index of the rate of adaptation. An alternative estimate of rate is obtained by measuring the reduction of the reflex magnitude at fixed time intervals.

Measurement Considerations

At least two measurement problems have been known to influence the findings of adaptation experiments in normal subjects (Wilson et al, 1984). These include the estimation of the acoustic reflex threshold and the correction of baseline drift.

The acoustic reflex threshold can vary up to 10 dB depending on the method used. Since acoustic reflex adaptation studies are conducted at suprathreshold levels (i.e. 10-15 dB above acoustic reflex threshold), errors in estimating the acoustic reflex threshold affect the level at which the adaptation measurement is made. As defined earlier, the acoustic reflex threshold is the lowest sound intensity which produces a measureable change in acoustic impedance (or admittance). The acoustic reflex threshold is highly dependent on the sensitivity of the measurement system, the procedures employed to monitor and evaluate the response, and the acoustic characteristics of the activating stimulus (Gelfand, 1984).

The significance of a measurement sensitivity effect on acoustic reflex threshold estimation has been shown by Popelka (1981). According to his calculations on acoustic reflex growth functions, if the measurement system were capable of detecting changes in impedance on the order of 60 acoustic ohms instead of 10 acoustic ohms, there would be a significant elevation in the acoustic reflex threshold for tonal and noise activators. The elevation in acoustic reflex threshold would be approximately 3 dB for a 500 Hz tonal signal and approximately 10 dB for noise stimulus using the low sensitivity system. Thus, not only would the thresholds change, but so would the differences between the thresholds for noise and tonal stimuli.

The procedures used to monitor reflex activity can also influence the estimation of the acoustic reflex threshold. For example, reflex activity may be visually detected as a deflection of a needle on the impedance meter (a typical clincal approach) or as a change on a strip chart recording, an oscilloscope trace, or computer-generated record. It has been found that the visual monitoring approach can result in an upward biasing of the acoustic reflex threshold by 5-10 dB, especially in studies on aged subjects (Silverman, 1981). In recent years, computer assisted techniques have been employed to monitor and record the acoustic reflex response (Norris, Stelmachowicz, Bowling and Taylor, 1974; Ruth and Niswander, 1976; Clemis and Sarno, 1980; Mangham et al, 1980; Silman and Gelfand, 1982; Wilson, 1979). Computer assisted techniques have resulted in better temporal resolution in the recording of reflex activity and improved delineation of the acoustic reflex threshold.

Differences in activator-step size (e.g. 2 dB vs 5 dB) also influence the measured acoustic reflex threshold. This influence has been demonstrated by Silverman (1982).

The acoustic reflex threshold has also been found to vary directly with the temporal characteristics of the eliciting signal. According to Silman and Gelfand (1982), the activator stimulus should have a duration of over 1 second and a rise/fall time of greater than 25 msec and the optimal interstimulus interval should exceed 2-3 seconds.

A consideration of measurement variables that can affect the acoustic reflex threshold are important since the reflex threshold often serves as the reference for adaptation measurements. An elevation in the threshold would result in higher sound pressure levels for the adaptation measurements. Recent research has shown that adaptation rate decreases with increases in intensity level above reflex threshold for certain stimuli (Wilson, Steckler, Jones, and Margolis, 1978; Given and Seidemann, 1979). These results suggest that adaptation measurements obtained at levels relative to an elevated threshold may not be comparable to those obtained with a precise threshold reference.

Baseline drift can confound measurements of acoustic reflex adaptation (Wilson et al, 1978). Baseline drift is a shift in the measured immittance from the pre-stimulus baseline to post-stimulus baseline that is not the result of reflex activation. It can be measured during the resting or reflexive state. Wilson et al(1978) systematically measured baseline drift in their study on acoustic reflex adaptation in young normal subjects. Six silent (no stimulus) trials were averaged over a 210 second period for seven subjects. The mean acoustic admittance began to decrease after 5 seconds and continued to decrease to .05 mmhos below its starting value over the 210 second period.

Wilson et al (1978) suggested that the baseline drift may be related to negative middle ear pressure over time which would result in a decrease in admittance. Failure to correct for baseline drift can lead to a misinterpretation of the adaptation characteristics.

Acoustic Reflex Adaptation in Normal Hearing Subjects

There are no published studies on the adaptation characteristics as a function of age. There are, however, numerous studies on the reflex adaptation characteristics in young normal hearing subjects. The majority of these studies have concentrated on the effects of frequency, intensity and bandwidth on normal reflex adaptation.

Effects of Frequency on Adaptation

Reflex adaptation has been found to be directly dependent on the frequency of the eliciting signal. That is, as the frequency of the activating stimulus increases, the rate (and onset) of adaptation increases. Djupesland et al (1967) published one of the first studies that showed the frequency dependence of reflex adaptation. These investigators observed the impedance change over time for activators 250 Hz, 1000 Hz and 4000 Hz presented at 10 dB above the acoustic reflex threshold for 11 normal subjects. They found that the reflex decayed to the pre-stimulus baseline after 152 secs, 87.5 secs and 19.7 secs for the 250, 1000, and 4000 Hz activators, respectively. Note that these researchers did not define the rate of adaptation by a half-life. Rather they estimated the time that 100% decay occurred (or the time taken for the reflex response to decay to its pre-stimulus resting state). Nevertheless, these results do indicate the strong frequency dependence of the adaptation phenomenon.

Kaplan, Gilman, and Dirks (1977) measured reflex adaptation in six normal hearing adults, aged 19-35, for five tonal activators (500, 1000, 2000, 3000, and 4000 Hz) at three suprathreshold levels (6, 12, and 18 dB SL re acoustic reflex threshold). Although they did not correct for baseline drift, a baseline check was made at the end of each adaptation run and the trial was discarded if noticeable drift had occurred. Adaptation measurements were made over a 180 second period. The adaptation results in this study revealed three important findings: (1) as the stimulus frequency increased, the rate of adaptation increased; (2) adaptation at 500 Hz and 1000 Hz were less than that at 2000 Hz and above; and (3) the onset of adaptation (i.e. 90% of maximum magnitude) occurred earlier for the high frequency activators, than for the low frequency activators. Kaplan et al (1977) also compared their adaptation data to a descriptive model suggested by Tietze (1969), which will be discussed later.

The characteristics of acoustic reflex adaptation were investigated by Wilson et al (1978) using a computer-based technique. The acoustic admittance (conductance and suspectance) of seven young normal hearing adults were measured for four tonal activators (500, 1000, 2000, and 4000 Hz) and a broad-band noise activator presented for 180 seconds at levels of 96, 104 and 112 dB SPL. They found, similar to the results of Kaplan et al (1977), that the rate and onset of reflex adaptation varied inversely with frequency. Specifically, the rate of adaptation, measured by half-lives ranged from 2.5 minutes to 4 secs for low to high frequency activators. The onset of adaptation ranged from 10-20 secs with a 500 Hz stimulus to 2 secs for a 4000 Hz activator, depending on the sound pressure level.

More recently, Wilson et al. (1984) studied reflex adaptation in normal hearing young subjects to 31 second activators presented at 10 dB above acoustic reflex threshold (a presentation level used in clinical tests of acoustic reflex adaptation). In this later study, the mean half-life time approximately halved with each doubling of frequency. For example, at 1500 Hz the half-life time was 20.5 secs, at 3000 Hz it was 9.8 secs and at 6000 Hz it was 5.3 secs. The onset of acoustic reflex adaptation was 11.5 secs, 8.5 secs and 3.4 secs for 500 Hz, 1000 Hz and 2000 Hz, respectively.

In summary, several studies have found that the rate and onset of acoustic reflex adaptation is directly related to the frequency of the activating stimulus (Djupesland et al, 1967; Kaplan et al, 1977; Wilson et al, 1978; and Wilson et al, 1984). The higher the frequency of the eliciting stimulus, the higher the rate and the earlier the onset of adaptation.

Intensity Effects on Acoustic Reflex Adaptation

The relation between reflex adaptation and activator intensity level is not as clear as that between adaptation and frequency. Some researchers have indicated that the effects of intensity level on reflex adaptation is dependent on the frequency of the activator signal.

Wiley and Karlovich (1975) studied adaptation functions for 10 normal subjects ranging in age from 22-30 years using 500 Hz, 4000 Hz, and broad-band noise activators. Reflex activity was observed for a period of five minutes for the 500 Hz and broad band noise activators and over three minutes for the 4000 Hz activator. The activators were presented at 5, 10, and 15 dB above acoustic reflex threshold. The data from this study showed that reflex adaptation did not vary with activator level, except for the 500 Hz activator. For 500 Hz, 10% reflex adaptation was found at 5 dB SL, 20-25% at 10 dB SL, and as much as 50% adaptation was found at 15 dB SL. Thus, for the 500 Hz activator, the amount of adaptation actually increased with increased presentation level above acoustic reflex threshold. Whereas, in a later study by Kaplan et al (1977), the amount of adaptation at 500 Hz was found to be independent of intensity level over a range of 6 to 18 dB above acoustic reflex threshold, when adaptation functions were normalized to 100% of maximum reflex magnitude.

Wilson et al (1978) observed that the effect of increased sound pressure level (SPL) of the activator signal systematically decreased the rate of adaptation for a 500 Hz and 1000 Hz signal at presentation levels from 96 dB SPL to 112 dB SPL. For the higher frequency activators (2000 Hz and 4000 Hz), no consistent effect was noted with increased level. It should be pointed out that the authors of this study did not report acoustic reflex threshold data for their subjects. Their criterion for subject selection included the presence of acoustic reflex thresholds at 96 dB SPL or below for each activator. However, measurements of adaptation were made at specific sound pressure levels (96 dB, 104 dB and 112 dB SPL) which may have represented a different sensation level relative to the acoustic reflex threshold for each subject.

Given and Seidemann (1979) reported on reflex adaptation data obtained for 28 normal subjects at five intensity levels (0, 5, 10, 15, and 20 dB re: acoustic reflex threshold) with four activator frequencies (500,1000, 2000, and 3000 Hz) during a 10 sec interval. In their study, adaptation was defined as "the magnitude of relaxation of the reflex relative to maximum contraction" (p. 538). These authors found a decrease in the median level of adaptation as a function of increasing sensation level (i.e. 0 to 20 dBSL) for 500 Hz, 1000 Hz and 2000 Hz. The most pronounced effect of increased intensity level on adaptation was observed between 0 dB SL and 10 dB SL for the activators below 3000 Hz. At 3000 Hz, no consistent effect of increased intensity level was noted (i.e. the amount of adaptation remained constant for the 3000 Hz activators up to 20 dB SL).

In summary, the more recent studies have found that as the intensity of the activating tonal stimulus increases, the rate of adaptation decreases, at least for 500 Hz and 1000 Hz activators (Wilson et al, 1978; Given and Seidemann, 1979). Why the first study by Wiley and Karlovich (1975) found the reverse effect is not clear. The effects of intensity on activators at or above 2000 Hz appears to be non-existent, but this topic warrants additional study.

Broad band Noise Activators and Adaptation

Reflex adaptation for broad band noise stimuli has not received extensive study. In an early paper by Dallos (1964), reflex adaptation was examined using broad-band noise (BBN) activators at levels near acoustic reflex threshold and at higher intensity levels. Dallos observed that some subjects demonstrated appreciable adaptation when the level of the activator was just above acoustic reflex threshold; however, adaptation became minimal as the intensity of the noise activator increased. In contrast to Dallos' findings, Wiley and Karlovich (1975) found similiar adaptation to BBN regardless of the intensity level above acoustic reflex threshold.

In a recent study by Wilson et al (1984), the rate of adaptation was studied in 35 normal hearing subjects using a BBN activator presented at 10 dB above acoustic reflex threshold. These researchers noted considerable variability in the rate of adaptation to BBN among their subjects. For example, the reflex response of 8 subjects adapted to 50 % within the first 8 sec, 20 subjects adapted between 8 and 28 sec and 7 subjects did not adapt to 50% during the 31 sec period studied. Wilson et al also noted that the rate of adaptation was slower for BBN than for most tonal stimuli. All three of the above studies pointed out that there was large intergroup variability in the adaptation data using noise stimuli.

To summarize the effects of frequency, intensity and bandwidth on normal acoustic reflex adaptation, three general observations can be made. First, there was a consensus among the studies that reflex adaptation is directly dependent on frequency. That is, as frequency increases the rate of adaptation increases and the time of onset decreases. Second, the majority of studies indicated that increased intensity level above the acoustic reflex threshold results in a decrease in adaptation for 500 Hz and 1000 Hz activators. For activators of 2000 Hz or higher and for broad-band noise, adaptation does not systematically change with increased presentation level. Third, the rate of reflex adaptation to BBN activators is slower than for most tonal activators. However, additional research is needed to systematically investigate the effect of stimulus bandwidth and its interaction with intensity level on reflex adaptation in normal hearing subjects.

A Model of Acoustic Reflex Adaptation

Reflex adaptation findings on young normal subjects have been compared to an empirical model proposed by Tietze (1969). The model assumes that the reflex magnitude during stimulation can be described by two exponential time constants that begin simultaneously at stimulus onset. One time constant accounts for the rise of the reflex magnitude at signal onset and a second time constant accounts for the decay of reflex magnitude during prolonged stimulation (Tietze, 1969). The mathematical equation used to describe the impedance change predicted by the model is as follows:

$$Z\ (\%) = [Tb/(Tb - Ta)]\ [e^{-t/Tb} - e^{-t/Ta}] * 100 \qquad (1)$$

Where:

$Z(\%)$	is the percentage of impedance change at any time t during stimulation
Ta	is the time constant of the exponential function describing the rise of the reflex magnitude
Tb	is the time constant of the exponential function describing the decay of the reflex magnitude.
t	is the time since stimulus onset

The existing data on acoustic reflex adaptation in normal young subjects lend support to the exponential function described by Tietze's model, at least as a first approximation (Kaplan et al, 1977; Wilson et al, 1978). The question of whether any model of adaptation would also predict the reflex adaptation function of normal hearing elderly subjects or of hearing impaired subjects remains unanswered in the published literature.

Neurophysiologic Correlates of Adaptation

Acoustic reflex adaptation has neurophysiologic correlates. Adaptation occurs throughout the auditory nervous system which includes the acoustic reflex arc. Studies of single auditory nerve fibers show that the rate of discharge in a neural unit increases at the onset of a tone burst, but gradually declines thereafter until it reaches a steady state (Moller, 1972). Upon cessation of the stimulus, the rate declines to below the level of spontaneous firing (Harris and Dallos, 1979). Moller (1984) pointed out that acoustic reflex adaptation, which is frequency dependent, is probably due to adaptation in the auditory system rather than the adaptation of the stapedius muscle itself. Further, he speculated that, since reflex adaptation is most prominent in the high frequencies, it may be related to the phase-locking response of the auditory nerve fibers which is known to deteriorate with increased frequency, rather than to the overall discharge rate. Empirical data on this topic are not available.

ACOUSTIC REFLEX ADAPTATION IN DIFFERENTIAL DIAGNOSIS OF SENSORINEURAL HEARING LOSS

The rate of acoustic reflex adaptation described earlier for normal hearing subjects is much higher in subjects with eighth nerve pathology. Anderson et at (1969; 1970) were the first to suggest the clinical utility of acoustic reflex adaptation to infer the integrity of the VIII nerve. They reported that patients with VIII nerve lesions demonstrated 50% adaptation (decay) in reflex magnitude within 5 seconds after stimulus onset for 500 Hz and 1000 Hz activators presented at 10 dB above acoustic reflex threshold. In their normal subjects, only 6-8% decay in reflex magnitude was noted with the same criterion and stimulus parameters. At the present time, clinical reflex decay tests in Europe still employ the 5 second criterion in accordance with the original recommendation of Anderson and colleagues. In the United States, a 10 second criterion was adopted in the clinical use of decay measurement for purposes of differential diagnosis (Jerger et al, 1974). The adoption of a 10 second criterion was based on numerous studies on reflex adaptation characteristics in cochlear and retrocochlear subjects (see Wilson et al, 1984). However, there is still controversy surronding the use of a 5 or 10 second criterion. As Jerger and Jerger (1983) pointed out, the duration criterion for the acoustic reflex decay test should be adjustable depending upon the purpose of the test. To maximize sensitivity (correct identification of retrocochlear pathology) they suggest the use of 10 seconds or greater duration. On the other hand, to maximize specificity (correct rejection of retrocochlear pathology), use of a 5 second criterion is perferred. These same authors indicate that, in terms of overall efficiency, there is no difference between a 10-sec and 5-sec criterion. In the following sections, studies on reflex decay measurements in various types of pathology will be reviewed.

Acoustic Reflex Adaptation in Sensorineural Hearing Loss of Cochlear Origin

Olsen, Noffsinger and Kurdziel (1975) studied acoustic reflex thresholds and reflex decay in 100 subjects with cochlear hearing loss. The subjects included 50 subjects (ages 16-62 years) with noise-induced hearing loss and 50 subjects (ages 28-61 years) with medically diagnosed Meniere's disease. Of the total 100 cases, 3 subjects had no acoustic reflex thresholds at 500 Hz and 1000 Hz, 11 subjects had no reflex at 2000 Hz. Only 2 subjects had no reflex response for the three test frequencies (500, 1000, and 2000 Hz). Abnormal reflex decay (>50% decay within 10 sec at 10 dB above acoustic reflex threshold) was observed at both 500 Hz and 1000 Hz for 1 subject, at only 500 Hz for 1 subject, and at only 1000 Hz for 11 subjects. Using a dual criterion of absent reflex response or abnormal reflex decay, these investigators found that approximately 21 of their 100 subjects with cochlear hearing loss exhibited results that were suggestive of retrocochlear pathology, yielding a false positive rate of approximately 20%. It should be noted that the ages of the 100 cochlear subjects ranged from 16 to 62 years. No specific mention was made by the authors regarding the ages of the subjects who exhibited false positive findings.

Acoustic reflex adaptation was investigated in 58 subjects with cochlear hearing loss in a study by Chiveralls, Fitzsimons, Beck, and Kernohan (1976). The cochlear group included subjects with hearing losses ranging from mild to severe. These researchers showed two important findings. First, they observed that decay occurred faster for the sensorineural hearing loss group than for the normal hearing group. For example, the mean half lives for a 1000 Hz activator was 32 seconds for the normal hearing group and 18.1 seconds for the sensorineural hearing loss group. Secondly, there was a high false positive rate among the sensorineural hearing loss group using the original decay criterion proposed by Anderson et al. Thirteen of the 58 subjects (22%) exhibited abnormal reflex decay for 500 Hz and/or 1000 Hz within the first 5 seconds of stimulation.

Later, Kurdziel, Stach and Olsen (1979) compared acoustic reflex decay results on 208 cochlear subjects using a 10 second criterion (proposed by Jerger et al in 1974) and a 5 second criterion (originally proposed by Anderson et al, 1970). The 208 subjects included 59 cases with medically diagnosed Meniere's disease and 149 cases with medically confirmed cochlear hearing loss of various etiologies. These investigators found that absent acoustic reflexes and 50% reflex decay using a 10 sec criterion or a 5 sec criterion occurred in 30% of the cochlear hearing loss sample.

Unlike previous studies, Mangham et al (1980) studied various properties of the acoustic reflex in 13 subjects (aged 24-69 years) who were considered to be "at risk" for VIII N lesions. That is, their subjects exhibited retrocochlear signs on several audiologic tests but were later found to have no radiographic evidence of retrocochlear pathology. Reflex decay was expressed as a time constant rather than by the conventional method of measuring the time interval to reach 50% of maximum reflex magnitude (The time constant was defined as the time interval from the onset of reflex response to the time when the magnitude had decayed by 63% of the maximum reflex magnitude). Reflex decay measurements were reported for a 500 Hz activator at intensity levels of 5, 10, 15, 20, and 25 dB above the acoustic reflex threshold. Mangham et al found that two of the 13 nontumor subjects (15%) exhibited abnormal reflex decay near threshold (10 dB SL), but not at higher intensity levels. In all cases, nontumor subjects showed increasing decay time constants with increasing intensity above reflex threshold. In this study, no account was taken of possible age effects on the decay time constants of the subjects who exhibited abnormal decay near reflex threshold.

Acoustic reflex threshold and reflex decay results for 58 patients with Meniere's disease were reported by Olsen, Stach and Kurdziel (1981). Reflex decay measurements were compared using a 5 sec and 10 sec criterion for 500 and 1000 Hz activators at 10 dB SL. Absence of reflex response for 500 Hz, 1000 Hz and/or 2000 Hz was observed for only 5% of the Meniere's subjects with pure tone averages < 65 dB HL. Abnormal reflex decay at 500 Hz and/or 1000 Hz was observed for 26% of the subjects using the 10 sec criterion, whereas abnormal decay was observed for 22% of the subjects using the 5 sec criterion. These investigators reported that using a dual index of absent reflex at 500, 1000, or 2000 Hz and of abnormal reflex adaptation within 5s or 10s at 500 Hz or 1000 Hz resulting in a false positive rate of 31%. That is, 18 out of 58 subjects with Meniere's disease were classified as high risk for retrocochlear pathology based on the dual index. In this study by Olsen et al, no mention was made regarding the ages of their Meniere's subjects.

Sanders, Josey, Glasscock and Jackson (1981) retrospectively analyzed acoustic reflex decay measurements in 135 subjects (ages 16-69 years) with cochlear pathology (N=152 ears). Abnormal decay, measured at 500 Hz and 1000 Hz, was defined as 50% decay within the first 5 secs. In four out of 141 ears with hearing loss <85 dB HL, acoustic reflexes were absent. Of the remaining 137 ears, only 6% exhibited abnormal acoustic reflex decay as defined by these investigators.

Olivary and Kileny (1984) compared adaptation findings to activators at frequencies of .5, 1, and 2 kHz of four subjects with sensorineural hearing loss to their normative data. They found that the four cases showed greater reflex decay to contralateral stimulation compared to the normal subjects at all frequencies, particularly at 1000 Hz and 2000 Hz. Two of the four subjects exhibited greater than 50% decay at 1000 Hz only within a 10 second stimulation time.

In conclusion, studies of acoustic reflex adaptation in subjects with cochlear hearing loss have yielded mixed results. Based on the studies reviewed above, the acoustic reflex decay findings were "abnormal" for between 6% to 31% of subjects known to have a cochlear site of pathology. In these cases, the adaptation measurements led to a false positive finding (i.e. nontumor cases identified as rétrocochlear). Obviously, the criteria used to judge the normalcy of the reflex decay (use of a 5 sec vs. 10 sec criterion, use of findings at 500 Hz vs findings at 500 Hz and/or 1000 Hz) will strongly influence the incidence of false positive cases. For example, in Olsen et al's study (1975) a lax criterion for defining both abnormal acoustic reflex response and reflex adaptation yielded a high false positive rate (31%) compared to the majority of studies.

It is also apparent from the review of these studies, that the effects of age or degree of cochlear loss on the acoustic reflex adaptation characteristics have not been examined. It is possible that older normal hearing subjects or subjects with cochlear hearing loss show a different pattern or rate of reflex decay than young normal hearing subjects. Therefore, changes in reflex adaptation that occurs as result of age or hearing loss should be explored before determining the efficiency of the 10 second criterion as commonly employed in the clinical differential diagnosis of auditory pathology.

Acoustic Reflex Adaptation in VIII Nerve Pathology

Anderson et al (1969, 1970) found that an ear with VIII N.pathology exihits faster decay that that seen in cochlear pathology. They studied reflex decay in 17 subjects with verified retrocochlear involvement in which the hearing losses were less than or equal to 60 dB HL. In 7 of the 17 cases, the reflex could not be elicited at maximum intensity (120 dB HL). In the remaining 10 cases, rapid reflex decay was noted within 5 seconds of stimulation for activator frequencies of 500 and 1000 Hz. The investigators concluded from the results of this study that two properties were distinctive of the tumor group, i.e. an elevated or absent acoustic reflex threshold and abnormally rapid decay in the reflex response.

Further studies have supported the findings of Anderson et al, although later reports found the absence or elevation of the reflex the predominant finding with VIII N. lesions, with reflex decay present in a small percentage of subjects. For example, Jerger et al (1974) investigated acoustic reflex data in 30 patients with surgically confirmed retrocochlear lesions. The acoustic reflex was normal in 7 patients, elevated in 4 patients, and absent in 19 of the 30 patients. Of the 11 patients who had measurable acoustic reflex responses, 4 exhibited abnormal reflex decay (10 sec criterion) at 500 Hz or 1000 Hz. The authors concluded that the twin index of elevated/absent reflexes and abnormal decay correctly identified 87% of the tumor cases.

In a similiar study by Sheehy and Inzer (1976) of 24 patients with VIII N. lesions, almost half (46%) had absent acoustic reflexes. Eight of the remaining 13 subjects with reflex responses showed abnormal reflex decay (10 sec criterion). The findings of this study indicated that reflex findings (threshold and decay) were able to identify the presence of retrocochlear pathology in 79% of the 24 tumor cases. Sander et al (1981) studied reflex data on 152 ears with acoustic tumor. Eighty four (55%) had absent reflexes and 33 (22%) showed abnormal reflex decay (5 sec criterion) at both 500 and 1000 Hz. The correct identification rate for retrocochlear pathology was approximately 77%.

Based on the studies reviewed above, the percentage of acoustic tumor subjects with no measurable acoustic reflex responses or with elevated reflexes was close to 50%. Use of a dual index (acoustic reflex thresholds and decay) resulted in a correct identification rate of 80% or more.

Acoustic Reflex Adaptation and Aging

Although measurements of acoustic reflex adaptation are used clinically in the differential diagnosis of cochlear and retrocochlear pathology, researchers have not to addressed the effects of aging on the characteristics of acoustic reflex adaptation. Information on the possible relation between age and acoustic reflex adaptation has both theoretical and clinical significance.

The review of the pertinent literature has highlighted how aging affects the neurophysiology of the auditory system which in turn causes a decline in auditory functioning. Furthermore, the literature also points out how aging affects several acoustic reflex measurements such as the acoustic reflex threshold, latency and magnitude growth. Studying the effects of aging on acoustic reflex adaptation may shed some light on the underlying neurophysiological changes that accompany aging. For example, if age effects are not found for reflex adaptation then reflex adaptation may reflect processes that are different from those proposed for other reflex measures.

As mentioned earlier, reflex adaptation findings on young normals have been compared to an empirical model proposed by Tietze (1969). In young normal subjects, it has been demonstrated that the acoustic reflex adaptation functions approximate the exponential functions predicted by the model. The question of whether Tietze's exponential model of adaptation predicts the reflex adaptation function of normal hearing elderly subjects remains unanswered.

The clinical justifications for investigating adaptation in older subjects is even more compelling. No study to date has considered the effects of age on reflex adaptation measurements in differential diagnosis. As already mentioned, age-related changes on acoustic reflex adaptation may well contribute to the number of cochlear cases who are falsely identified as having retrocochlear pathology based on currently used criteria for judging abnormal reflex adaptation. Age-related changes within the auditory system may reduce the effectiveness of acoustic reflex adaptation as a clinical tool with older subjects unless these effects are taken into account. Alternatively, the absence of an age effect on reflex decay would increase the confidence with which these measurements could be applied diagnostically regardless of the patient's age.

Chapter 3.

RESEARCH RATIONALE AND PLAN

Research Rationale

The main motivation for the proposed study was the possible need to modify clinical tests of reflex decay. As mentioned in the previous chapter, the measurement of reflex decay is used clinically for the diagnosis of neurotologic pathology (e.g. in the detection of acoustic tumors). Typically, the clinical criterion defines abnormal reflex decay as a decrease in reflex magnitude of greater than 50% to a 10 second signal at 500 Hz and/or 1000 Hz presented at 10 dB above the acoustic reflex threshold.

A large portion of the clinical population seen for diagnostic testing is older. It has been found that other reflex parameters (e.g. threshold, latency, magnitude growth) are substantially affected by the process of aging, even in the presence of normal hearing sensitivity. It is, therefore, reasonable to question whether reflex decay is also affected by aging. It is clear from the literature that clinical studies of reflex decay have not addressed this issue. Furthermore, one may reasonably speculate that a percentage of false positive cases (i.e. where there is significant reflex decay in the absence of retrocochlear involvement) reported in these studies may have been exaggerated due to a failure to account for aging effects.

In view of the above considerations, the first purpose of the present study was to test the hypothesis that there are significant differences in the rate of reflex decay between young normal hearing subjects and older normal hearing subjects. If the data were in support of this hypothesis then the current clinical criterion would need to be modified when the older normal hearing subject is evaluated clinically.

The clinical population of older subjects consists not only of those with normal hearing but includes those who exhibit a presbycusic hearing loss. A number of published studies have found that cochlear hearing loss has a significant effect on other reflex parameters, including threshold and magnitude growth. In the clinical application of reflex decay there is the possibility that aging and cochlear hearing loss may be confounded. If this were the case, the existing reflex decay criterion may need to be modified for the presbycusic subject. Consequently, a second purpose of this research was to test the hypothesis that there are significant differences in the rate of reflex decay behavior between older normal hearing subjects and older subjects with an age-related cochlear hearing loss.

In addition to subject variables in the investigation of reflex decay behavior, the variables related to the activating stimulus must be considered. Research literature indicates that within a subject, reflex decay rate is a function of the type of activating stimulus. Specifically, the rate of reflex decay is 9faster for the high frequencies than for the lower ones. This frequency effect may be due to different adaptation rates in the auditory neural pathways. Whatever the explanation, it is necessary to consider the interaction between stimulus effects and any aging or presbycusic effects, particularly because the clinical reflex decay test employs two different stimuli, namely, 500 Hz and 1000 Hz. Therefore, the third purpose of this research was to test the hypothesis that age and presbycusic effects, if they exist, are different for different stimuli.

Clinical tests of reflex decay have traditionally used a presentation level of 10 dB above the acoustic reflex threshold. A number of published studies have found that the rate of reflex decay decreases with increases in intensity level above the reflex threshold. In this regard, Mangham et al (1980) suggest that the combined use of 10 dB and a higher sensation level (e.g. 15 or 20 dB SL) may help to reduce the number of false positive cases in the clinic. The fourth purpose was to test the hypothesis that age or prebycusic effects, if they exist, are different for different sensation levels.

Research Plan

To test the four hypotheses, acoustic reflex activity was measured during prolonged stimulation in three subject groups. The groups consisted of 12 young normal-hearing subjects, 12 old normal-hearing subjects, and 12 older subjects with presbycusis. Four stimuli (.5, 1, 2 KHz and broad band noise) were used. Two of these stimuli (.5 and 1 KHz) are used clinically, whereas the other two stimuli (2 kHz and broad band noise) have been used in past studies on the acoustic reflex threshold and magnitude growth with aged subjects. Each of the four stimuli was presented at two sensation levels above the acoustic reflex threshold. A level of 10 dB was chosen since this is the level used clinically. The higher level of 15 dB SL was used to investigate how reflex decay adaptation varied as a function of intensity within and across the three groups.

The first hypothesis was tested by comparing the adaptation results of the young normal hearing group to those of the older normal hearing group. Because these two groups were matched with respect to hearing sensitivity, differences in adaptation behavior between them was assumed to be due to the effect of age. The second hypothesis was tested by comparing the older normal hearing group with the presbycusic group. These groups were matched with respect to age and so differences in reflex adaptation behavior were primarily attributable to presbycusic effects. The third and fourth hypotheses were tested by investigating the interaction of subject group with stimuli and sensation level, respectively.

Reflex decay has been measured clinically and in most research studies by a half life. The half life is defined as the time taken for the admittance change to decay to 50% of its maximum value. This method of quantifying reflex decay proved to be difficult in this study for a variety of reasons. Consequently, two alternative approaches to quantification were adopted. These approaches will be explained in detail in the results chapter (Chapter 5).

Chapter 4.

METHODOLOGY

Instrumentation

Audiometric Equipment. Testing was performed in an IAC sound booth. Air conduction pure tone thresholds, speech tests and tone decay tests were administered using a Maico MA 41 audiometer with TDH-49 air conduction transducers mounted in MX 41/AR cushions. Speech materials were fed from a tape cassette recorder (Tascam 122) to the speech channel of the audiometer. Bone conduction thresholds were obtained using a Radioear (Model B70A) transducer.

Reflex Activating System. Experimental Stimuli. Figure 2 shows the instrumentation used for the reflex decay experiment. The reflex activating stimuli consisted of tonal signals (500 Hz, 1000 Hz, and 2000 Hz) and a broad band noise signal. The tonal stimuli were generated by a voltage controlled oscillator (Coulbourn, Model S24-05) and the noise stimuli were generated by a noise generator (Coulbourn, Model S81-02). The stimulus envelope was gated and shaped (25 msec rise-fall) by an electronic

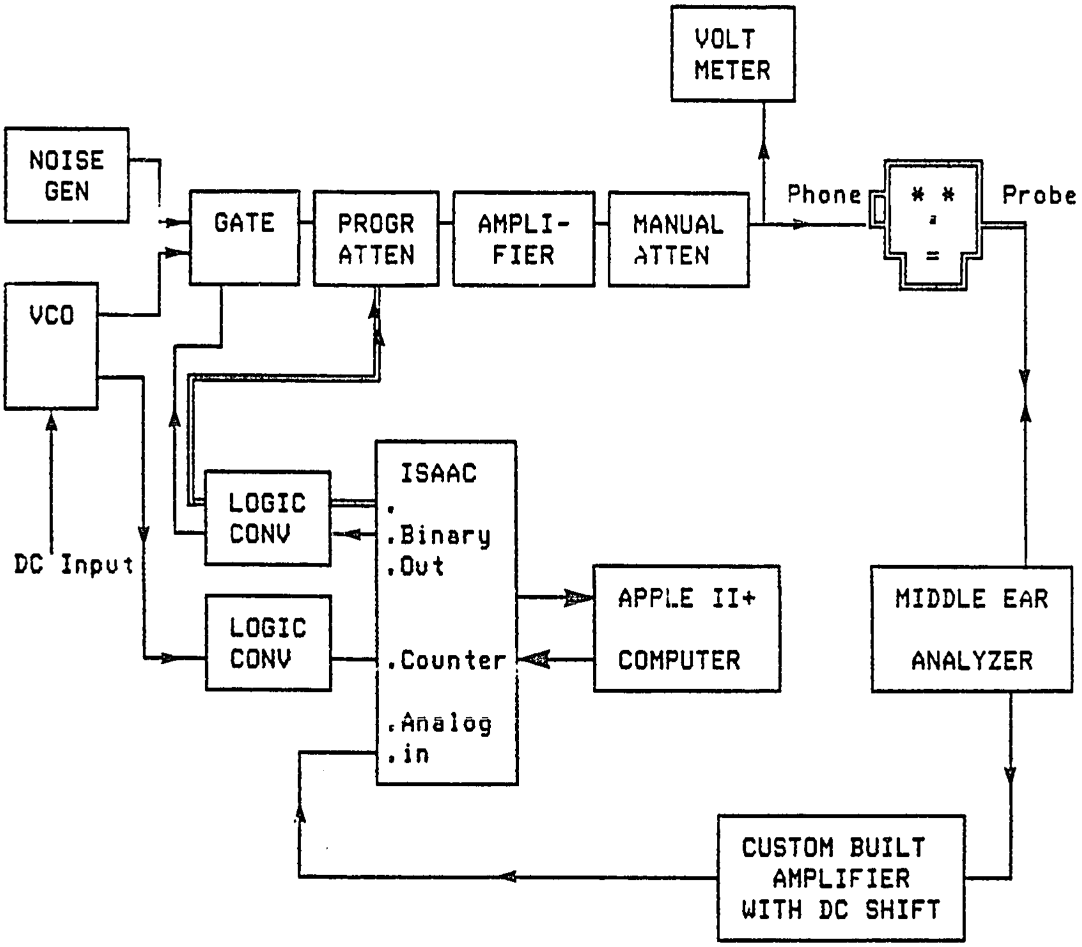


Figure 2. Block diagram of instrumentation.

switch (Coulbourn, Model S84-04), which was triggered by a logical assertion from the Apple II+ computer via a Cyborg interface (Issac 91A). From the electronic switch, the stimulus was sent to a programmable attenuator (Coulbourn, Model S85-08) and fed to an audio mixer/amplifier (Coulbourn, Model S82-24) and manual attenuator (Coulbourn, Model S85-02). The output of the manual attenuator was delivered to a TDH-49 earphone encased in an MX 41/AR cushion. The electrical signal reaching the earphone was monitored by a volt meter (Leader, Model LMV 181-A).

Reflex Monitoring System. The contralateral acoustic reflex activity was measured with a 220 Hz probe from an middle ear analyzer (Grason-Stadler, Model 1723). This oto-admittance meter functions by comparing the signal picked up by the probe microphone with that being sent to the probe receiver. Internal circuits automatically adjust the overall phase and gain relationships between the probe signal and the initial static reflected signal. The latter change with the impedance change of the outer and middle ear systems. At an early stage in the circuitry, the adjusted signal carries both an AC ripple at the frequency of the probe tone and a DC offset. Later in the circuitry, the ripple is removed by filtering and the DC component is eliminated by introduction of a dc voltage of opposite polarity. In the early stages of the present experiment, it was found that the filtering slowed the response of the system to rapid changes in impedance. Therefore, it was decided to extract the signal in the circuitry before filtering, dc offset, amplification and final smoothing. The output from the oto-admittance was taken at pin J1-11 on the YGB board. This was a point at the output of the calibration adjustment amplifier immediately following the first stage of smoothing (See Appendix A.1). A mixer amplifier was built which amplified the output (signal gain of x50) and completely cancelled the dc offset (See Appendix A.2). The gain and dc offset were adjusted so that full deflection on the admittance meter caused an output change of -5 to +5 volts (corresponding to the voltage range of the Issaac 91A A/D converter). The output from the amplifier was then sampled, digitized and stored using an Apple II+ computer with a Cyborg laboratory interface (Isaac 91A).

CALIBRATION OF INSTRUMENTATION AND EXPERIMENTAL STIMULI

Audiometer. Electroacoustic calibration of the Maico MA 41 audiometer was performed weekly in accordance with ANSI-S3.6-1969 specifications for air conduction and at the beginning of the experiment in accordance with

ANSI-S.3.13-1972 for bone conduction. The calibration of the audiometer included measurement of sound pressure output, attenuator linearity, frequency, and harmonic distortion.

Oto-admittance Meter. Prior to data collection, the oto-admittance meter was calibrated to the manufacturer's specifications. Calibration included pressure accuracy calibration, and measurement of the frequency and sound pressure level of the probe tone. A microliter syringe coupled to the probe was used to determine the relationship between the volume changes in the syringe and the digital output of the A/D converter. Figure 3 shows a linear relationship between syringe volume and the output of the A/D converter. The slope of this relationship shows that a change of 0.01 milliliters (equivalent to .01 millimhos in admittance) produces a change of 176 digital units. Complete calibration of the monitoring system was accomplished every two weeks throughout the experiment and at the completion of the experiment. Calibration measurements remained stable over the course of time.

Stimulus. Measurement and adjustment of the maximum levels of the experimental stimuli was performed before

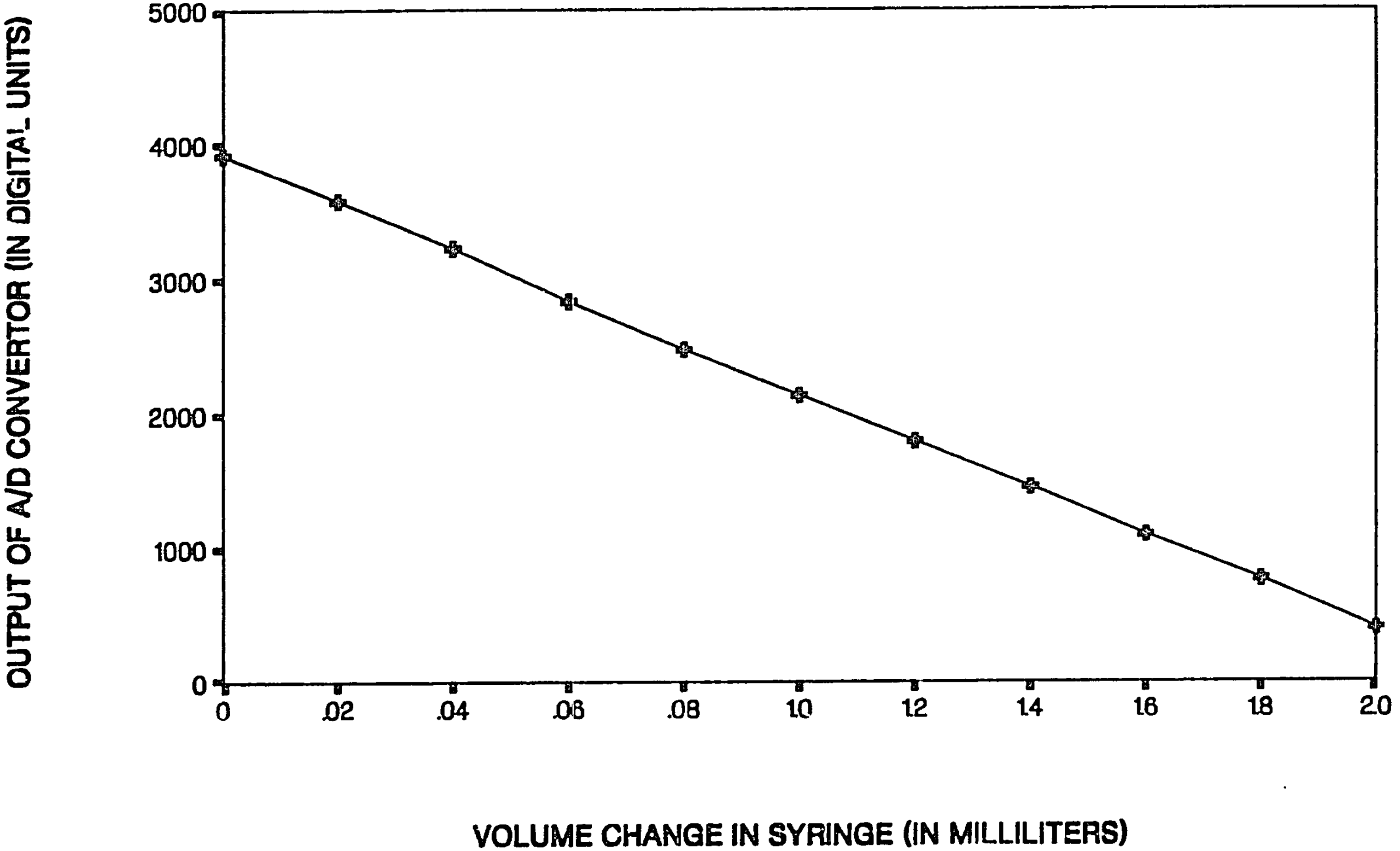


Figure 3: RELATIONSHIP BETWEEN VOLUME CHANGES IN SYRINGE AND DIGITAL OUTPUT OF THE ISAAC A/D CONVERTOR

each test session as follows: (1) the programmable and manual attenuators were set to zero, (2) the mixer/amplifier was adjusted so that the signal produced an output of 1 volt on the voltage meter, (3) the TDH-49 earphone was then placed on an artifical ear (B&K Type 4152) and the sound pressure level was measured separately for each stimulus (500 Hz, 1000 Hz, 2000 Hz and broad-band noise) on a sound level meter (B&K,Type 2203) and (4) the maximum output values were entered into the software programs designed for the measurement of the acoustic reflex thresholds and acoustic reflex adaptation functions. The maximum output levels were 126 dB SPL, 126 dB SPL, 123 dB SPL and 116 dB SPL for 500 Hz, 1000 Hz, 2000 Hz and broad-band noise, respectively.

Initial calibration of the experimental stimuli also included measurement of frequency, attenuator linearity (both programmable and manual), distortion and rise/fall times. The linearity of the manual attenuator was further checked once a month. The frequency response of the TDH-49 earphone was measured and is shown in Figure 4.

SUBJECTS

Three groups of subjects were included in the study:

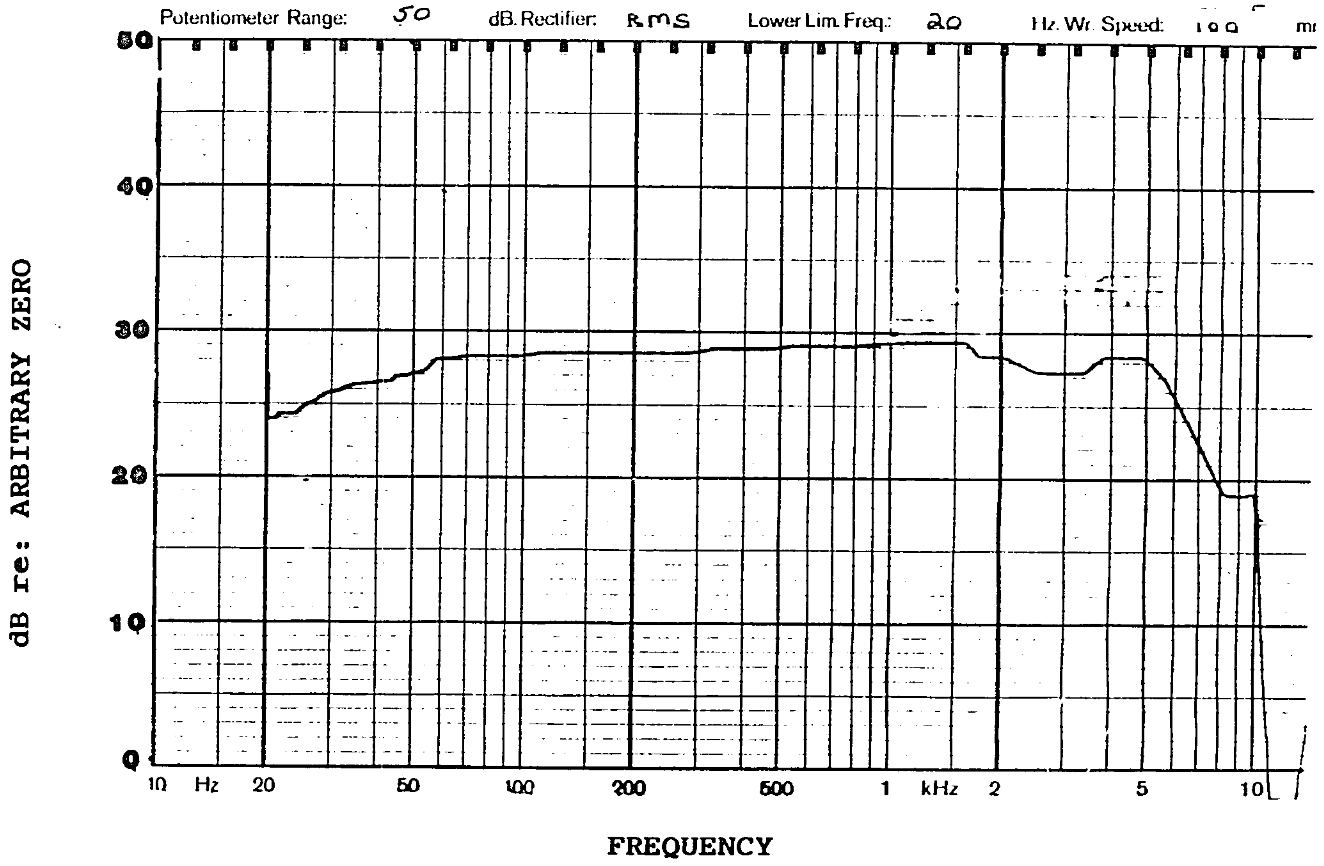


FIGURE 4: FREQUENCY RESPONSE OF TDH - 49 EARPHONE

Group I (young normals) consisted of twelve subjects (7 females and 5 males) between 20 to 29 years of age with normal hearing sensitivity. The criterion for normal hearing was defined as air conduction thresholds less than or equal to 20 dB HL (ANSI, 1969) from 250 Hz to 8000 Hz.

Group II (older normals) included twelve subjects (7 females and 5 males) between 60 to 69 years of age with normal hearing. The lower age cutoff of 60 years was chosen for the older group based on age-related findings found for other acoustic reflex parameters. For example, studies on acoustic reflex thresholds (Silverman, 1979), acoustic reflex magnitude (Thompson et al., 1980) and acoustic reflex latency (Bosatra et al., 1984) show consistent age effects for subjects of 60 years and older. The criterion for normal hearing for Group II was the same as for group I, i.e. air conduction thresholds </= 20 dB from 250 Hz to 8000 Hz.

Group III (presbycusics) consisted of twelve subjects (7 females and 5 males) between 60-69 years of age with hearing typical for their age group (Corso, 1971; Spoor, 1967). More specifically, the criterion for inclusion in this group was air conduction thresholds as follows: </= 25 dB from 250 Hz to 1000 Hz, between 25 dB and 40 dB at 2000 Hz, and between 25 dB and 55 dB above 2000 Hz.

Subjects in Group III were matched with respect to age (+/- 2 years) to subjects in Group II (older normals).

Tables 1 and 2 show the means, standard deviations and ranges for the age and hearing threshold levels for each of the three subject groups, respectively. The individual subject data are listed in Appendices B.1-B.3.

All subjects met the following criteria: (a) bone conduction thresholds (ANSI, 1972) within 5 dB of the air conduction thresholds (Studebaker, 1962); (b) tympanograms with the peak pressure point at +/- 50 mm H O; (c) static acoustic admittance values greater than .3 mmhos at 220 Hz bilaterally; (d) no complaint or history of current ear disease; (e) no reported history of central nervous system disorder; (f) the absence of obstruction in the ear canals bilaterally; (g) speech recognition scores of 88% or more using CID-W22 presented at 50 dB HL or at PB-maximum level and (h) threshold tone decay within 60 seconds of less than 30 dB at 500 Hz, 1000 Hz, and 2000 Hz (Carhart, 1957).

PROCEDURES

(1) A case history was taken to rule out a complaint of current ear disease, history of central nervous system

Table 1.

Means, Standard Deviations, and Ranges of Ages for the Young Normal Hearing, Older Normal Hearing and Older Presbycusic Subjects.

Group	Mean (years)	s.d. (years)	Range (years)
Young Normal	25	3	20-29
Older Normal	65	3	60-69
Older Presbycusic	65	3	60-69

Table 2.

Means, Standard Deviations, and Ranges of Young Normal, Older Normal, and Presbycusic Subjects Hearing Threshold Levels.

Frequency		Mean (dB HL)	s.d. (dB)	Range (dB HL)
250 Hz	(young normal)	5	3	0-10
	(older normal)	9	5	5-20
	(presbycusic)	12	5	5-20
500 Hz	(young normal)	5	4	0-10
	(older normal)	9	5	5-20
	(presbycusic)	11	6	0-15
1 kHz	(young normal)	2	3	0-5
	(older normal)	10	6	5-20
	(presbycusic)	13	6	0-20
2 kHz	(young normal)	2	3	0-5
	(older normal)	9	5	0-20
	(presbycusic)	23	7	10-35
4 kHz	(young normal)	5	3	0-10
	(older normal)	15	5	5-20
	(presbycusic)	38	6	30-50
8 kHz	(young normal)	6	3	5-15
	(older normal)	15	5	10-20
	(presbycusic)	42	6	35-50

disorder, or significant history of noise trauma (See Appendices C.1).

(2) Otoscopic examination was done by this experimenter to determine any obstruction in the ear canals bilaterally. Subjects who showed evidence of ear canal collapse were excluded from the study.

(3) Pure tone air- and bone-conduction thresholds were determined using a modified Hughson-Westlake procedure (Carhart and Jerger, 1959).

(4) Speech recognition scores were obtained for each ear at 50 dB HL for all subjects using CID-W22 monosyllablic words. For Group III, higher intensity levels were sometimes used to determine the PB-maximum score.

(5) Tone decay tests were administered at 500 Hz, 1000 Hz and 2000 Hz according to the procedure described by Carhart (1957).

(6) The subject was seated in the sound test room and instructed to avoid swallowing, chewing or related activities during each test trial. The instructions and consent forms appear in Appendices C.2-C.3.

(7) Tympanometry at 220 Hz was then done as follows: air pressure in the outer ear was varied from +200 mm H20 to -343 mm H20 in order to establish the point of maximum

admittance and to determine whether the tympanogram was within the established criterion for normalcy outlined above. The test ear (right vs left) was chosen by randomization of ears within each group.

(8) Following tympanometry, acoustic reflex thresholds and acoustic reflex adaptation functions were obtained for each activator signal. The presentation order of the activator signals was randomized across subjects.

Obtaining Acoustic Reflex Thresholds. Reflex thresholds were measured by digitally monitoring changes in the output of the admittance meter for systematic increments in the level of the activating signal. A sampling routine was implemented which provided a measurement of baseline and reflex activity. The routine, illustrated in Figure 5, consisted of three phases. In the first phase, the computer sampled for 1500 msec (50 samples, 30 msec per sample), which represented a pre-stimulus baseline sampling period. A signal of 2000 msec duration was then introduced automatically initiating the second phase of the sampling routine. The computer did not sample the output for the first 500 msec of the signal to eliminate effects of reflex latency and overshoot. The third and last phase was initiated 500 msec after the onset of the activating signal. Sampling was then continued for the

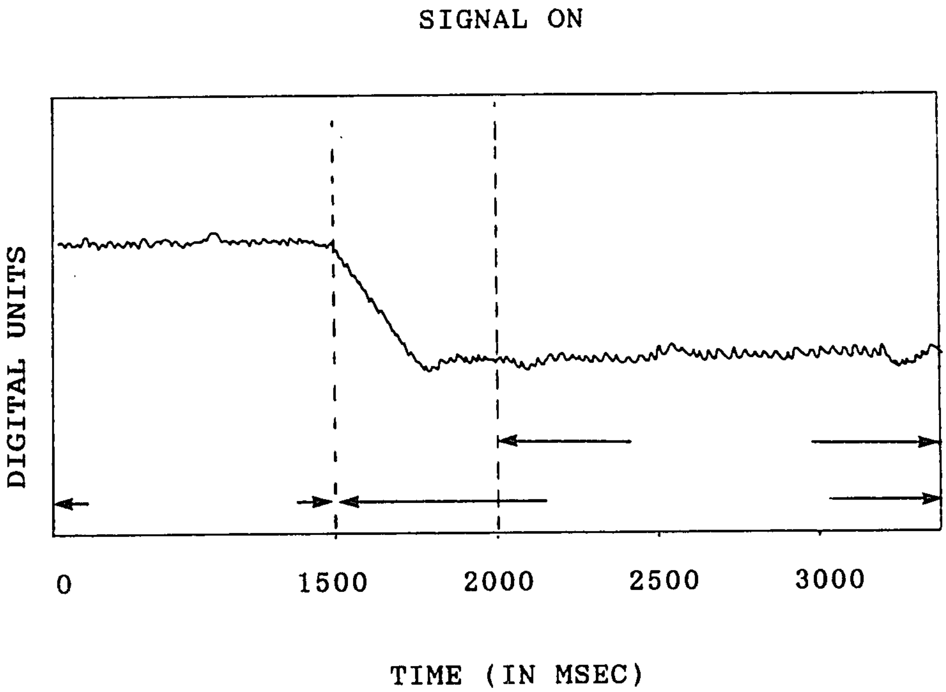


FIGURE 5: SAMPLING ROUTINE FOR DETERMINING THE ACOUSTIC REFLEX THRESHOLD

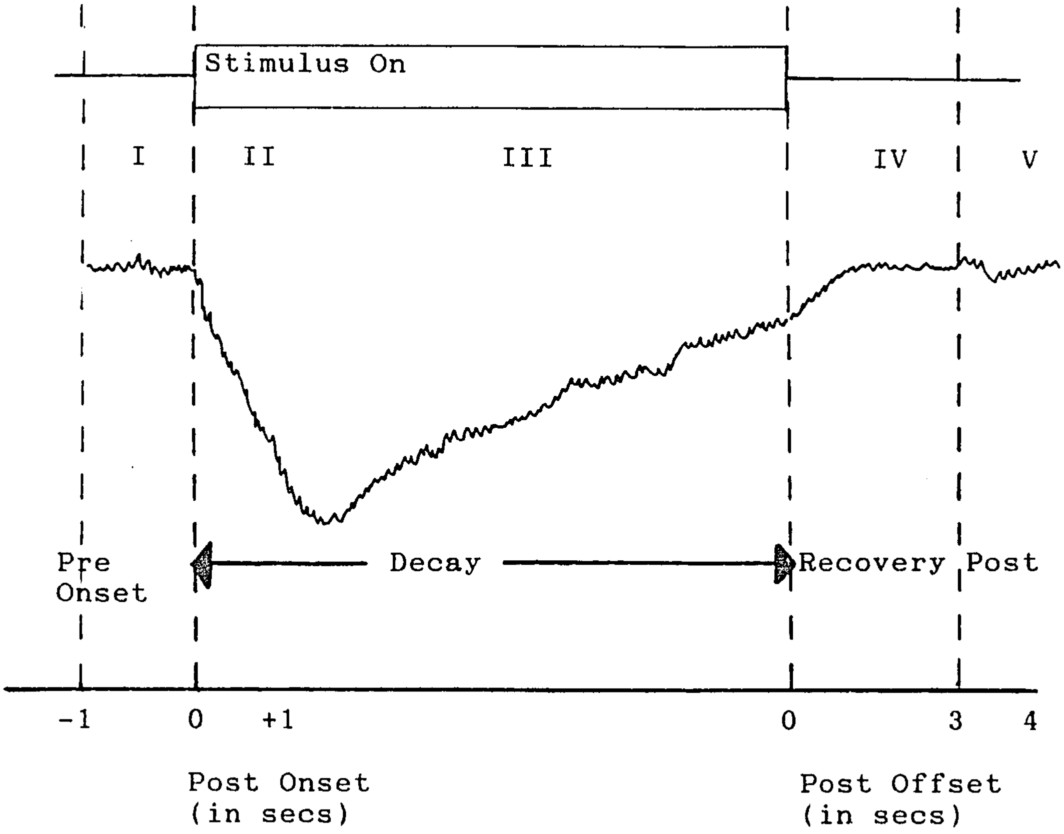
last 1500 msecs of the signal (50 samples, 30 msec per sample), which represented the stimulus sampling period. The sampling routine was repeated for each level of the activating stimulus.

The following rule was used to determine if the acoustic reflex had been activated. The mean value of 50 post-stimulus samples was subtracted from the mean value of 50 pre-stimulus samples. If the difference was equal to or exceeded 176 digital units then the criterion for reflex threshold was met. This criterion corresponded to an admittance change of .01 millihos, as shown in Figure 3.

A bracketing (ascending/descending) procedure was used to determine the level of reflex threshold. Initially the sound pressure level of the activating signal was set well below the acoustic reflex threshold. The tone was increased in 10 dB steps until the criterion for reflex activation was exceeded. The tone was then lowered by 6 dB and increased in 2 dB steps until criterion was exceeded again. The bracketing procedure (i.e. descending in 6 dB steps and ascending in 2 dB steps) was repeated until criterion was met at the same sound pressure level on two ascending trials. The bracketing procedure was then terminated. Typically 2 or 3 ascents of 2 dB steps were required.

Obtaining Acoustic Reflex Adaptation Functions. Reflex adaptation measurements were accomplished immediately following the determination of acoustic reflex threshold for a given signal. Acoustic reflex adaptation functions were measured sequentially for each activator signal at two intensity levels (10 dB and 15 dB) above the acoustic reflex threshold. The 10 dB sensation level condition was presented first.

The sampling routine used to monitor reflex activity is illustrated in Figure 6. The sampling routine consisted of five phases. During Phase I, the computer sampled for 1000 msec (50 samples at 20 msec per sample), which represented a pre-stimulus or baseline sampling period. The activator signal was then introduced. This initiated the second phase of the routine. During the Phase II, the computer continued to sample at 20 msec per sample for another 1000 msec, so as to obtain reflex onset data. In the third phase, the signal remained on while the computer sampled at a slower rate for an additional 200 samples. The sampling rate was different for each activator (See Table 3).



I = Pre-stimulus sampling at 20 msec per sample
II = Reflex Onset sampling at 20 msec per sample
III = Reflex Decay sampling for 200 samples
(sampling rate depended on activator stimulus)
IV = Reflex recovery phase (3 minutes)
V = Post-stimulus sampling at 20 msec per sample

Figure 6: SAMPLING ROUTINE FOR THE ADAPTATION FUNCTIONS

Table 3. Sampling Period and Total Duration Time of Phase III for the Tonal and Noise Stimuli.

Activator Signal	Sampling Period	Duration of Phase III
500 Hz	500 msec	10000 msec
1000 Hz	350 msec	7000 msec
2000 Hz	200 msec	4000 msec
Broad band Noise	500 msec	10000 msec

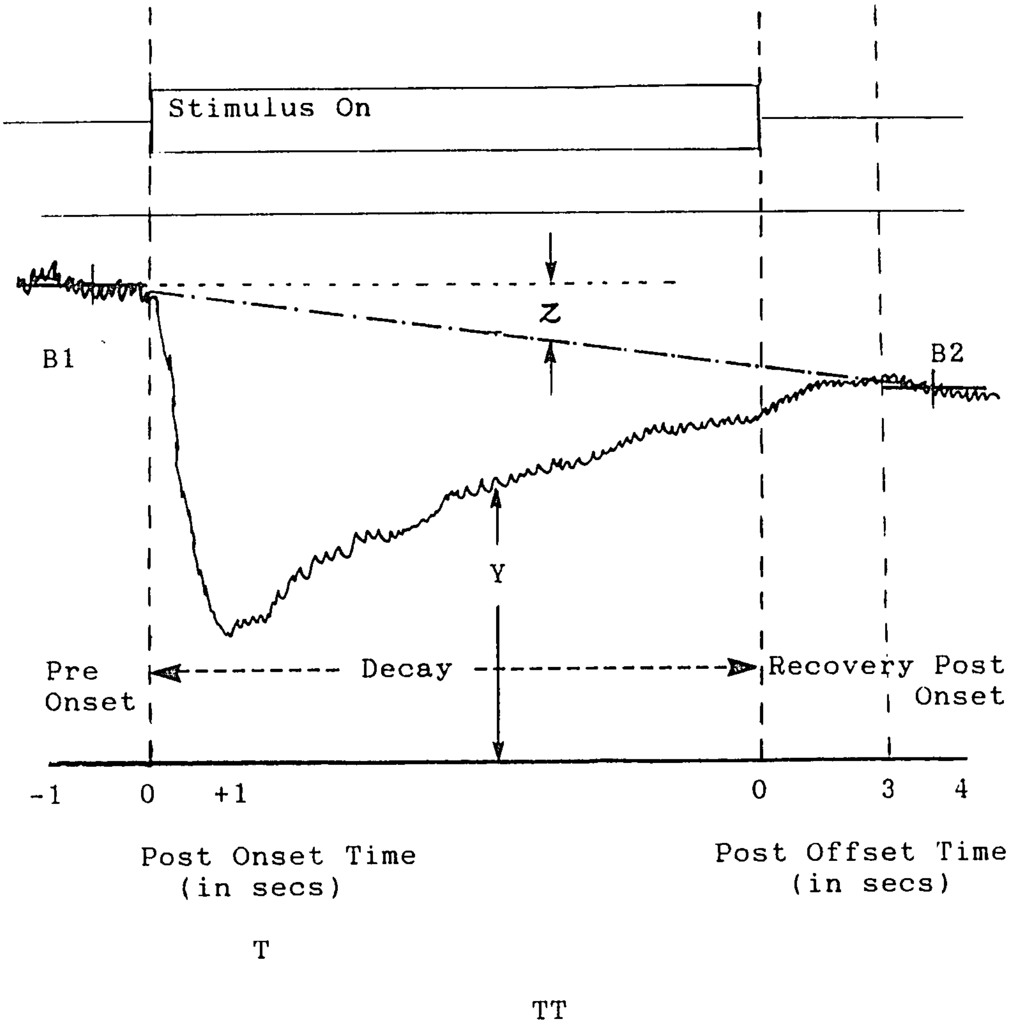
Phase IV consisted of a break in the sampling routine. The activator signal was switched off and sampling was discontinued for a 3 sec interval, which allowed for reflex recovery. The fifth and last phase was initiated after the 3 second break and lasted for 1000 msec (50 samples at 20 msec per sample). During this phase, the admittance was sampled in order to obtain post-stimulus baseline data.

Data were collected for each activator signal at the two intensity levels and stored on a floppy disk. A separate disk was used for each subject. If the subject moved or swallowed during the data collection period, or if the air-tight seal of the probe in the ear canal was interrupted, the data were discarded and the trial was repeated.

PROCESSING OF THE DATA

After collection and storage on diskette, the data were retrieved and processed in several ways before analyzing them statistically. Three features were built into a main software program for data pre-processing. These included (1) a procedure to correct for baseline shift, (2) a procedure to smooth the adaptation function, and (3) a procedure to print the data in both graphic and numeric form.

Procedure for Baseline Shift Correction. An idealized adaptation function is illustrated in Figure 7 to help describe the baseline shift correction procedure. The assumption is made that baseline shifts uniformly from the center of the pre-stimulus baseline level to the center of the post-stimulus baseline level (Wilson et al, 1978). The total time (TT) between these two points is given by the sum of 50% of the pre-stimulus sampling time (.5 secs), the reflex onset sampling time (1 secs), the reflex decay sampling time (500 secs for 500 Hz and broad band noise, 70 secs for 1000 Hz and 40 secs for 2000 Hz),



B1 = Average of 50 pre-stimulus baseline samples
B2 = Average of 50 post-stimulus baseline samples
Z = Amount of admittance shift from baseline
Y = Measured admittance change
T = Time since onset from middle of baseline 1 to middle of baseline 2
TT = Total time
Y+Z = Corrected Admittance Change

Figure 7: ILLUSTRATION OF BASELINE CORRECTION PROCEDURE

the reflex recovery time (3 secs) and 50% of the post-stimulus sampling time (.5 secs). The gradient of the baseline shift over time is given by:

$$G = (B1 - B2) / TT \tag{2}$$

Where, B1 and B2 are the average pre- and post-stimulus baseline readings and TT is the total time from the center of baseline 1 to the center of baseline 2. By interpolation, assuming a linear baseline shift (Wilson et al, 1978), the shift at time T (measured from the center of baseline) is:

$$Z = G \times T \tag{3}$$

Substituting from (2) gives:

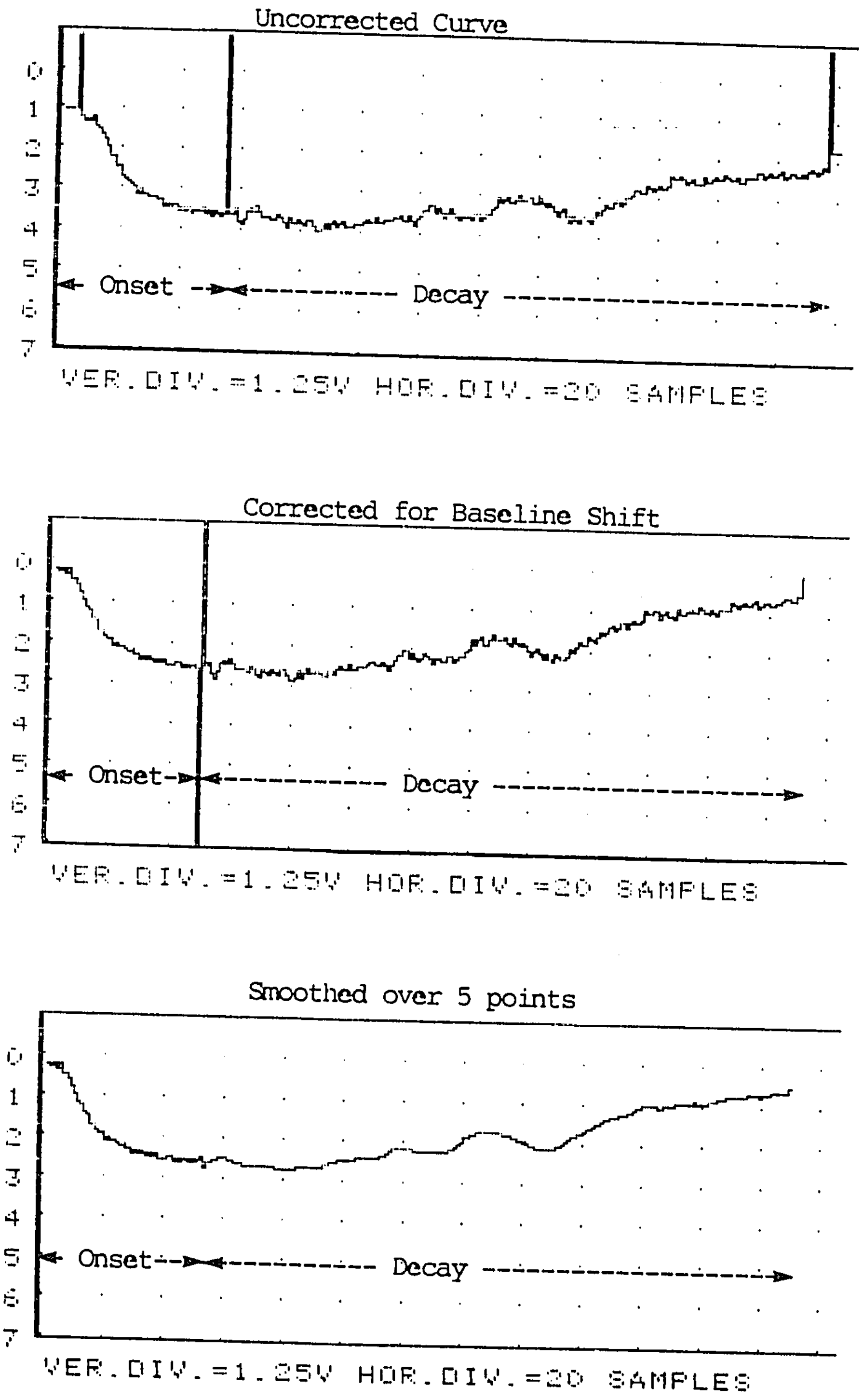
$$Z = (B1 - B2) / TT \times T \tag{4}$$

Equation (4) was used to calculate a correction factor for each admittance sample.

Procedure for Smoothing the Data. The reflex adaptation data beyond .96 seconds post stimulus time were smoothed to reduce the short-term variations in the reflex decay curve. Each point in the reflex decay array was replaced by the running average of 3 data points for 500 Hz, 1000

Hz, and BBN stimuli and by the running average of 5 data points for the 2000 Hz stimulus.The smoothing procedure was done for data included in the analysis on the magnitude of the reflex decay, presented in the next chapter.

Printing the Data. Another feature of the main software program allowed for the printing of the individual adaptation function. Figure 8 illustrates three typical examples of the graphic printout of an adaptation function of a young normal hearing subject for a 1000 Hz tonal activator presented at 10 dB above acoustic reflex threshold. The top graph illustrates the adaptation function before pre- processing. The middle graph illustrates the function after correation for baseline shift only. The bottom graph shows the function after baseline shift correction and smoothing.


Uncorrected Curve

Corrected for Baseline Shift

Smoothed over 5 points

Figure 8: Graphic Printouts of Adaptation Curves for a Young Normal Subject. Top Graph: Before Baseline Correction. Middle Graph: After Correction. Bottom Graph: After Correction and Smoothing.

Chapter 5.

RESULTS

This study was concerned with four major issues about acoustic reflex adaptation. These issues were (1) the effect of age on the rate of reflex adaptation, (2) the effect of presbycusic hearing loss on the rate of reflex adaptation, (3) the interaction between age or presbycusic hearing loss and stimulus type on the rate of reflex adaptation, and (4) the interaction between age or presbycusic hearing loss and sensation level on the rate of reflex adaptation. Related issues were the effects of age, hearing loss, and stimulus type on the acoustic reflex threshold and the effects of age, hearing loss, and sensation level on the magnitude of the reflex response over time.

The results of the study are presented in five separate sections. The first section presents acoustic reflex threshold results. The second section presents results on reflex magnitude changes during the first .96 seconds following stimulus onset while the third section presents results on reflex magnitude changes during the time period between .96 seconds post-stimulus and stimulus offset. The taxomony of the reflex adaptation curves is described in the fourth section. Finally, the fifth section presents time constants of the adaptation curves, derived from the least squares fit of the reflex decay data to an exponential function.

I. ACOUSTIC REFLEX THRESHOLD RESULTS

The means, standard deviations, standard errors and ranges of the acoustic reflex thresholds for the young normal hearing, old normal hearing and presbycusic groups are shown in Table 4 (Individual data can be found in Appendices D.1-D.3). An analysis of the variance in these data was performed and the effects of group (young normals, older normals, and presbycusics), stimulus (500 Hz, 1000 Hz, 2000 Hz and broad band noise) and their interactions were examined (Table 5).

The effect of group was not statistically significant at the .05 probability level. The lack of group effect indicates that neither the effect of age (young normal vs older normal) nor the effect of hearing loss (older normal vs presbycusic) were statistically significant.

The effect of stimulus, however, was highly significant ($F(3,99) = 45.32$, $p<.01$). The effect of

Table 4.

MEANS, STANDARD DEVIATIONS, AND RANGES OF THE YOUNG NORMAL, OLD NORMAL AND PRESBYCUSIC SUBJECTS' ACOUSTIC REFLEX THRESHOLDS.

Activator Stimulus	Group	Means (dB SPL)	S.D. (dB)	Ranges (dB SPL)
500 Hz	Young Normals	101.2	5.5	94-108
	Older Normals	104.2	4.0	96-110
	Presbycusics	102.5	5.4	90-110
1000 Hz	Young Normals	96.5	3.8	90-102
	Older Normals	96.7	6.4	84-104
	Presbycusics	97.0	3.7	90-104
2000 Hz	Young Normals	98.8	3.7	93-107
	Older Normals	101.0	6.4	91-113
	Presbycusics	99.4	7.0	89-108
BBN	Young Normals	87.9	4.9	80-98
	Old Normals	90.6	8.0	76-101
	Presbycusics	91.7	7.2	80-101

Table 5.

An Analysis of Variance with Repeated Measures in the Acoustic Reflex Threshold Data for the Three Experimental Groups. Reflex Stimuli included a 500 Hz, 1000 Hz and 2000 Hz pure tones and Broad-band Noise.

Source	Sum of Squares	df	Mean Square	F	Prob.
Group	105.39	2	52.69	.88	.42
Error	1979.69	33	59.99		
Stimulus	3132.91	3	1044.30	45.32	.00
St*G	69.94	6	11.66	.51	.80
Error	2281.40	99	23.04		

stimulus can be observed in Figure 9 which illustrates the mean acoustic reflex thresholds for each stimulus collapsed across groups. Post Hoc analysis using the Newman-Kuels procedure (Winer, 1971) revealed that the acoustic reflex threshold for broad-band noise was significantly lower than the reflex thresholds for the pure tone stimuli (500 Hz, 1000 Hz, and 2000 Hz) at the .01 probability level. Furthermore, post hoc analysis also showed that the reflex thresholds for 1000 Hz were significantly lower than the reflex thresholds for 500 Hz and for 2000 Hz, while the reflex thresholds for 2000 Hz was significantly lower than that for 500 Hz. The interaction between group and stimulus was not significant at the .05 probability level.

In summary, the acoustic reflex thresholds in this study were not significantly affected by age or hearing loss but were affected by the type of activator stimulus. In particular, the ART for broad-band noise was significantly lower than the ARTs for pure tone stimuli. For the tonal stimuli, the ART for 1000 Hz was the lowest while the ART for 2000 Hz was lower than for 500 Hz.

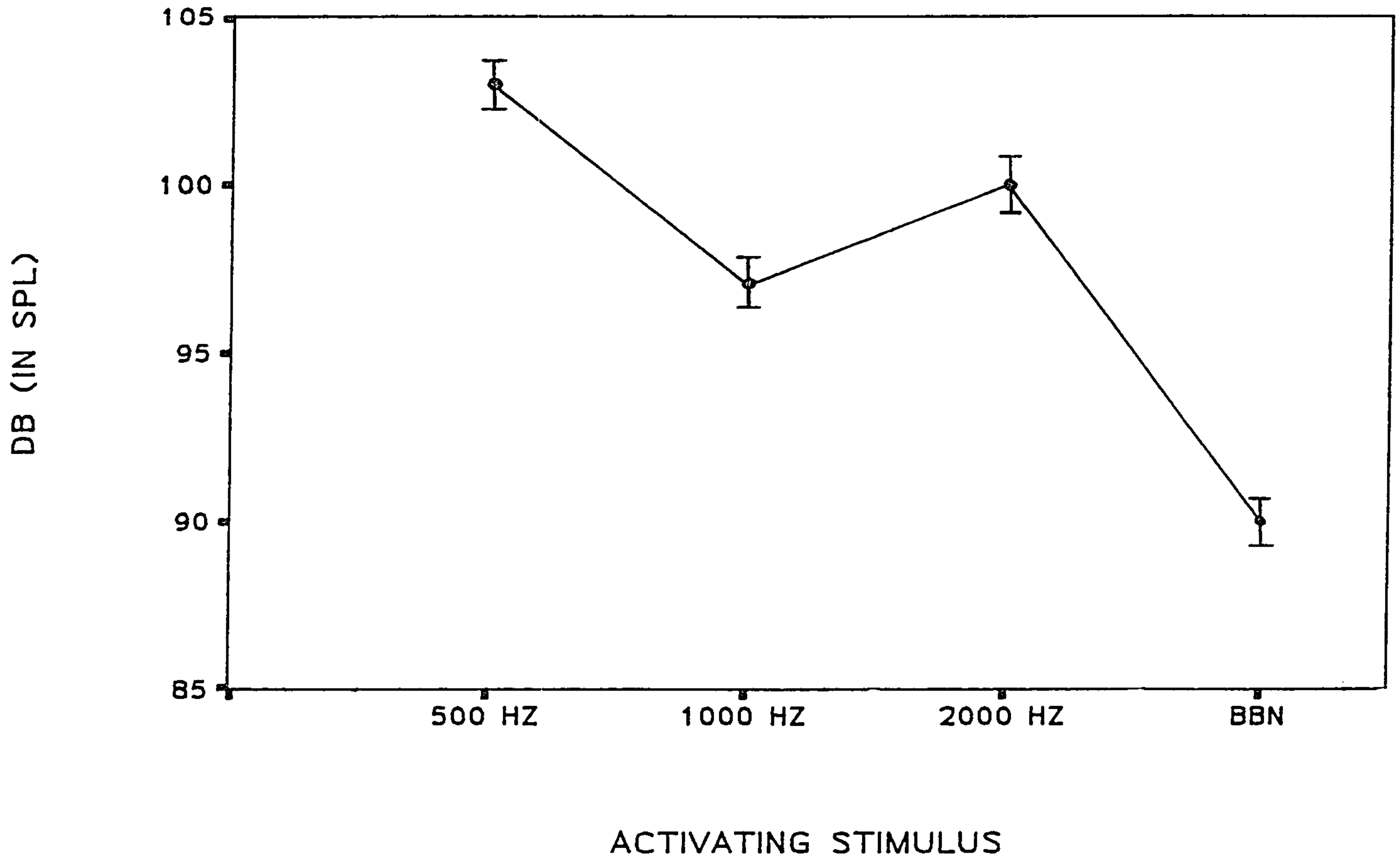


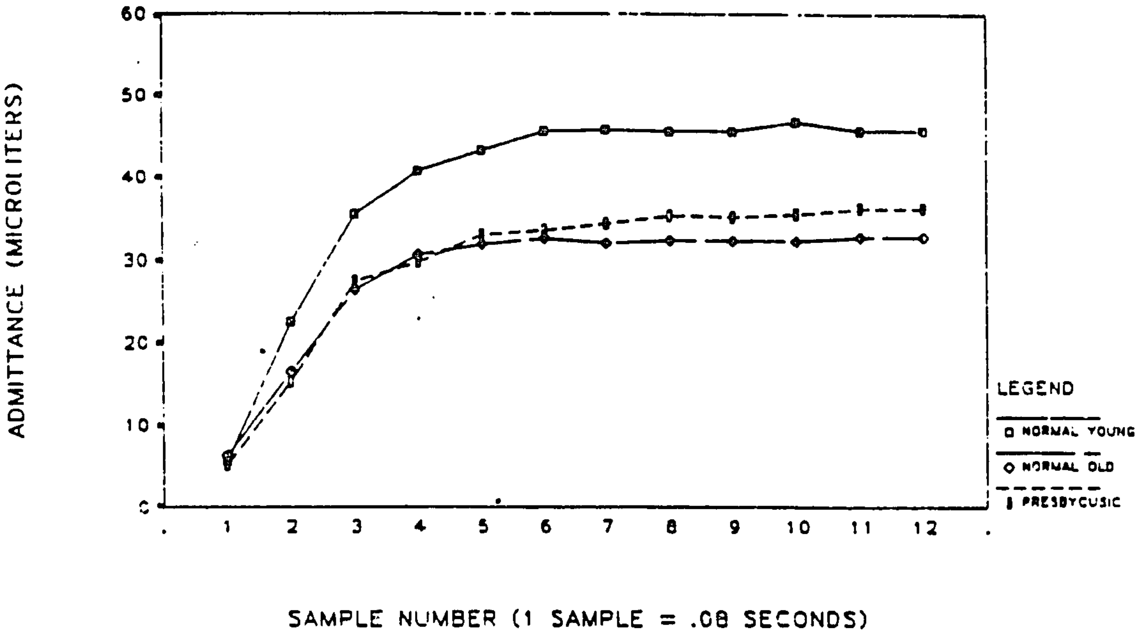
FIGURE 9: MEAN ACOUSTIC REFLEX THRESHOLDS COLLAPSED ACROSS GROUP FOR TONAL AND BROADBAND NOISE ACTIVATORS (STANDARD ERROR = +/− 1.8)

II. RESULTS OF THE REFLEX RESPONSE DURING THE REFLEX ONSET PERIOD

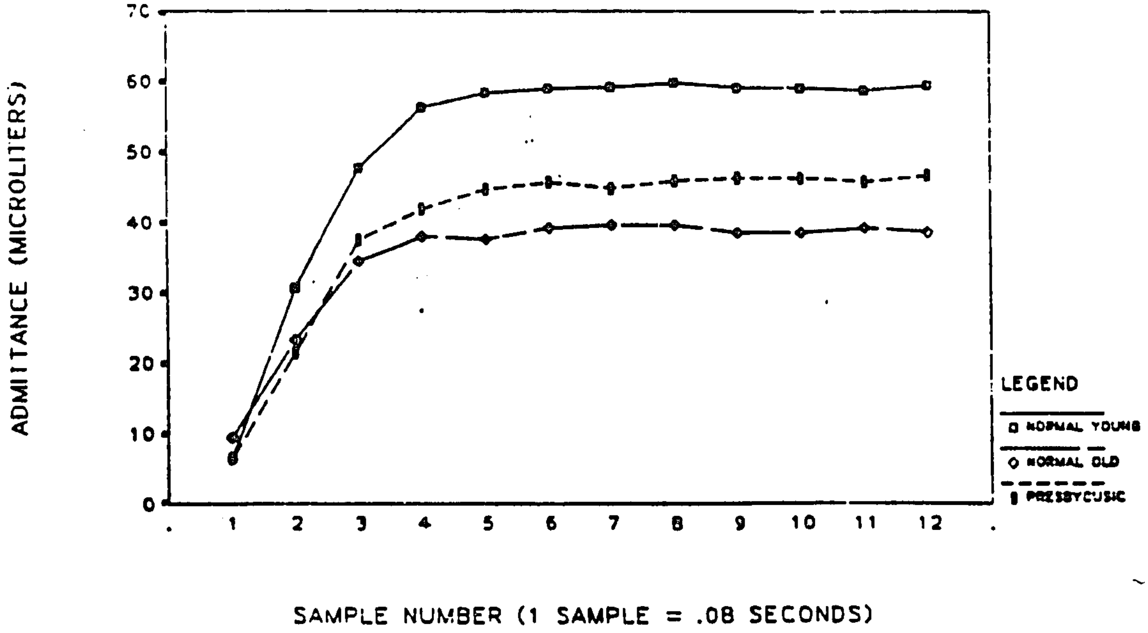
The effects of age, hearing loss, stimulus, and sensation level on the reflex magnitude during a 0-96 msec period following stimulus onset (reflex onset period) were examined as a related issue in this study. Before dealing with these effects, however, a description of the admittance change during the entire reflex onset period will be presented.

The individual admittance values (in digital units) as a function of time and sensation level during the entire reflex onset period are shown in Appendix E.1-E.4. (Recall from Figure 3 that a change of 176 digital units corresponds to a change in admittance of .01 mmhos or 10 microliters from pre-stimulus baseline). Group means at .08 sec intervals, converted into microliters, are shown in Appendices F.1-F.4 and illustrated in Figures 10-13. As can be seen in the figures, the mean admittance change for the three groups rapidly increased over time after stimulus onset, at least within the first .4 to .5 seconds, after which it reached a plateau.

An analysis of the variance in the peak reflex magnitude data was performed by using only the mean admittance for the time intervals of .72, .80, .88 and

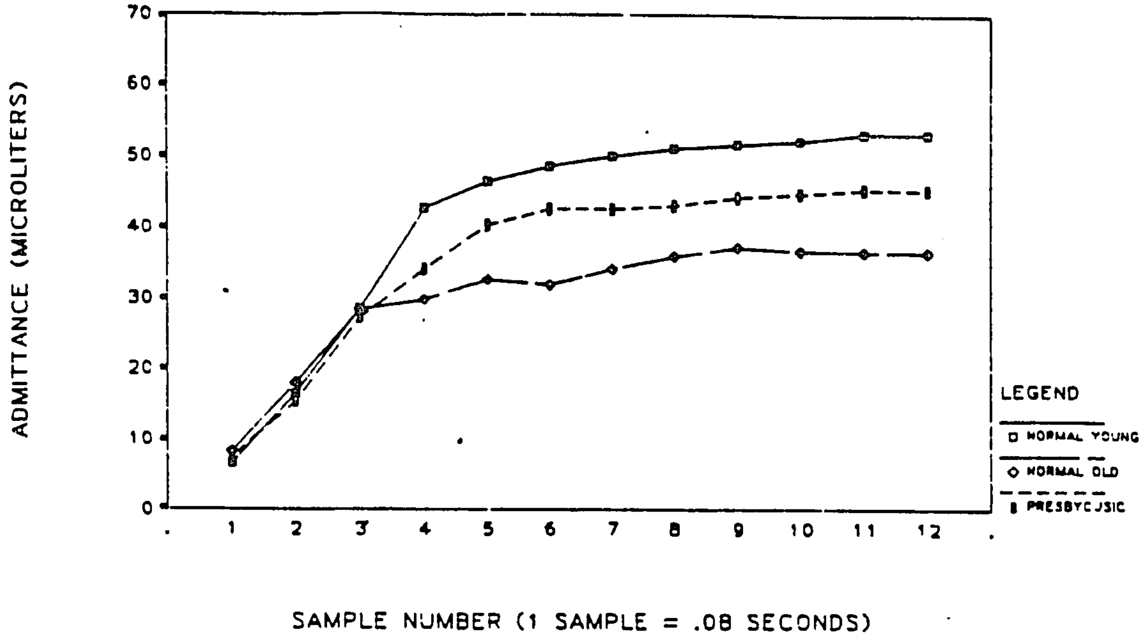


MEAN ADMITTANCE CHANGE DURING THE REFLEX ONSET PERIOD. ACTIVATOR WAS 500 HZ PRESENTED AT 10 DB ABOVE ACOUSTIC REFLEX THRESHOLD.

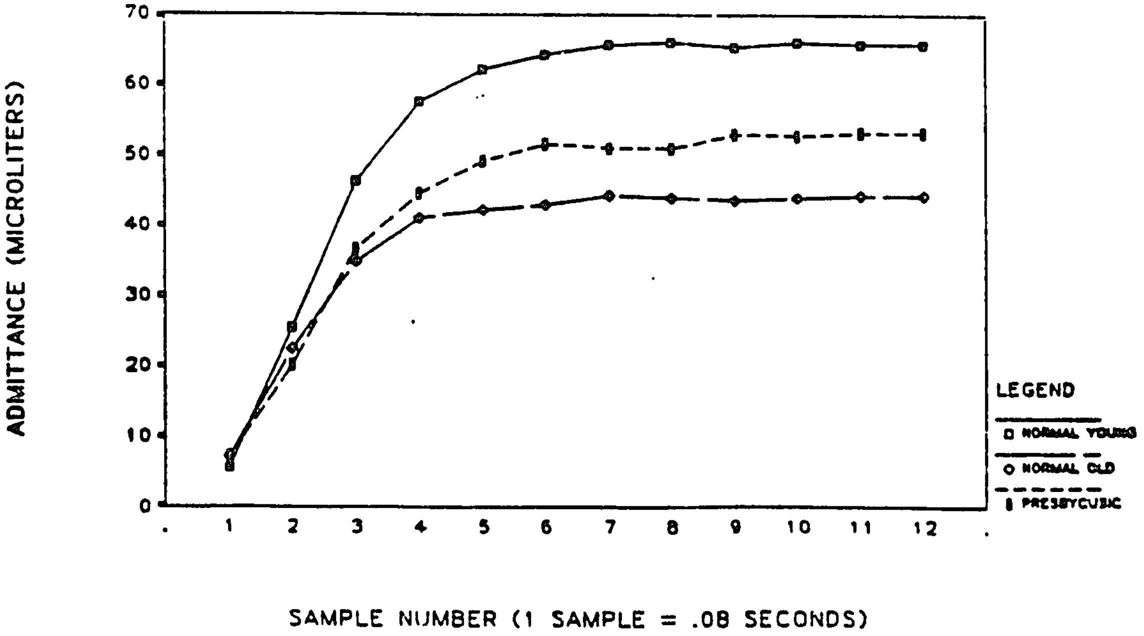


MEAN ADMITTANCE CHANGE DURING THE REFLEX ONSET PERIOD. ACTIVATOR WAS 500 HZ PRESENTED AT 15 DB ABOVE ACOUSTIC REFLEX THRESHOLD.

Figure 10.

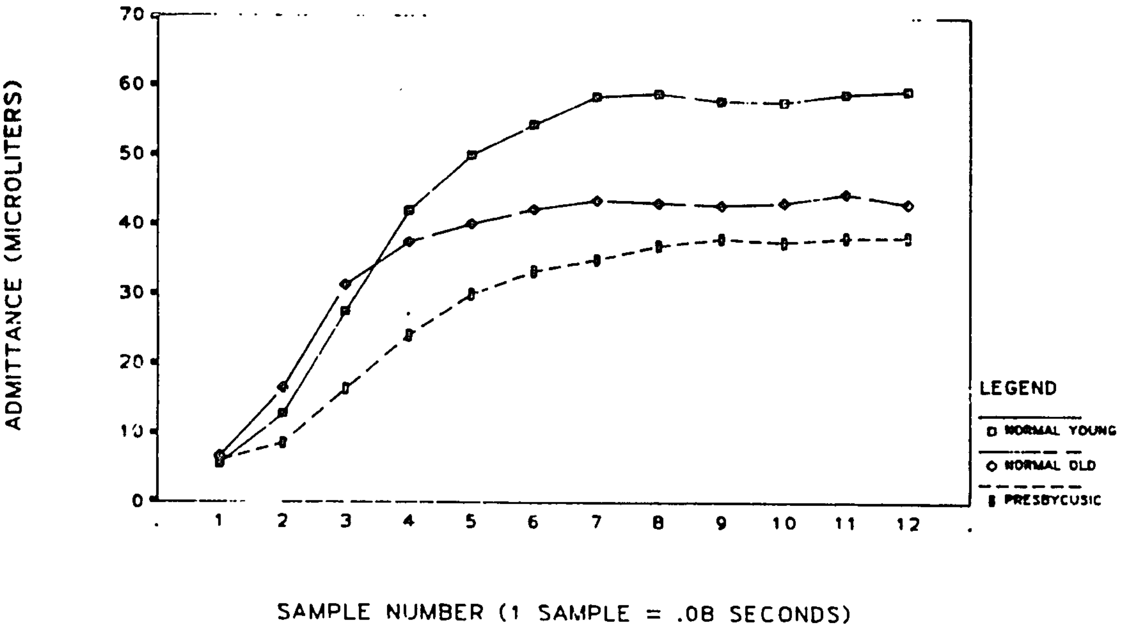


MEAN ADMITTANCE CHANGE DURING THE REFLEX ONSET PERIOD. ACTIVATOR WAS 1000 HZ PRESENTED AT 10 DB ABOVE ACOUSTIC REFLEX THRESHOLD.

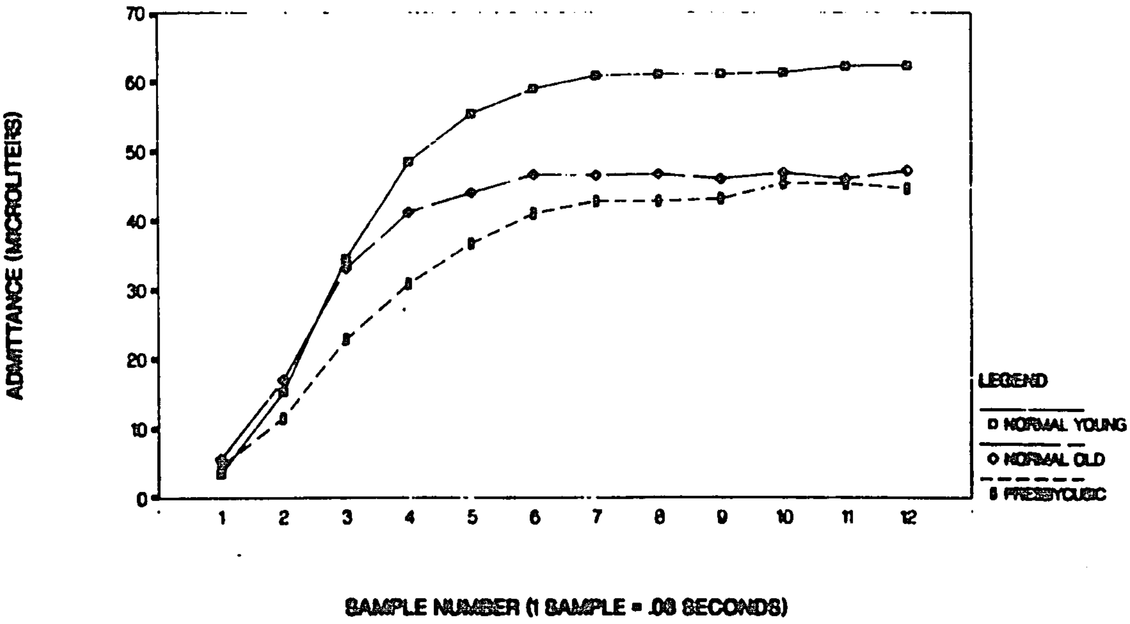


MEAN ADMITTANCE CHANGE DURING THE REFLEX ONSET PERIOD. ACTIVATOR WWAS 1000 HZ PRESENTED AT 15 DB ABOVE ACOUSTIC REFLEX THRESHOLD.

Figure 11.

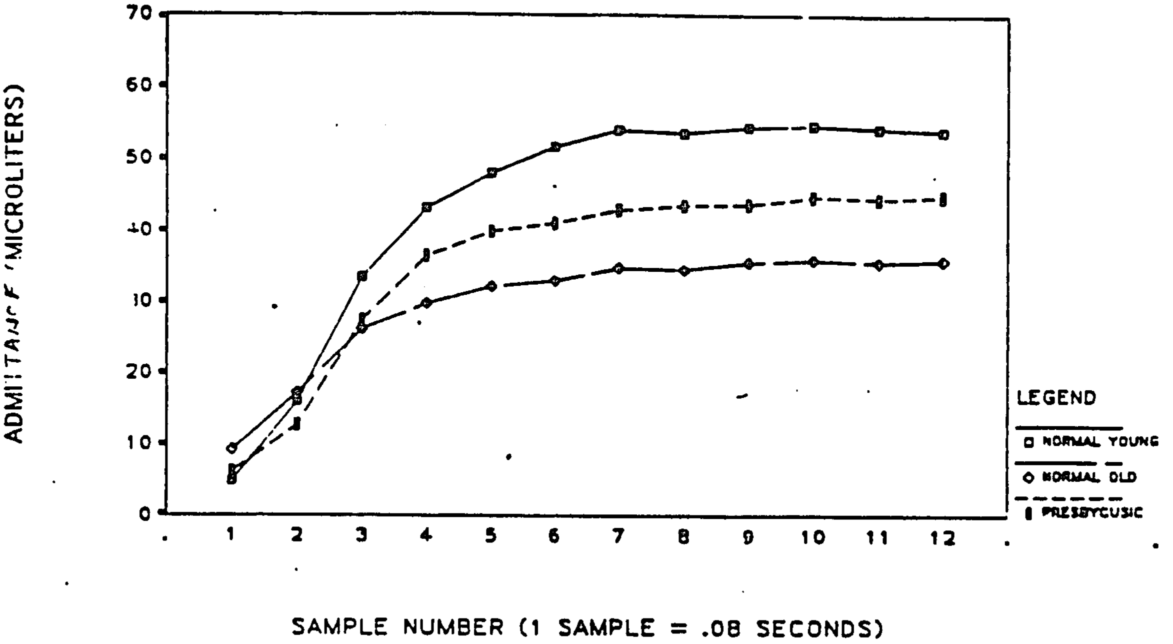


MEAN ADMITTANCE CHANGE DURING THE REFLEX ONSET PERIOD. ACTIVATOR WAS 2000 HZ PRESENTED AT 10 D DB ABOVE ACOUSTIC REFLEX THRESHOLD.

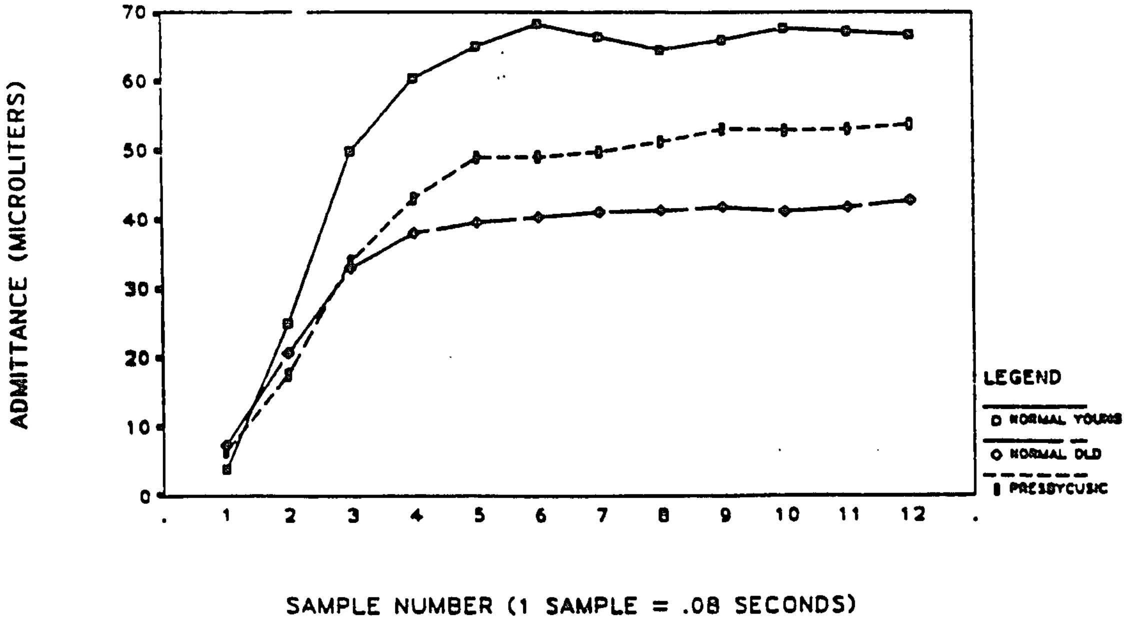


MEAN ADMITTANCE CHANGE DURING THE REFLEX ONSET PERIOD. ACTIVATOR WAS 2000 Hz PRESENTED AT 15 dB ABOVE ACOUSTIC REFLEX THRESHOLD.

Figure 12.



MEAN ADMITTANCE CHANGE DURING THE REFLEX ONSET PERIOD. ACTIVATOR WAS BROAD-BAND NOISE PRESENTED AT 10 DB ABOVE ACOUSTIC REFLEX THRESHOLD.



MEAN ADMITTANCE CHANGE DURING THE REFLEX ONSET PERIOD. ACTIVATOR WAS BROAD-BAND NOISE PRESENTED AT 15 DB ABOVE ACOUSTIC REFLEX THRESHOLD.

Figure 13.

.96 seconds. This represented the later portion of the reflex onset period, or the time over which the plateau in the response was noted. Results are shown in Table 6. Data from 33 subjects (11 subjects per group) were included in the analysis (One subject from each group needed to be excluded due to the lack of data at one of the eight stimulus conditions).

The effect of group was not statistically significant at the .05 probability level. The absence of a group effect indicated that neither the effect of age (young normals vs. older normals) nor the effect of hearing loss (older normals vs. presbycusics) had a significant effect on peak magnitude. There were also no significant interactions between group and the other variables of stimulus and sensation level.

There was a significant effect of sensation level ($F(1,30) = 42.93$, $p<.01$). In addition, there was a significant interaction between sensation level and stimulus ($F(3,90) = 4.40$, $p<.01$). Figure 14 illustrates the admittance values for the 10 dB and 15 dB sensation levels for each stimulus collapsed across group. It can be seen that for 500 Hz, 1000 Hz, and BBN, there is a difference of approximately 9-10 microliters in

Table 6.

Analysis of Variance with Repeated Measures of Admittance Data during the Later Portion of the Reflex Onset Period (.72-.96 sec). Admittance Data were Collapsed across Time for Each Subject and Stimulus Condition. Stimuli included 500 Hz, 1000 Hz, 2000 Hz and Broad Band Noise at 10 dB and 15 dB above Acoustic Reflex Threshold.

Source	Sum of Squares	df	Mean Square	F	Prob.
Group	5597059.84	2	2798529.92	2.18	.13
Error	38532272.41	30	1284409.08		
Stimulus	687959.45	3	229319.82	4.52	.01
Stimulus x Group	333961.73	6	55660.29	1.10	.37
Error	4564691.02	90	50718.79		
S Level	1241062.09	1	1241062.09	42.93	.00
SL x Group	117995.88	2	58997.94	2.04	.15
Error	867317.82	30	28910.59		
Stim. x SL	109724.72	3	36574.91	4.40	.01
StxSLxG	52299.32	6	8716.55	1.05	.40
Error	748668.34	90	8318.54		

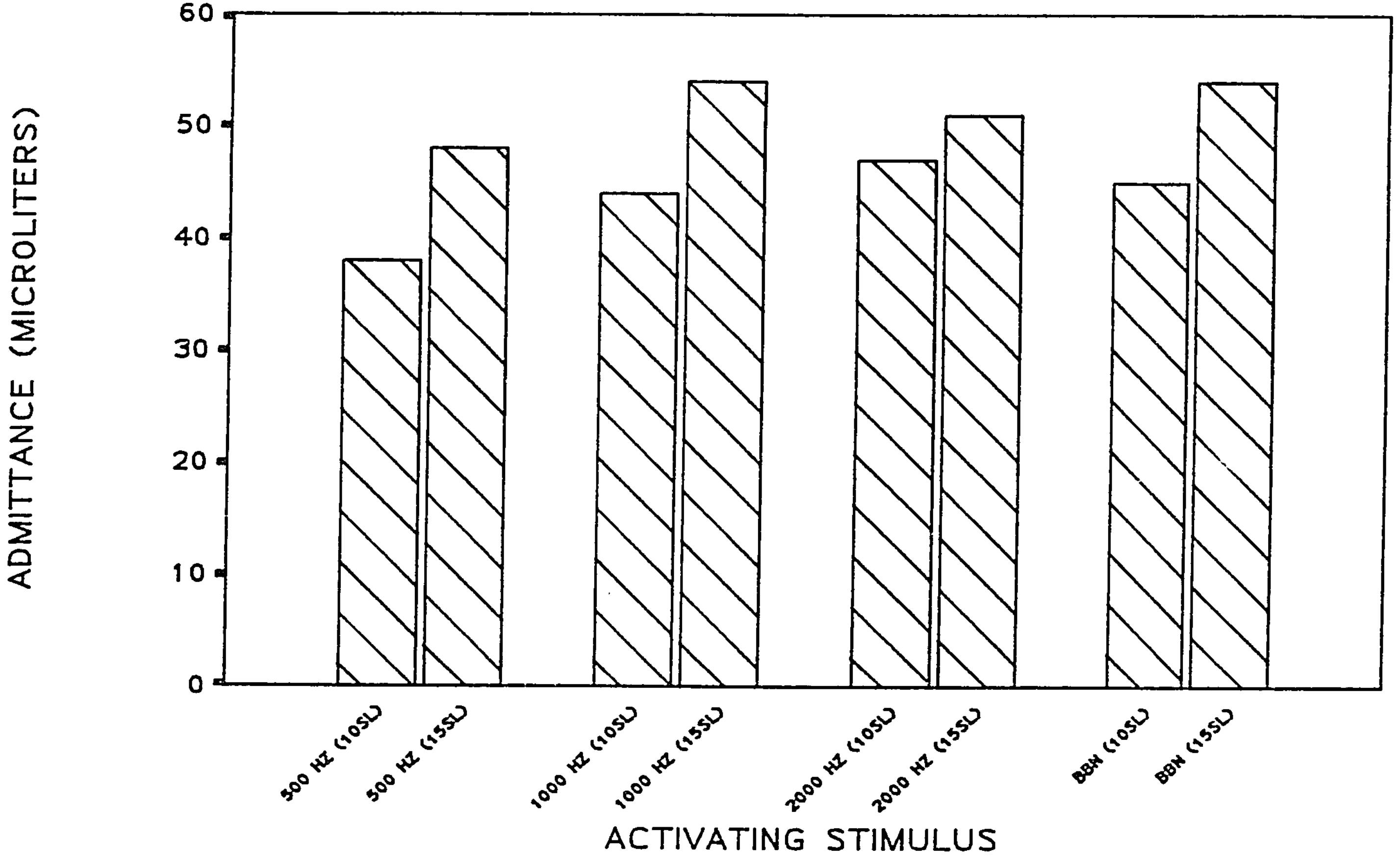


FIGURE 14: MEAN ADMITTANCE DURING REFLEX ONSET COLLAPSED ACROSS GROUP FOR TONAL AND NOISE ACTIVATORS

admittance between the 10 dB and 15 dB condition. For 2000 Hz, the difference is only 4 microliters.

There was a significant effect of stimulus at the .05 probability level (F(3,90) = 4.52). Post Hoc analysis using the Newman-Kuels procedure indicated that the magnitude during the later portion of the onset period"was significantly lower for 500 Hz than for broad-band noise.

In summary, the magnitude of reflex admittance change at the end of the reflex onset period was not significantly affected by age or hearing loss, but was affected by stimulus type and sensation level. Specifically, the reflex magnitude for 500 Hz was significantly lower than for the broad band noise. Sensation level effects were evident for 500 Hz, 1000 Hz, and BBN and to a lesser extent for 2000 Hz.

III. REFLEX RESULTS DURING THE REFLEX DECAY PERIOD

In the early stages of this experiment it was thought that a half life could be used as an estimate of the rate of reflex adaptation. Recall that the half life is the time taken for the admittance change to decay to 50% of its maximum value. The half-life measures would then have been examined in an analysis of variance for evidence of main effects of group and their interactions. In fact, many subjects showed little or no decay during the stimulation time used here, and therefore did not provide a half life measure. Two approaches were adopted to deal with this problem. The first, which will be described in this section uses the values of reflex magnitude measured at equally spaced sampling points during the decay period. The second approach, involving an estimation of decay rate for each subject will be described in section V.

The admittance values at .96 seconds and at every sixteenth sample thereafter (14 samples out of a total of 200) were used in the analyses of variance to determine the effects of group, sensation level, time and their interactions for the reflex decay period. Four separate analyses were done, one for each stimulus.

The individual admittance values (in digital units) for 500 Hz as a function of time and sensation level are listed in Appendix G.1. Group means, converted into microliters, at 8 second intervals, are listed in Appendix G.2 and illustrated in Figures 15 and 16. The analysis of variance in these data is presented in Table 7.

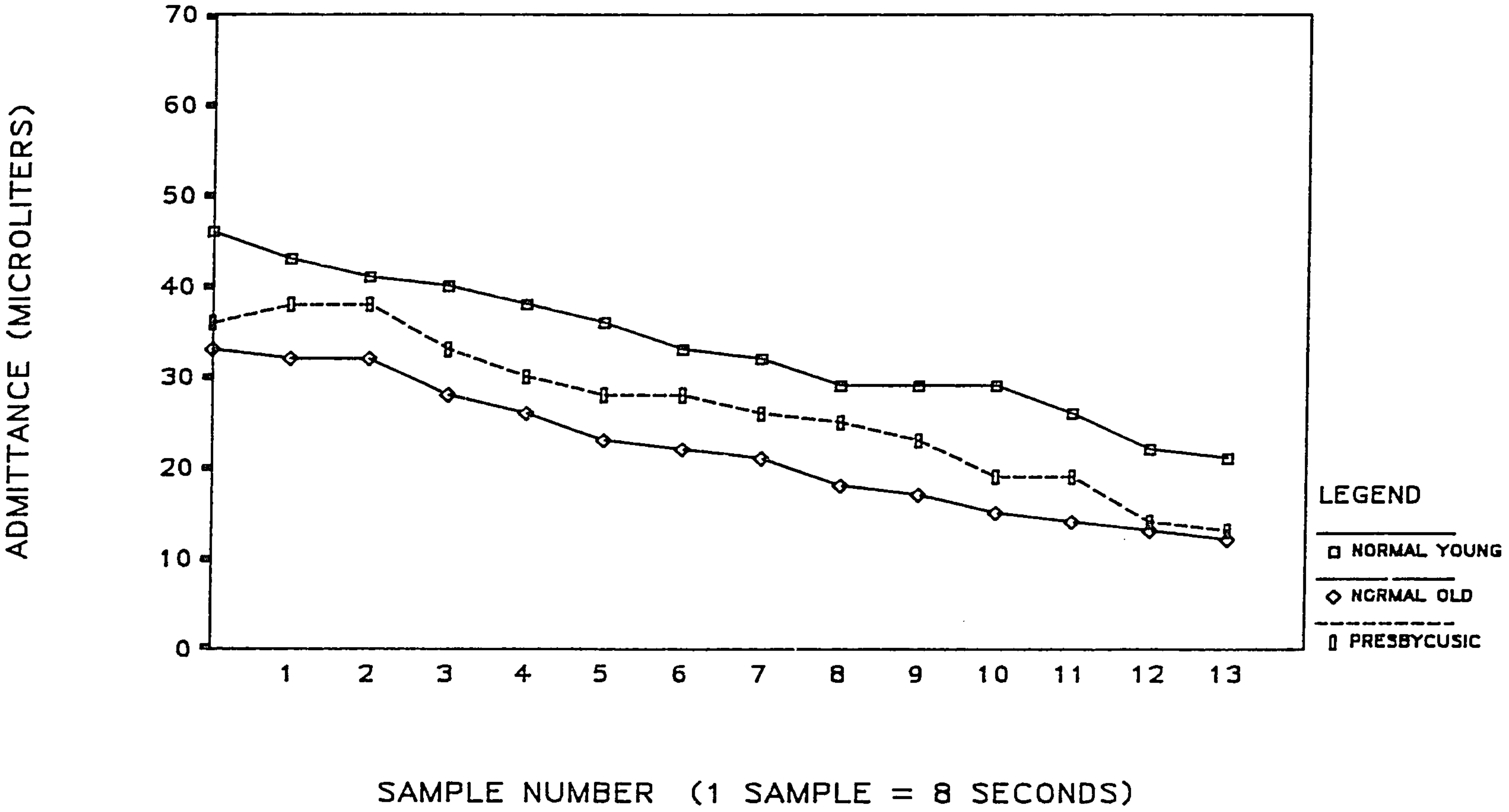


FIGURE 15: MEAN ADMITTANCE CHANGE DURING THE REFLEX DECAY PERIOD. ACTIVATOR WAS 500 HZ PRESENTED AT 10 DB ABOVE ACOUSTIC REFLEX THRESHOLD

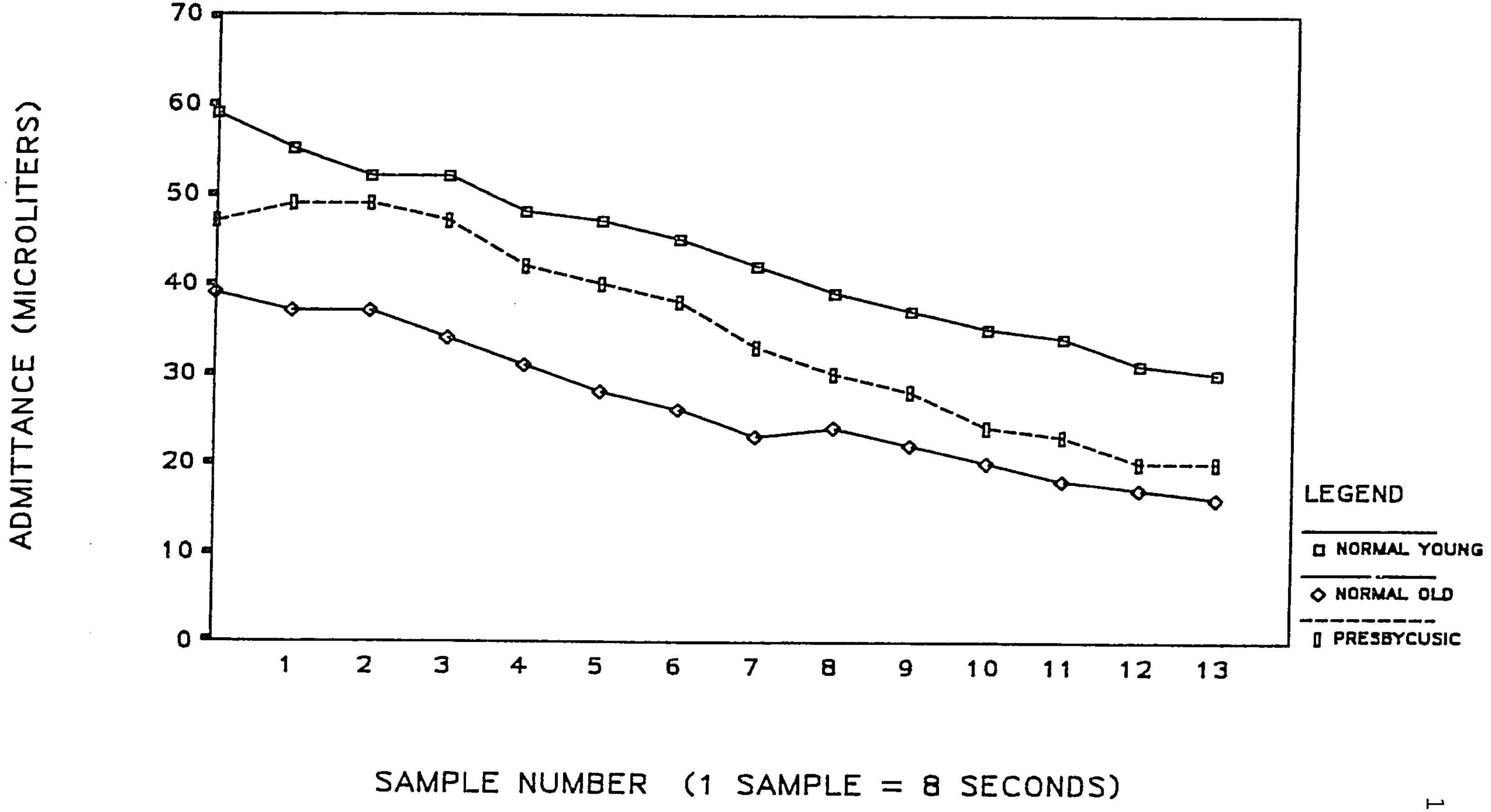


FIGURE 16: MEAN ADMITTANCE CHANGE DURING THE REFLEX DECAY PERIOD. ACTIVATOR WAS 500 HZ PRESENTED AT 15 DB ABOVE ACOUSTIC REFLEX THRESHOLD

Table 7.

Analysis of Variance with Repeated Measures of Admittance Data for 14 Time Intervals (.96 to 100.5 sec) during the Reflex Decay Period. Reflex Activator was 500 Hz presented at 10 dB and 15 dB above Acoustic Reflex Threshold.

Source	Sum of Squares	d.f.	Mean Square	F	Prob.
Group	9728383.38	2	4864191.69	3.77	.03
Error	41278848.72	32	1289964.02		
SL	4587860.46	1	4587860.46	31.98	0.00
SL x Group	424746.34	2	212373.17	1.48	0.24
Error	4509557.88	32	143454.93		
Time	20447431.78	13	1572879.37	39.84	0.00
Time x Group	395621.90	26	15216.23	0.39	0.99
Error	16421970.94	416	39475.89		
SL x T	236234.30	13	18171.87	4.72	0.00
SLxTxG	172430.90	26	6631.96	1.72	0.16
Error	1600180.39	416	3846.59		

There was a significant main effect of group (F(232) = 3.77, p =.03). This effect can be see in Figure 17 which illustrates the admittance data for the three groups, collapsed across sensation level. From this figure, there is noted a difference between the young normal and older normal group and between the older normal and presbycusic group. The interaction between group and sensation level, group and time, and the three way interaction between group, time, and sensation level failed to reach significance at the .05 probability nevel. The absence of a signficant group-time interaction indicates that there were no age or hearing loss effects on the rate of reflex adaptation for the 500 Hz activating stimulus.

There was a significant main effect of sensation level (F(1,32) = 31.98, p=.00). The analysis of variance shows a significant two-way interaction between sensation level and time (F(13,416) = 4.72, p= .00). The reason for this finding can best be seen in Figure 18, which illustrates the decay data collapsed across group, as a function of sensation level (10 and 15 dB) and time. It can be observed that with increased time, the effect of sensation level becomes smaller.

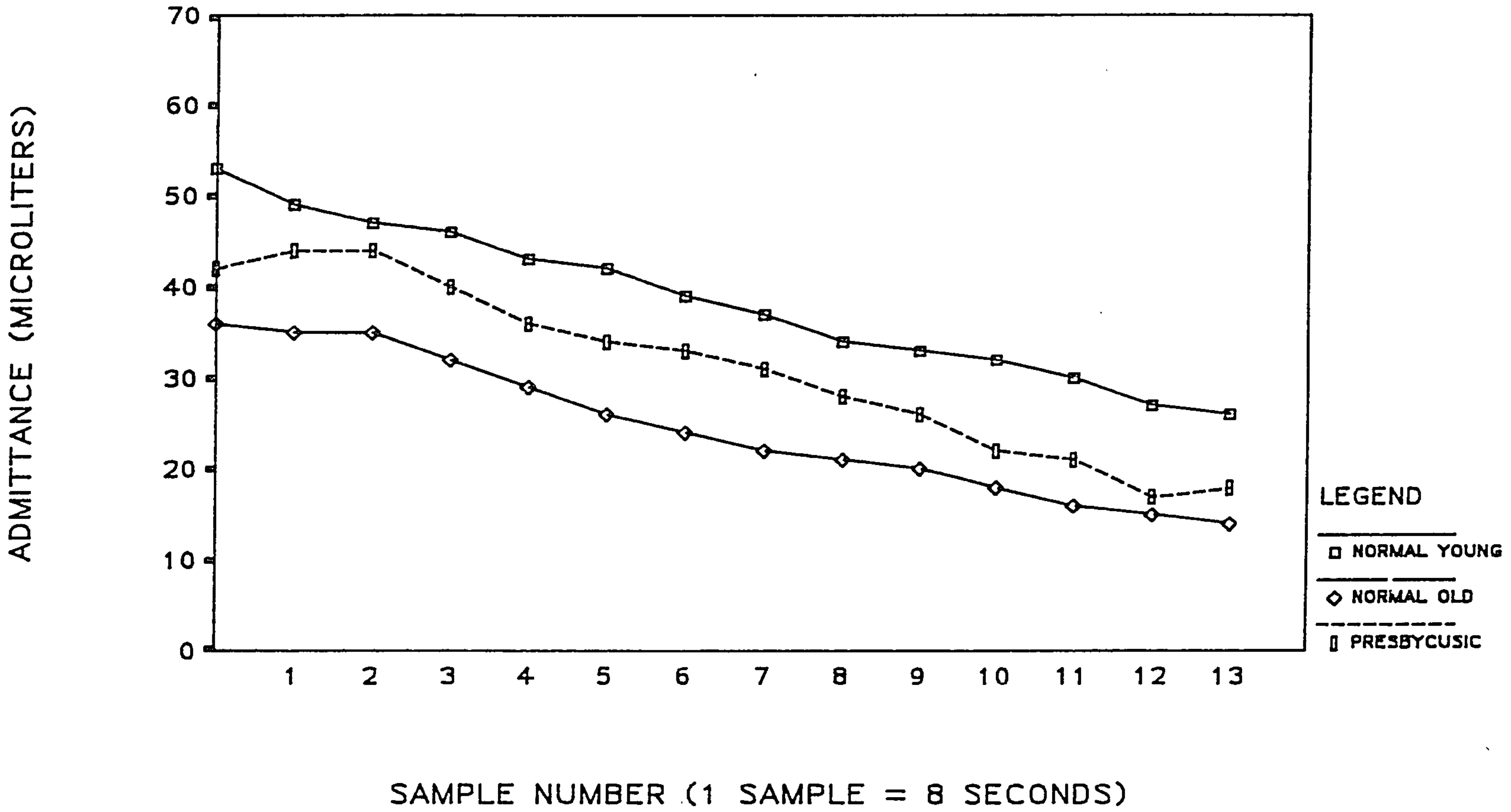


FIGURE 17: MEAN ADMITTANCE CHANGE DURING DECAY COLLAPSED ACROSS SENSATION LEVEL. ACTIVATOR WAS 500 HZ

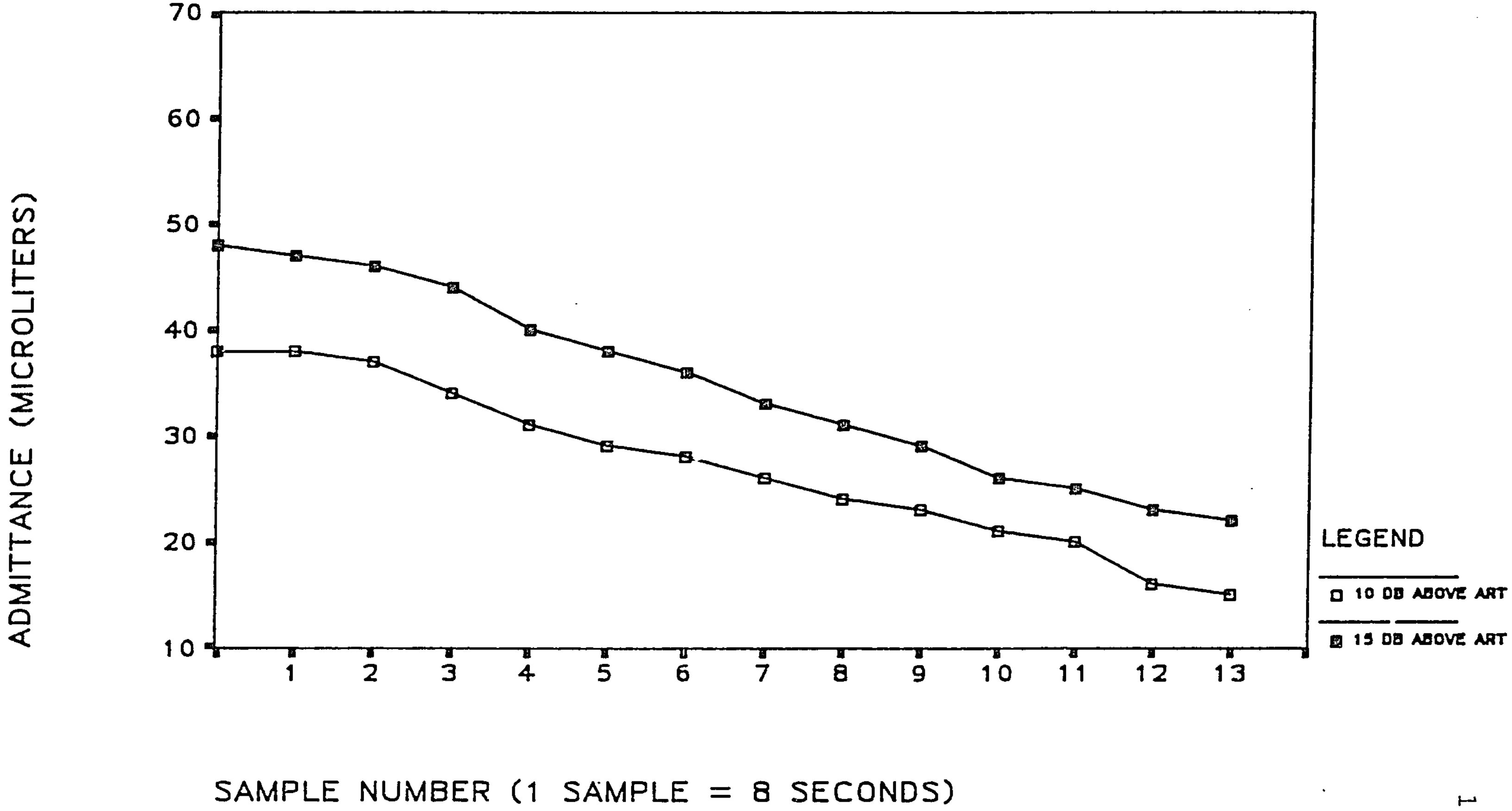


FIGURE 18: MEAN ADMITTANCE CHANGE DURING DECAY COLLAPSED ACROSS GROUP. ACTIVATOR WAS 500 HZ PRESENTED AT 10 AND 15 DB RE ART.

Appendix G.3 lists the individual admittance values, in digital units, for 1000 Hz as a function of sensation level and time. The group means, converted into microliters, at 5.6 second intervals ape shown in Appendix G.4 and illustrated in Figures 19 anf 20. An analysis of variance, shown in Table 8, was done to determine the effects of group (age and hearing loss), sensation level, time and their interactions.

The main effect of group was not significant $(p>.05)$ and there was no significant interaction between group and sensation level, group and time, and group, sensation level and time. The lack of group effects indicates that there were no significant age or hearing loss effects on the magnitude of the reflex response during the decay period for 1000 Hz. More importantly, the lack of a significant group-time interaction indicates that age and hearing loss do not affect the rate of reflex adaptation for the 1000 Hz activator.

It can be seen in Table 8 that there was a significant effect of sensation level $(F(1,33) = 28.96, p<.01)$. Again, the effect of sensation level reflects the higher admittance values for the 15 dB condition compared to the 10 dB condition, as noted in the reflex onset data analysis. There was also a significant

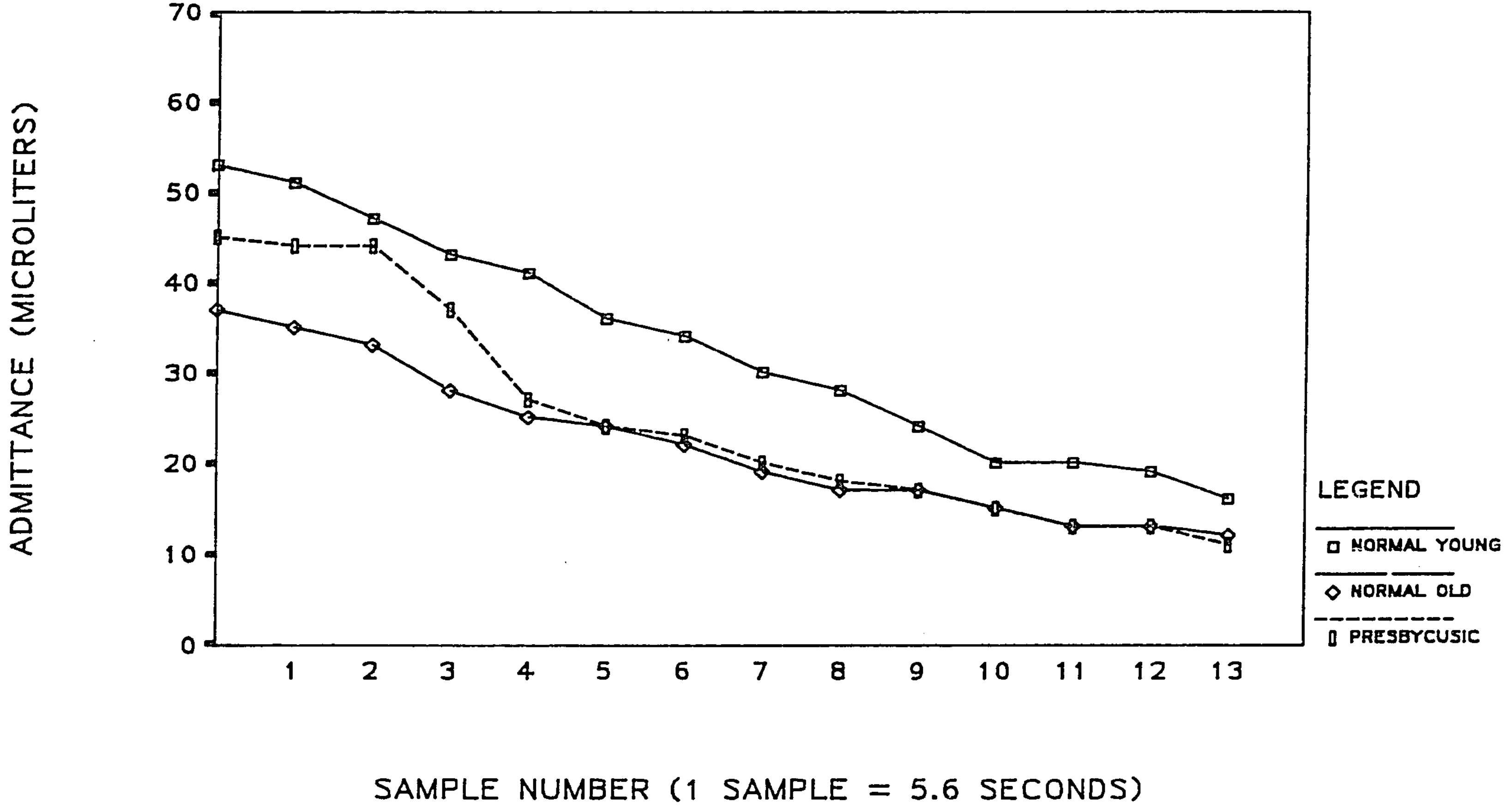


FIGURE 19. MEAN ADMITTANCE CHANGE DURING THE DECAY PERIOD. ACTIVATOR WAS 1000 HZ PRESENTED AT 10 DB ABOVE REFLEX THRESHOLD

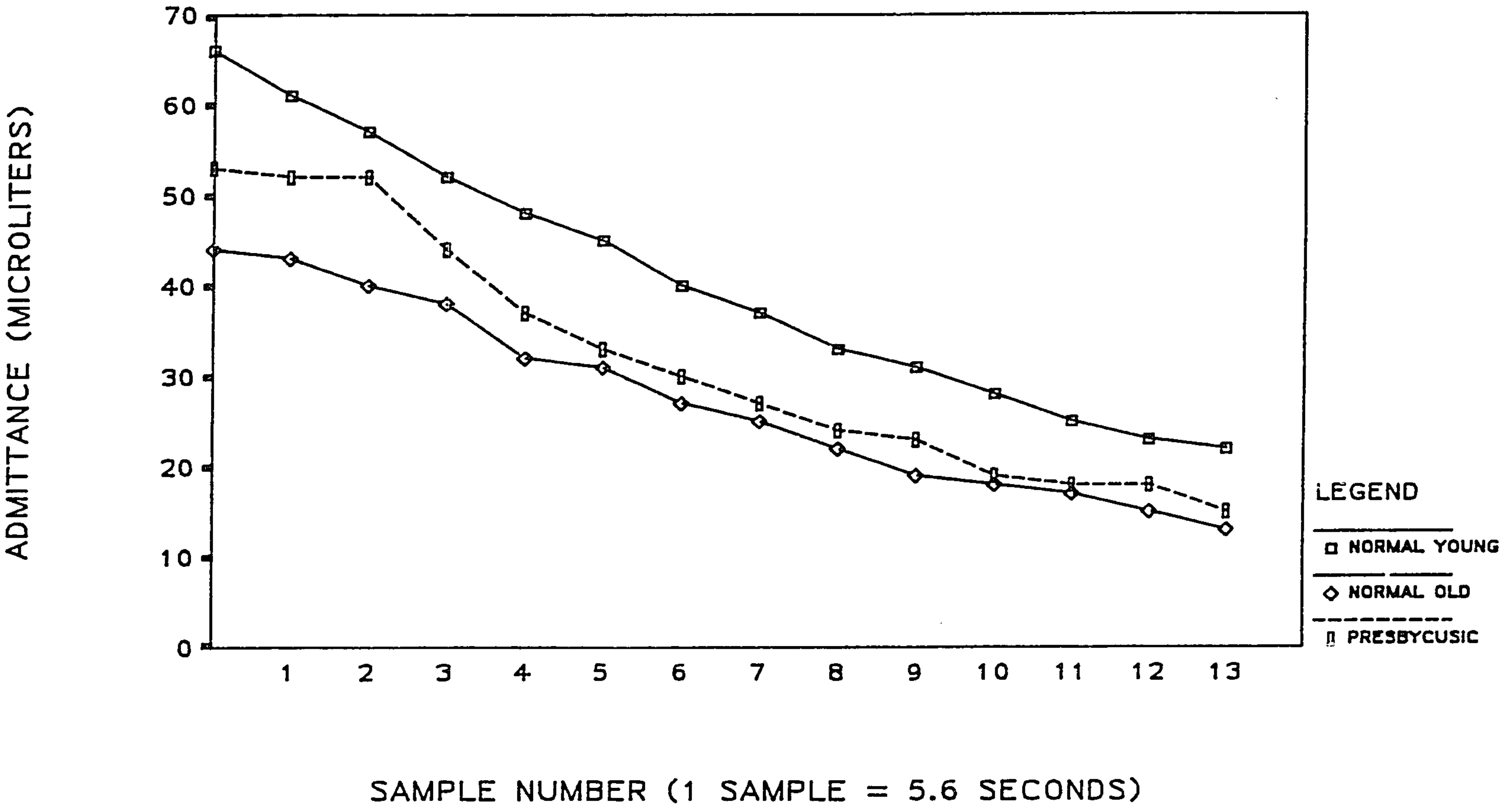


FIGURE 20: MEAN ADMITTANCE CHANGE DURING THE DECAY PERIOD.
ACTIVATOR WAS 1000 HZ PRESENTED AT 15 DB ABOVE REFLEX THRESHOLD

Table 8.

Analysis of Variance with Repeated Measures of Admittance Data for 14 Time Intervals (.96 sec to 70.8 sec) during the Reflex Decay Period. Reflex Activator was 1000 Hz presented at 10 dB and 15 dB above Acoustic Reflex Threshold.

Source	Sum of Squares	d.f.	Mean Squares	F	Prob.
Group	7869142.73	2	3934571.37	2.49	.10
Error	52239849.38	33	1583025.74		
SL	3308593.75	1	3308593.75	28.96	.00
SL/G	69418.34	2	34709.17	0.30	.74
Error	3770324.63	33	114252.2		
Time	41329341.77	13	3179180.14	59.47	.00
T/G	1130854.38	26	43494.40	0.81	.73
Error	22932739.70	429	53456.27		
SL/T	287074.06	13	22082.62	4.94	.00
SL/T/G	86174.94	26	3314.42	.74	.82
Error	1916588.29	429	4467.57		

interaction between sensation level and time (F(13,429 = 4.94, p<.01). The interaction can be seen in Figure 21, which illustrates the decay data for the two sensation levels over time after the data were collapsed across group. By inspection of the figure, it can be observed that the effect of sensation level decreases as time increases, as with the 500 Hz data.

Appendix G.5 lists the individual admittance values for 2000 Hz. The same data at 3.2 second intervals expressed in group means and converted into microliters are shown in Appendix G.6 and illustrated in Figures 22 and 23. The analysis of variance is shown in Table 9.

As can be seen in Table 9, the main effect of group failed to reach significance at the .05 probability level. There is, however, a significant group-time interaction (F(26,403) = 1,70, p<.01). This interaction can be seen in Figure 24 which illustrates the mean admittance over time for the three groups, collapsed across sensation level. By inspection of this figure, one can see a clear difference between the groups, at least at the start of the reflex decay period. Specifically, at the beginning of the reflex decay period (.96 and 2.7 seconds), the young normal hearing subjects show the highest mean admittance values, followed by

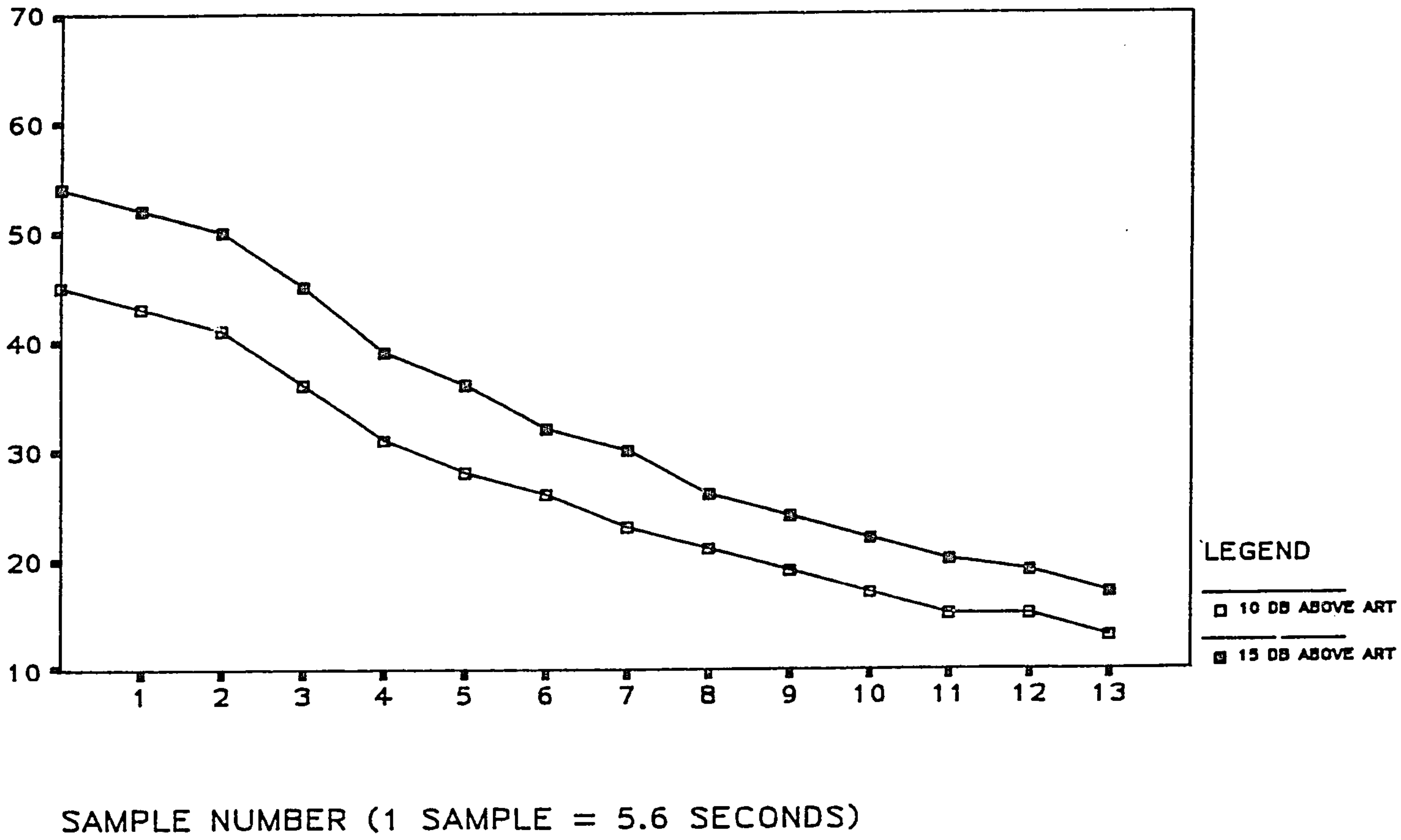


FIGURE 21: MEAN ADMITTANCE CHANGE COLLAPSED ACROSS GROUP. ACTIVATOR WAS 1000 HZ PRESENTED AT 10 DB AND 15 DB RE: ART

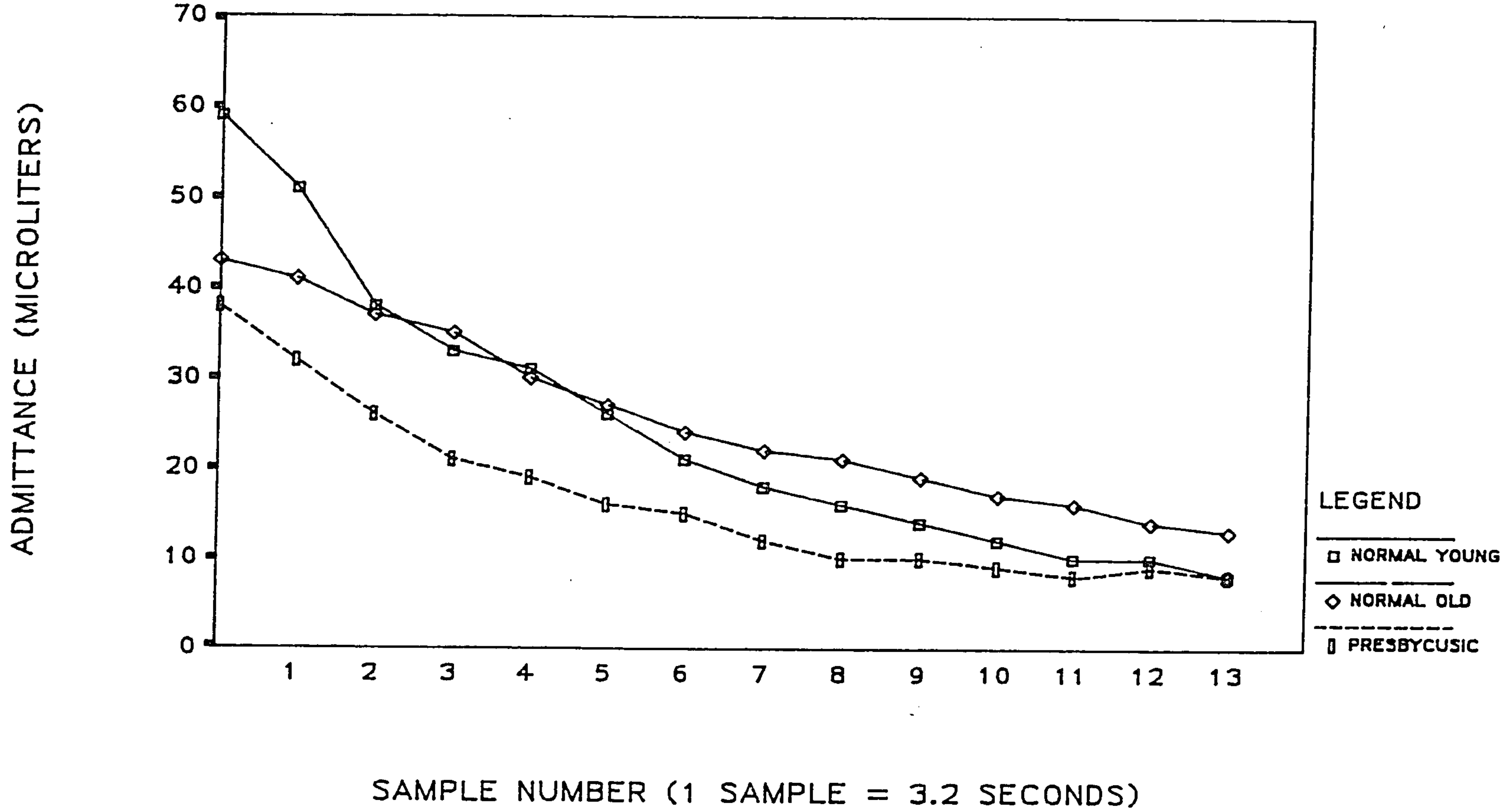


FIGURE 22: MEAN ADMITTANCE CHANGE DURING THE REFLEX DECAY PERIOD. ACTIVATOR WAS 2000 HZ PRESENTED AT 10 DB ABOVE REFLEX THRESHOLD.

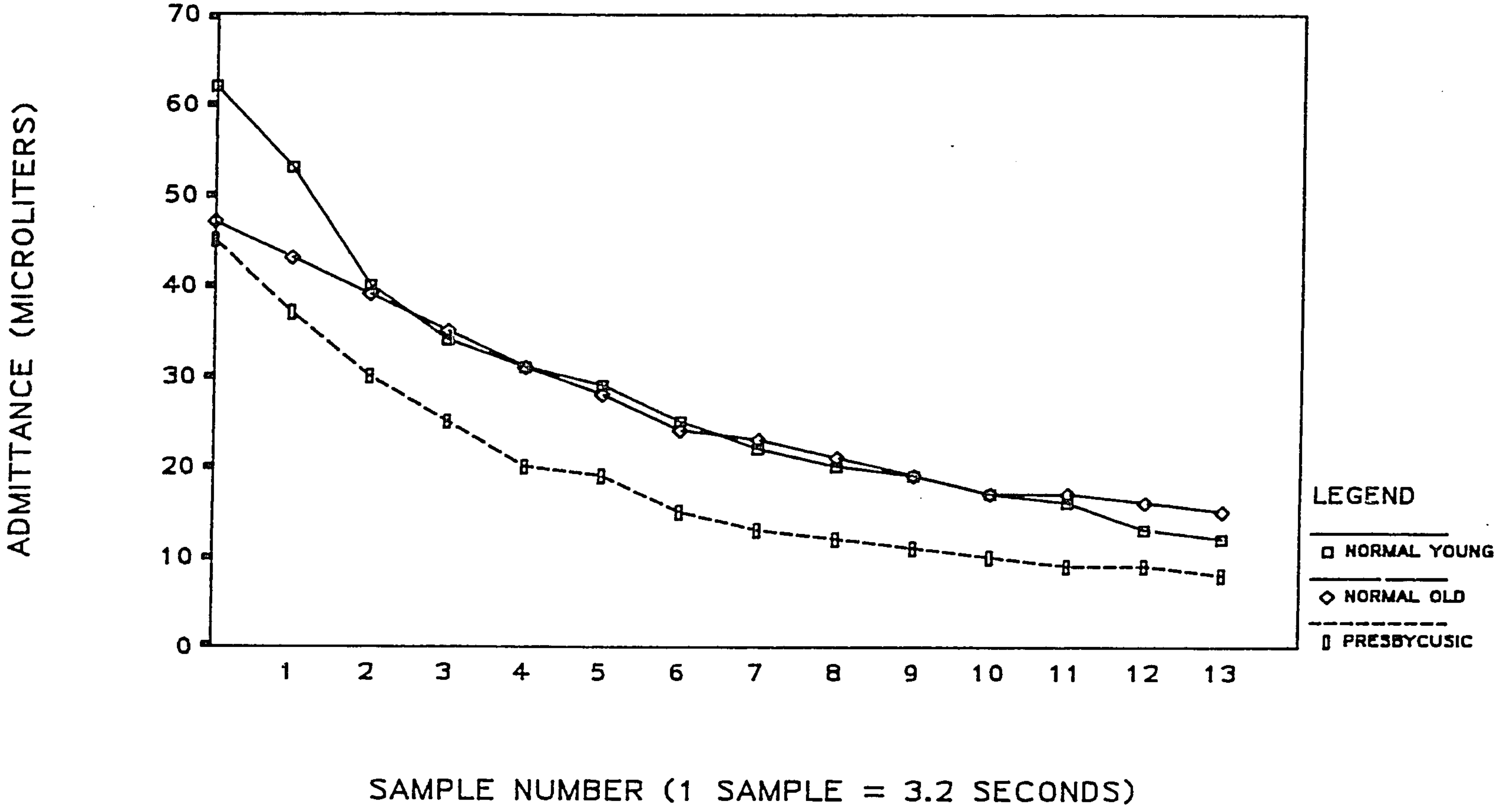


FIGURE 23: MEAN ADMITTANCE CHANGE DURING THE REFLEX DECAY PERIOD. ACTIVATOR WAS 2000 HZ PRESENTED AT 15 DB ABOVE ACOUSTIC REFLEX THRESHOLD

Table 9.

Analysis of Variance with Repeated Measures of Admittance Data for 14 Time Intervals (.96 sec to 44.1 sec) during Reflex Decay Period. Reflex Activator was 2000 Hz presented at 10 dB and 15 dB above Acoustic Reflex Threshold.

Source	Sum of Squares	d.f.	Mean Square	F	Prob.
Group	5032789.25	2	2516394.63	1.24	.30
Error	63040305.81	31	2033558.25		
SL	324383.84	1	324383.84	1.41	.24
SLxG	59599.99	2	29799.99	.13	.88
Error	7119196.34	31	229651.49		
Time	40093574.75	13	3084121.13	68.23	.00
TxG	1997926.45	26	76843.32	1.70	.02
Error	18216288.86	403	45201.71		
SLxT	54777.67	13	4213.67	.66	.80
SxTxG	125825.98	26	4839.46	.76	.80
Error	2574162.46	403	6387.50		

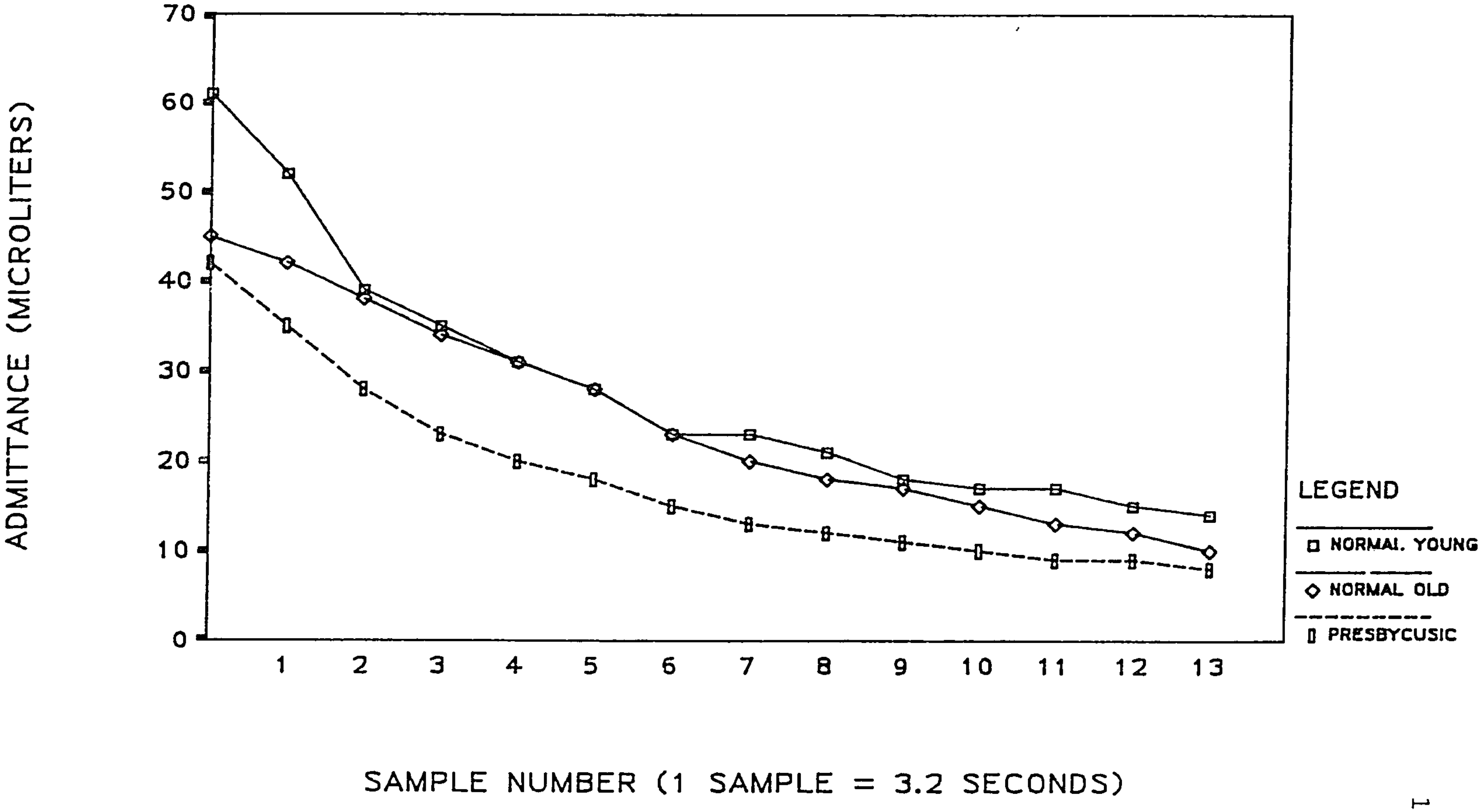


FIGURE 24: MEAN ADMITTANCE CHANGE DURING DECAY COLLAPSED ACROSS SENSATION LEVEL. ACTIVATOR WAS 2000 HZ.

those of the old normal hearing subjects and then by those of the presbycusic subjects. As time increases, the mean admittance values for the three groups tend to converge. Post Hoc analysis revealed that the significant interaction between time and group was due to a significant age effect only (young normals vs. older normals). The effect of presbycusis did not significantly contribute to the group x time interaction at 2000 Hz.

In order to determine if the initial portion of the reflex decay data contributed to the significant time-group interaction, a second analysis of variance was performed. In this analysis (Table 10), the first three data points (.96 to 5.9 seconds) were excluded from each group. The findings remained identical to the findings of the first analysis, except for one important difference. That is, the interaction between time and group failed to reach significance at the .05 probability level. It can be concluded, therefore, that the difference between groups at the beginning of the reflex decay function contributed to the significant interaction between time and group in the first analysis. The absence of a significant interaction between group and time in the second analysis indicates that when the data from the initial portion of the reflex decay period are

Table 10.

Analysis of Variance with Repeated Measures of Admittance Data for 11 Time Intervals (9.1 s to 41.1 sec) during Reflex Decay Period. Reflex Activator was 2000 Hz presented at 10 dB and 15 dB above Acoustic Reflex Threshold.

Source	Sum of Squares	d.f.	Mean Square	F	Prob.
Group	3393390.50	2	1696695.25	1.11	.34
Error	47585776.53	31	1535025.05		
SL	178797.00	1	178797.00	.88	.35
SLxG	103330.13	2	51665.07	.25	.78
Error	6288726.45	31	202862.14		
Time	9287767.46	10	928776.75	73.09	.00
TxG	398432.85	20	19921.64	1.57	.06
Error	3939314.19	310	12707.47		
SLxT	12992.92	10	1299.29	.31	.98
SLxTxG	61975.56	20	3098.78	.73	.79
Error	1308943.98	310	4222.40		

excluded, there is no effect of age (young normals vs older normals) or hearing loss (older normals vs presbycusics) on the rate of the reflex decay at 2000 Hz.

The effect of sensation level and its interactions with group and time were not statistically significant for the 2000 Hz stimulus.

The individual admittance values for broad-band noise (BBN) are listed in Appendix G.7. The group means at 8 second intervals, expressed in microliters, are shown in Appendix G.8 and illustrated in Figures 25 and 26. Table 11 shows the results of a three way analysis of variance with repeated measures.

In the analysis of variance the main effect of group failed to reach significance at the .05 probability level. There was, however, a significant interaction between group and time ($F(26,416) = 1.92$, $p<.05$). Figure 27 shows the reflex decay data as a function of time and group, collapsed across sensation level, to illustrate the time-group interaction. Post Hoc analysis revealed that the significant interaction between time and group was due to a significant age effect (young normals vs older normals), and not due to a significant hearing loss effect (older normals vs. presbycusis).

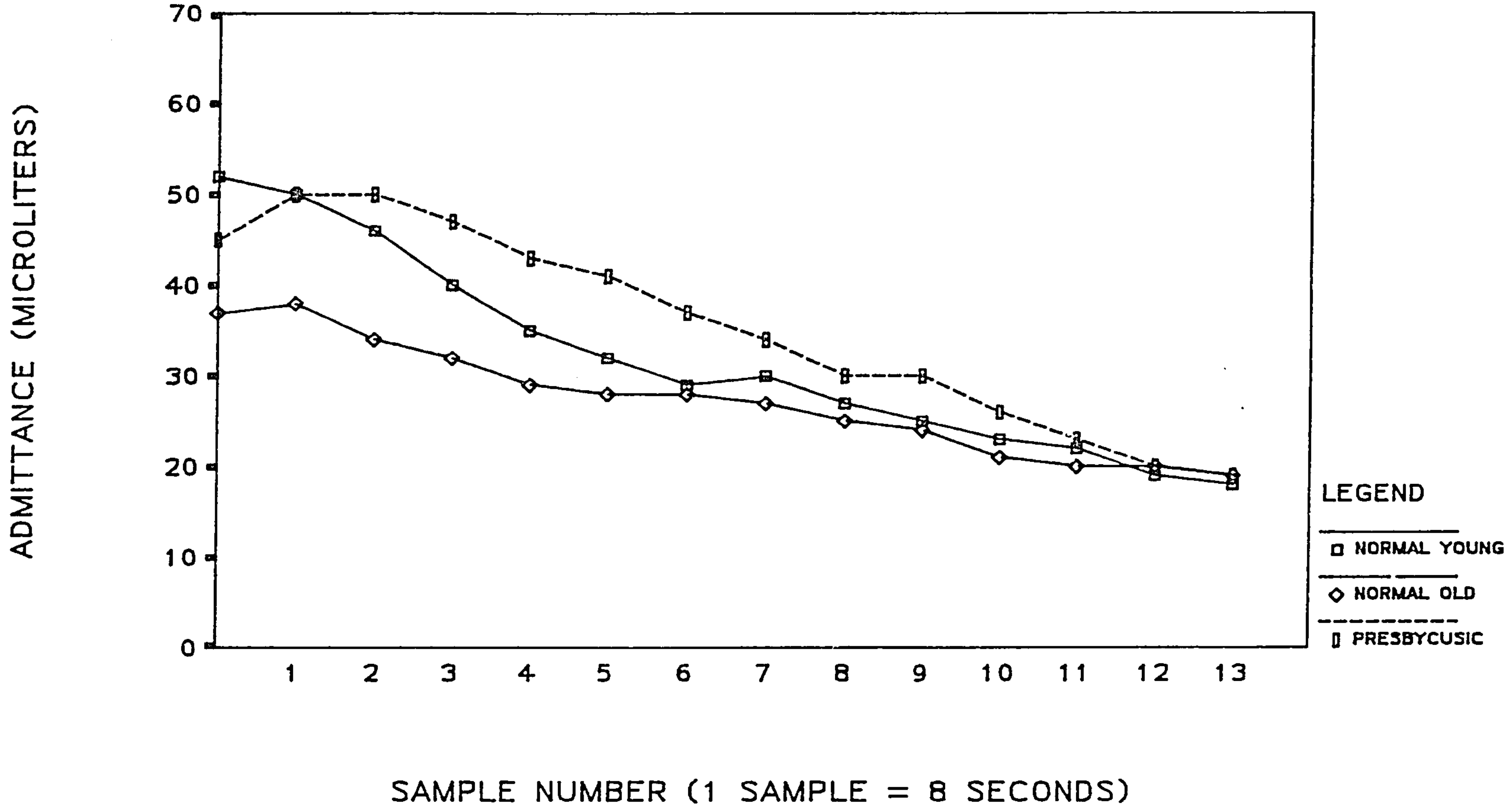


FIGURE 25: MEAN ADMITTANCE CHANGE DURING THE REFLEX DECAY PERIOD. ACTIVATOR WAS BBN PRESENTED AT 10 DB ABOVE ACOUSTIC REFLEX THRESHOLD.

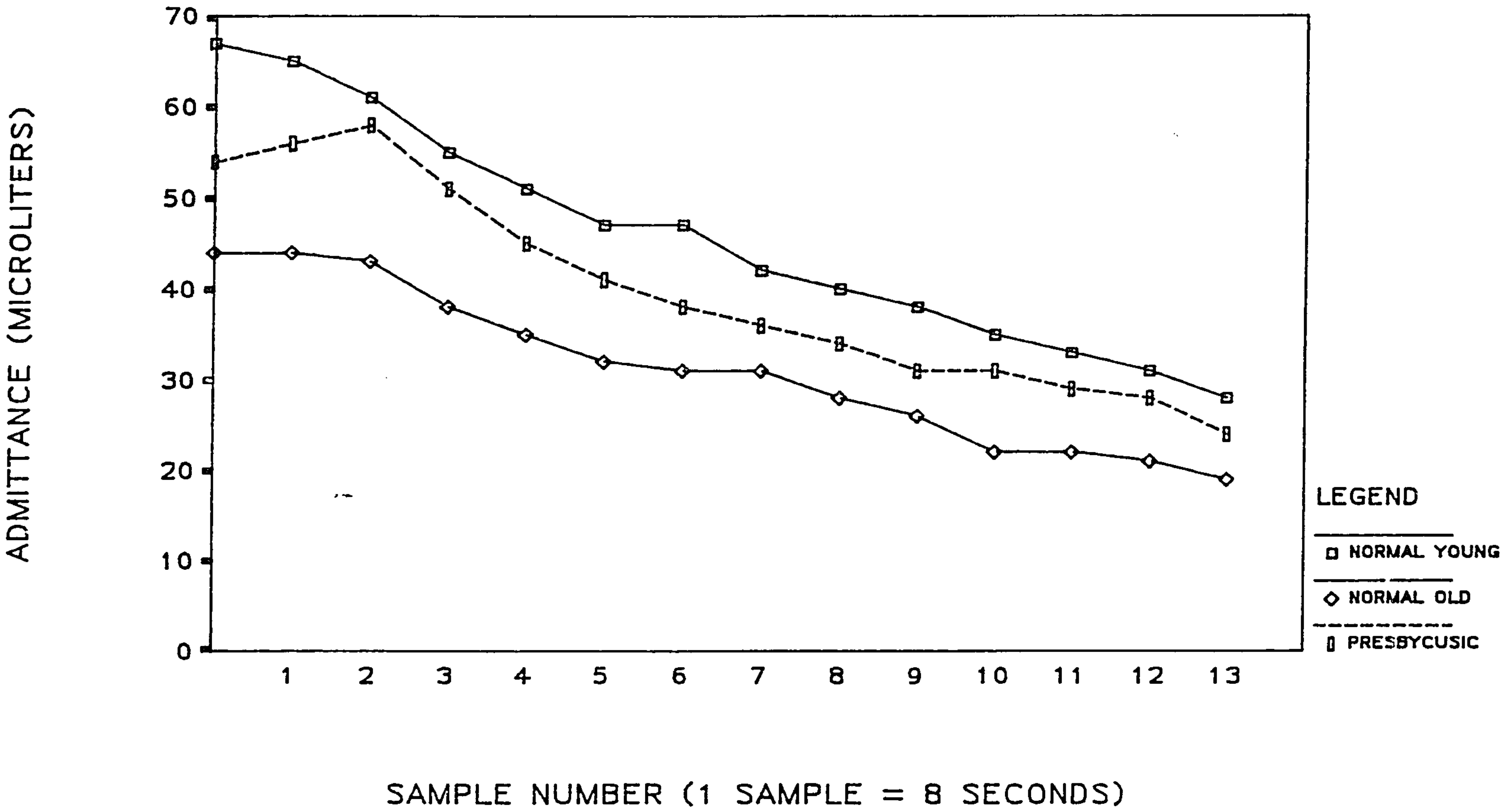


FIGURE 26: MEAN ADMITTANCE CHANGE DURING THE REFLEX DECAY PERIOD. ACTIVATOR WAS BBN PRESENTED AT 15 DB ABOVE ACOUSTIC REFLEX THRESHOLD

Table 11.

Analysis of Variance with Repeated Measures of Admittance Data for 14 Time Intervals (.96 sec to 100.5 sec) during the Reflex Decay Period. Reflex Activator was Broad Band Noise presented at 10 dB and 15 dB above Acoustic Reflex Threshold.

Source	Sum of Squares	d.f.	Mean Square	F	Prob.
Group	5461102.78	2	2730551.39	.91	.41
Error	96116507.39	32	3003640.86		
SL	4054716.18	1	4054716.18	19.75	.00
SLxG	1549436.99	2	774718.49	3.77	.03
Error	6569938.32	32	205310.57		
Time	28420590.77	13	2186199.29	80.30	.00
TxG	1360935.60	26	52343.68	1.92	.00
Error	11326193.05	416	27226.43		
SLxT	188913.99	13	14531.85	1.98	.02
SLxTxG	270452.58	26	10402.02	1.42	.09
Error	3049910.82	416	7331.52		

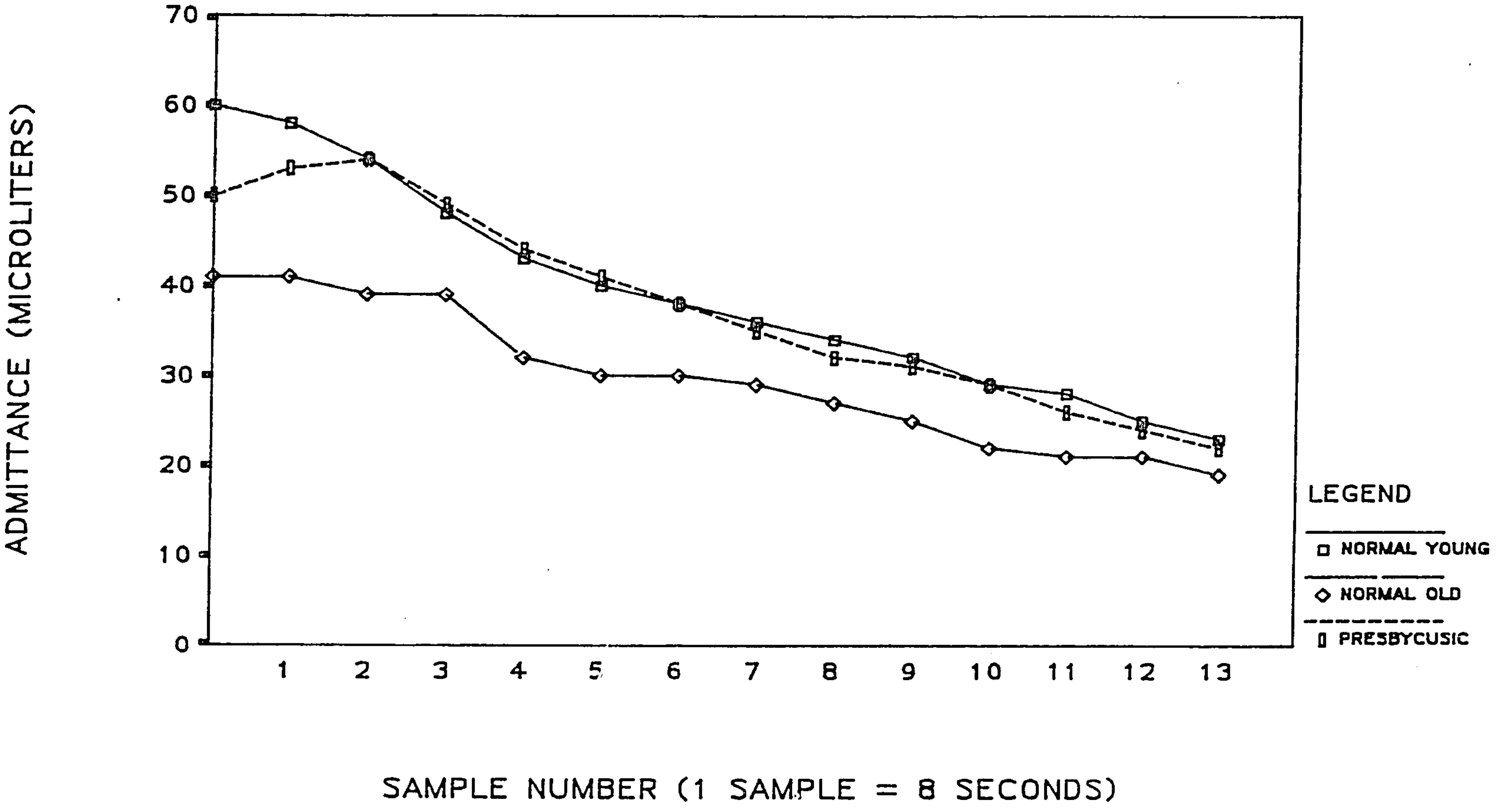


FIGURE 27: MEAN ADMITTANCE CHANGE DURING DECAY COLLAPSED ACROSS SENSATION LEVEL. ACTIVATOR WAS BROAD BAND NOISE

To further explore the group x time interaction, a second analysis of variance was done which excluded the first three data points for each group. This analysis still showed a group x time interaction but the effect was not strong ($p=.04$).

Table 11 shows a significant main effect of sensation level ($F(1,32)= 19.75$, $p<.01$) and significant interactions between sensation level and time ($F(13,416) = 1.98, p<.05$) and between sensation level and group ($F(2,32) = 3.77$, $p<.05$). Figure 28 shows the reflex decay data as a function of sensation level and time, collapsed across groups, to illustrate the sensation level-time interaction. As can be seen, the effect of sensation level decreases as time increases. Figure 29 shows the reflex decay data for the BBN stimulus collapsed across time for the two sensation levels and three groups, to illustrate the sensation level-group interaction. It can be seen from the figure that the reflex magnitude during the reflex decay period is greater for the young normal and presbycusic subjects than for the older normal subjects. However, the analysis shows that the three-way interaction between sensation level, time and group was not significant ($p>.05$).

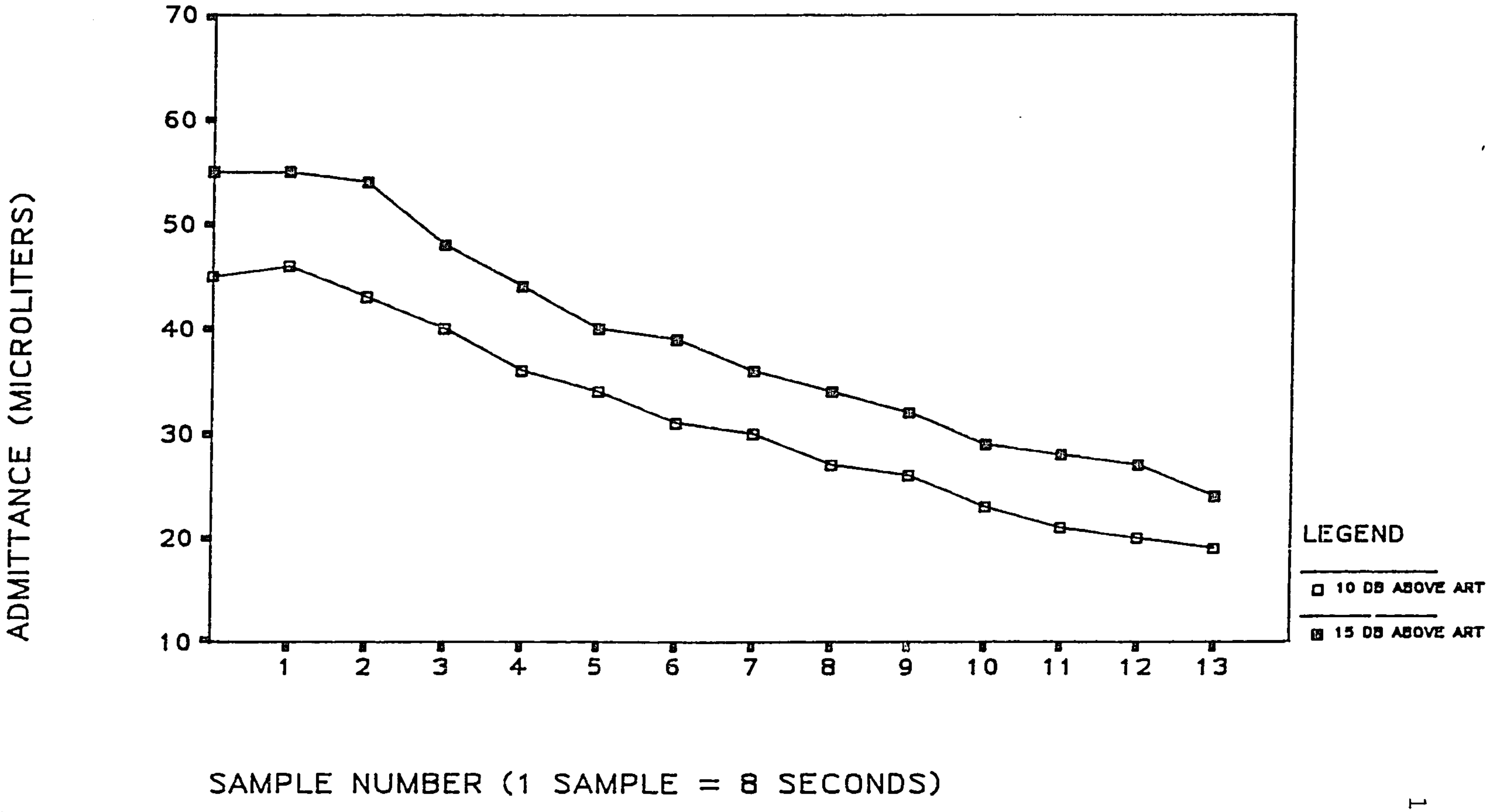


FIGURE 28: MEAN ADMITTANCE CHANGE COLLAPSED ACROSS GROUP. ACTIVATOR WAS BBN PRESENTED AT 10 DB AND 15 DB RE ART.

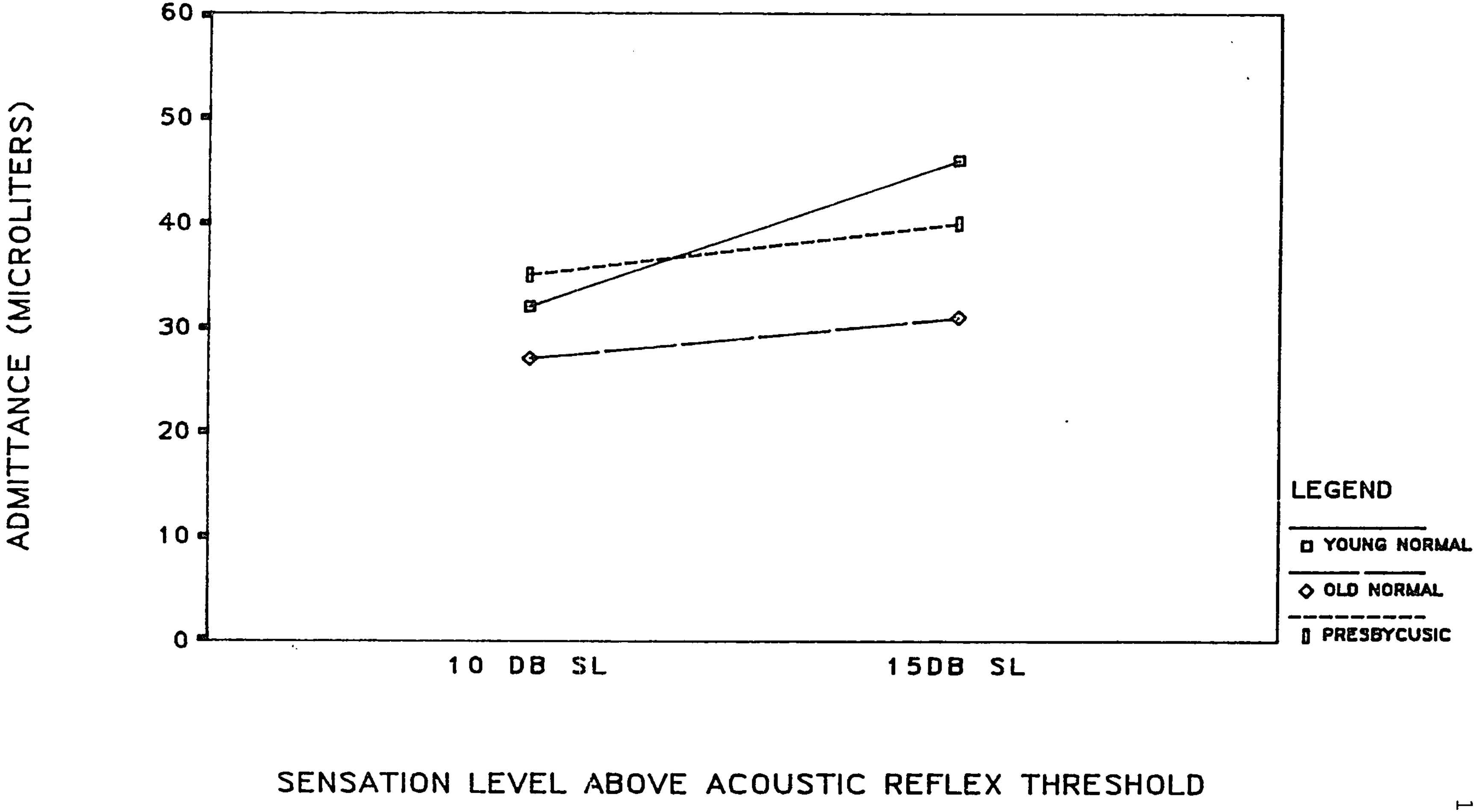


FIGURE 29: MEAN ADMITTANCE CHANGE DURING DECAY COLLAPSED ACROSS TIME. ACTIVATOR WAS BROAD BAND NOISE AT 10 AND 15 DB RE:ART.

The significant and non-significant effects from the analysis of variance for each of the four stimuli are listed in Table 12. The following is a summary of significant effects according to the variables of group (age and hearing loss), sensation level, time and their interactions.

Group is significant as a main effect for the 500 Hz reflex activating stimulus only, suggesting that there is a group effect on the reflex magnitude during the decay period studied. The group effect here was not strong (p = .03).

Sensation level was significant as a main effect for the 500 Hz, 1000 Hz and BBN stimuli, but not for the 2000 Hz stimulus. For these three stimuli, the overall reflex magnitude for the reflex decay period was greater for the 15 dB stimulus condition than for the 10 dB condition.

There was also a significant interaction between sensation level and time for 500 Hz, 1000 Hz, and BBN. Again, this effect was not significant for 2000 Hz. The sensation level-time interaction indicates that the relationship between the reflex magnitude at 10 dB and 15 dB differs across time.

Table 12.

Summary of Significant and Non-significant Findings from the Analysis of Variance for Each of the Four Stimuli during the Reflex Decay Period. Probability Values are Listed for the Four Experimental Stimuli.

	500 Hz	1000 Hz	2000 Hz	BBN
Main Effects				
Group	.03*	.10	.30	.41*
SL	.00*	.00*	.24	.00*
Time	.00*	.00*	.00*	.00*
2-Way Interaction				
SLxG	.24	.74	.88	.03*
TimexG	.99	.73	.02*	.00*
SLxT	.00*	.00*	.80	.02*
3-Way Interaction				
SLxTxG	.16	.82	.80	.09

*Indicates probability less than or equal to .05

A significant interaction between sensation level and group was found for the BBN stimulus only. The sensation level effect for the young normal subjects and presbycusic subjects was greater than for the older normal subjects.

The main effect of time is significant for all four stimuli, as expected, reflecting the decay of the reflex response over time.

There was a significant interaction between time and group for 2000 Hz and broad band noise. For both of these stimuli, the interaction was due to a significant effect of age (young normals vs. older normals), and not due to an effect of hearing loss (older normals vs. presbycusics). The significant time x group (age) interactions suggest that age affects the rate of reflex adaptation for 2000 Hz and broad band noise activators when the change in reflex magnitude is analyzed across time at specific time intervals.

A second analysis of variance which excluded the initial portion of the reflex function for the 2000 Hz stimulus failed to show a significant time x group interaction, which indicated that the group difference was at the beginning of the reflex decay period only. A second analysis of variance which excluded the initial portion of the decay function for the broad band noise still indicated a significant time x group interaction.

The three-way interaction between sensation level, time and group was not significant for all four stimuli. The absence of a significant interaction between sensation level, time and group suggests that any group effect on the rate of adaptation is not different as a function of sensation level for the four stimuli.

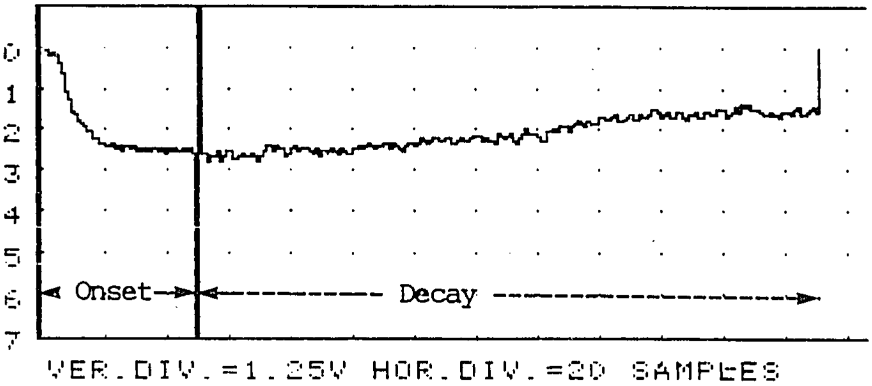
IV. TAXONOMY OF THE ADAPTATION CURVES

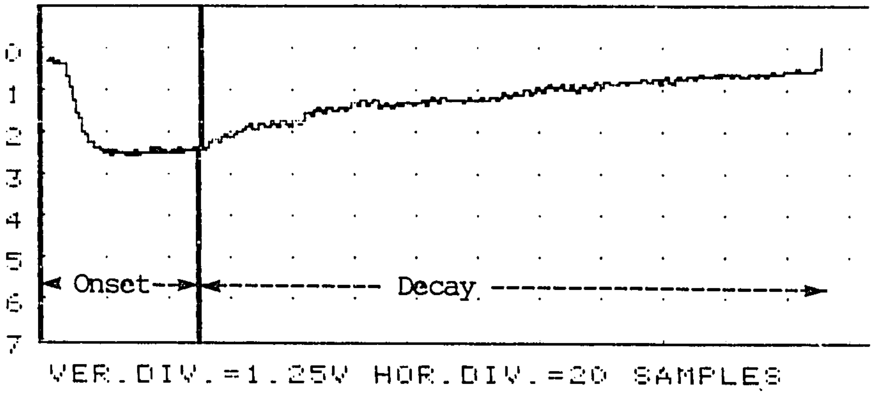
After analysing the admittance change over time during the reflex decay period, it became clear that the adaptation functions did not always follow the "classical" pattern of decay as reported in the literature. Therefore, individual adaptation curves were carefully examined. It was found that the adaptation curves could be described by four distinct pattern types.

The following section deals with the description of these four types. Statistical analyses which indicate the relationship between type distribution and subject group or stimulus type are also presented.

Type I is the "classical" type of adaptation curve. The classical type shows a sudden decrease in admittance after stimulus onset which is followed by a smooth increase in admittance toward the pre-stimulus resting level. Figure 30 shows three examples of a Type I pattern obtained in the present study.

The Type II category includes adaptation curves which are characterised by a "double plateau" of minimum admittance. Figure 31 shows three examples of a Type II pattern. The curves show a plateau of minimum admittance





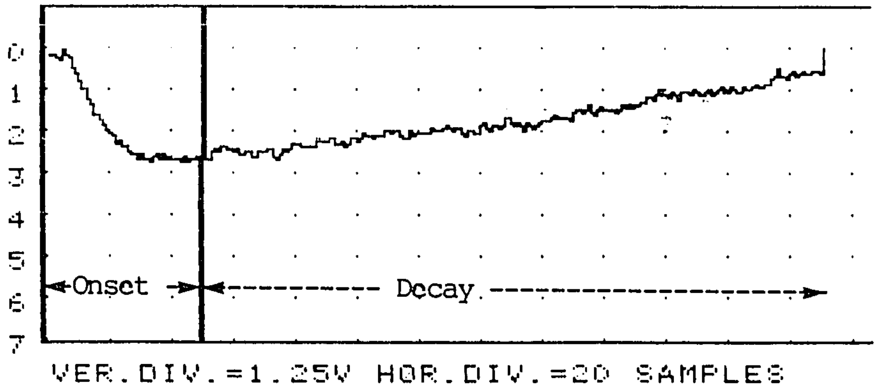


Figure 30: Examples of the Classical (Type I) Decay Pattern. Activator was 1000 Hz at 15 dB SL

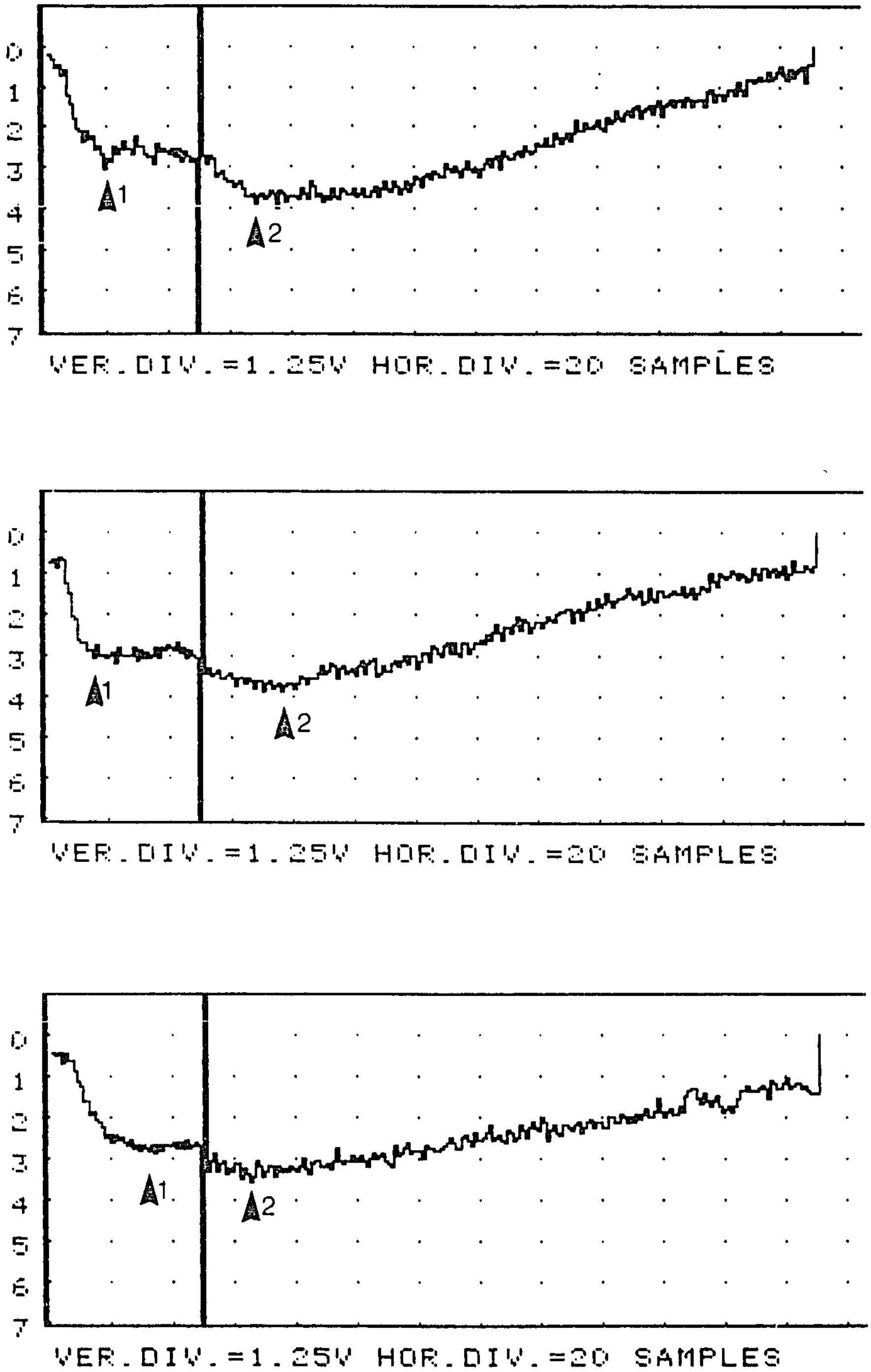


Figure 31: Examples of the Double Plateau (Type II) Decay Pattern. Activator was 500 Hz at 10 dB SL

within the first second after stimulus onset which is followed by a second plateau.

Examples of the Type III pattern are shown in Figure 32. This type of curve shows a decaying pattern; however, as the admittance is increasing toward its resting state, there are series of fluctuations (or decay/recovery) in the admittance along the curve. A special case of the Type III pattern is shown by the bottom graph in the figure. In this case a single recovery pattern is seen toward the end of the reflex decay period rather that throughout the decay period.

The type IV category included curves which showed a rapid decay in admittance followed by a slower exponential decay. Figure 33 illustrates examples of this "rapid/slow" decay pattern.

The frequency distribution of the four decay patterns as a function of subject group is illustrated in Figure 34. The distribution of pattern types varied with subject group ($p< .01$; Pearson ChiSquare Test). Based on the frequency distribution, the Type II (or double plateau) pattern was found more frequently for the older normal and presbycusic group than for young normal group. The type I (or classical) pattern was more prevalent for

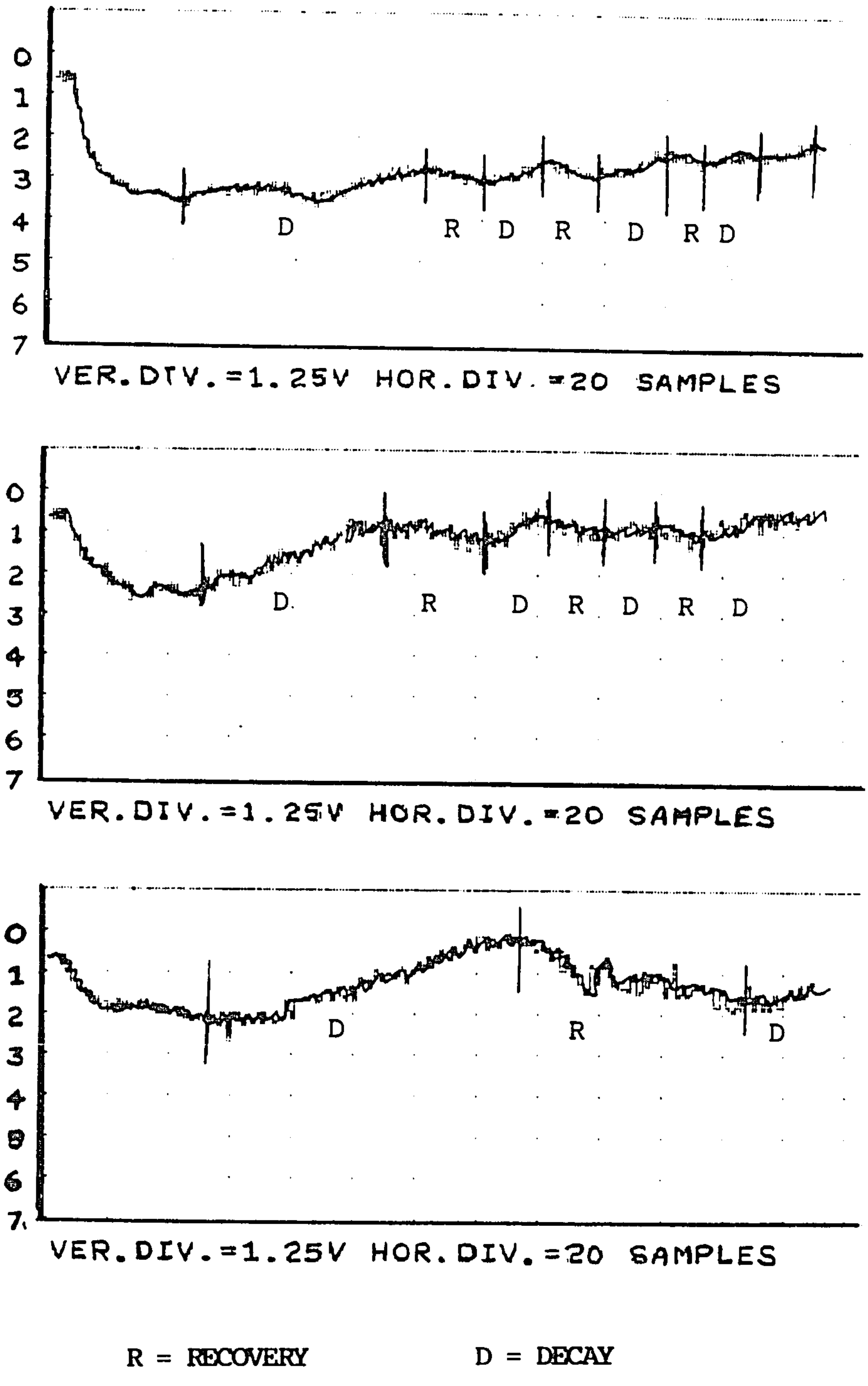


Figure 32: Examples of the Decay/recovery (Type III) Decay Pattern. Activator was 500 Hz at 10 dB SL

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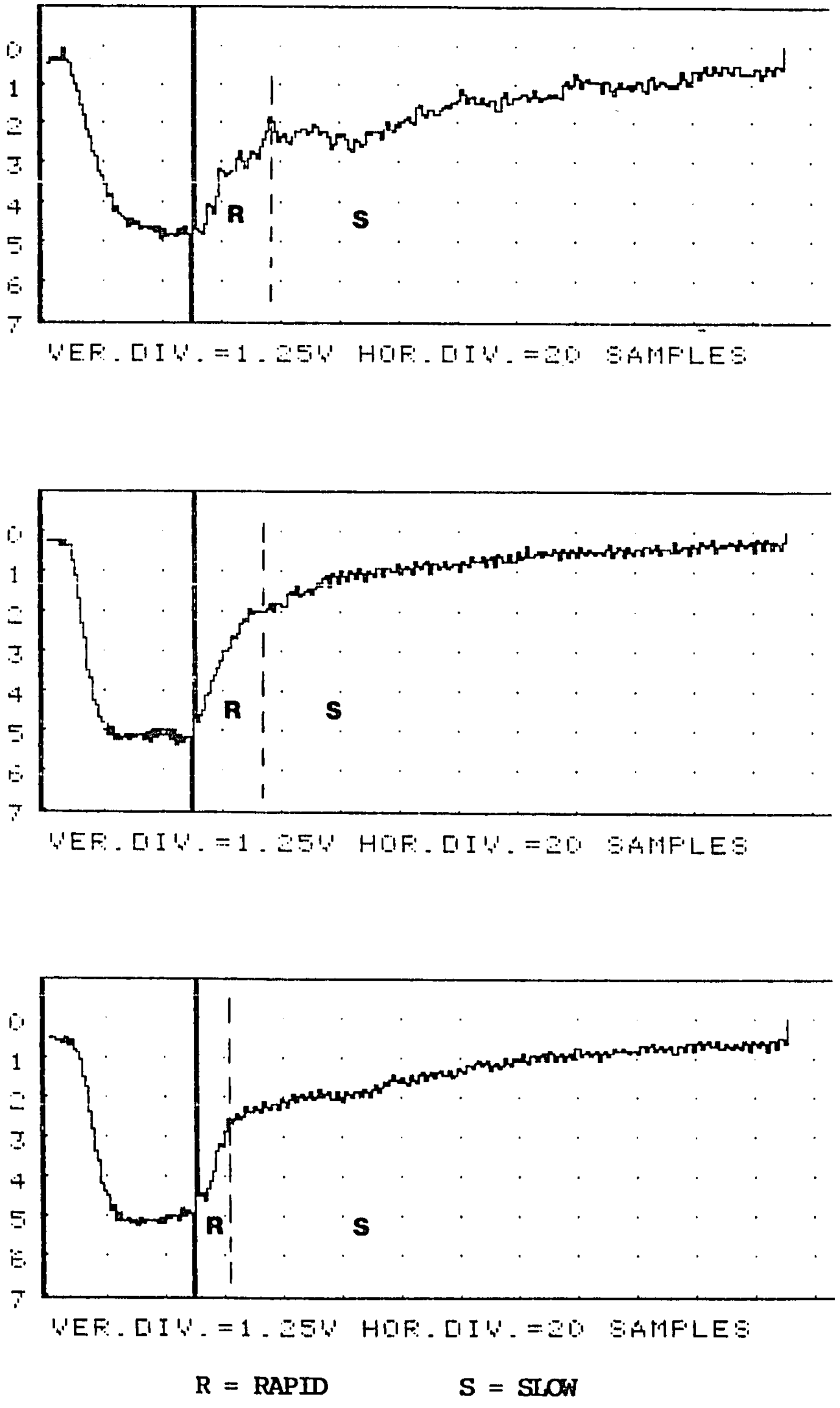


Figure 33: Examples of the Rapid/Slow (Type IV) Decay Pattern. Activator was 2000 Hz at 15 dB SL

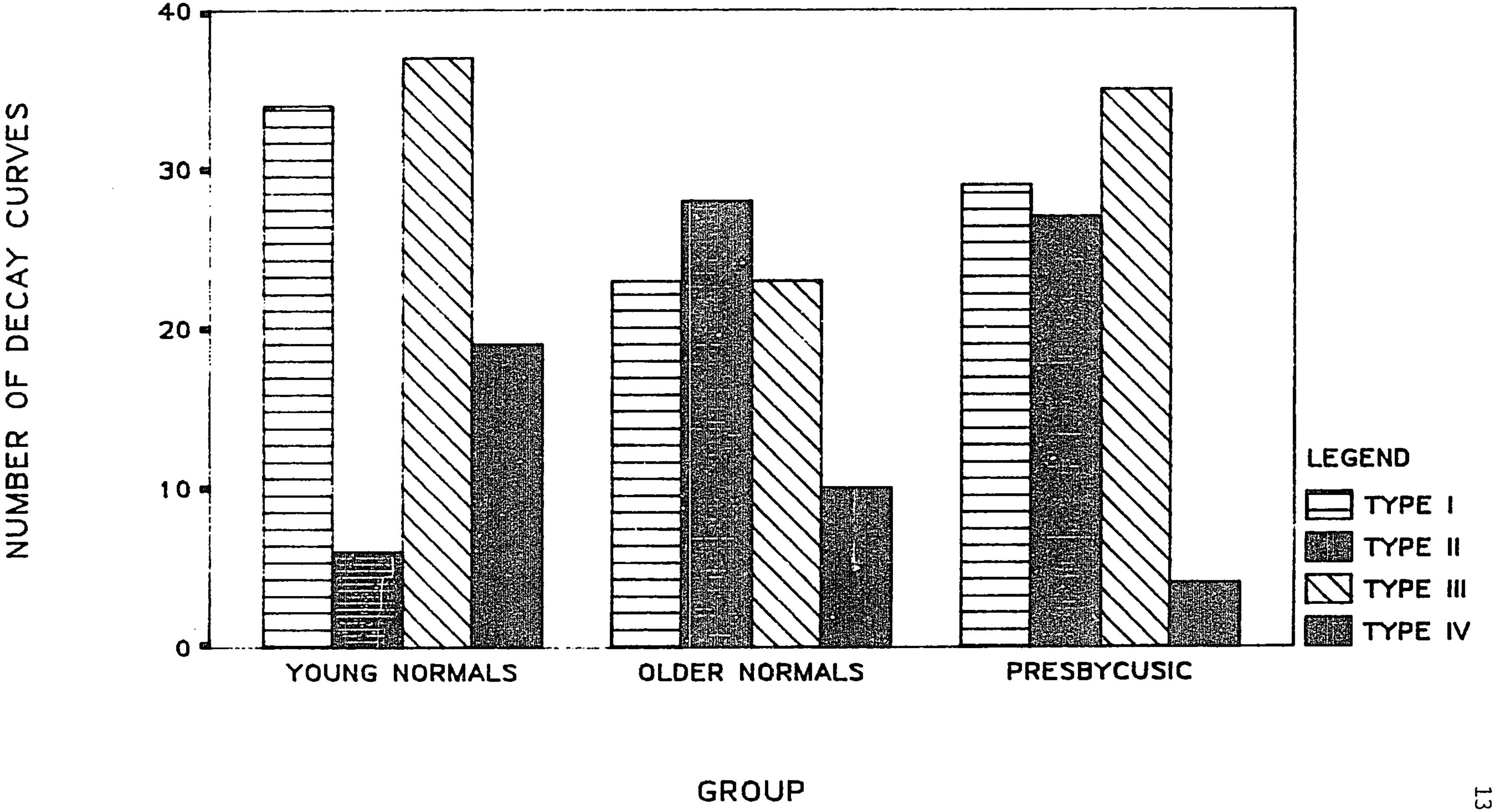
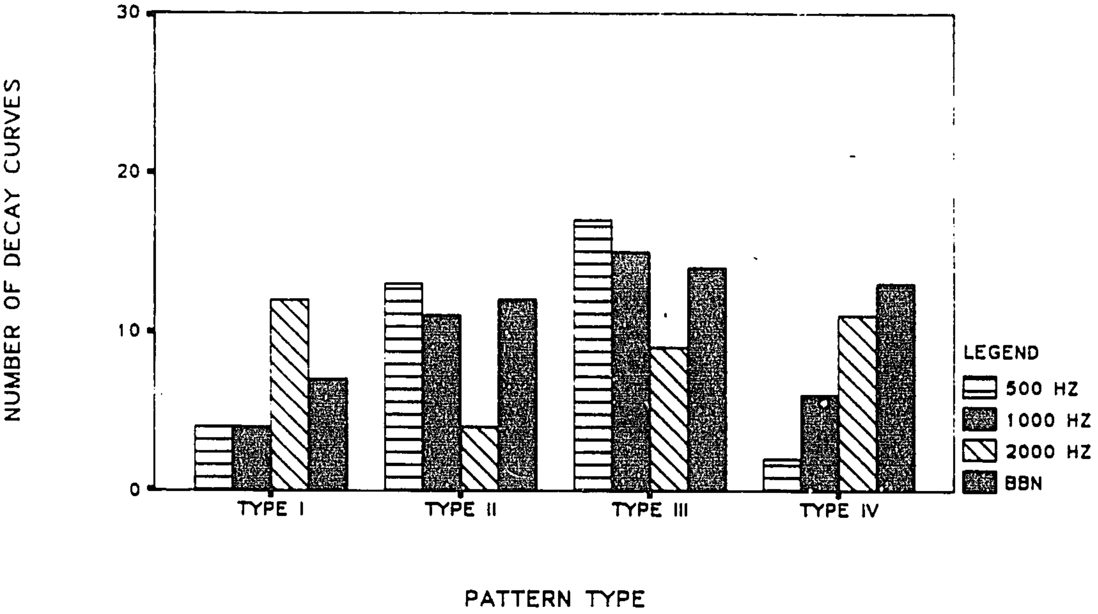


FIGURE 34: NUMBER OF DECAY CURVES WITHIN EACH PATTERN TYPE AS A FUNCTION OF GROUP

the young group than for the older groups. The type IV (or rapid/slow decay) pattern was more prevalent for the young normal and older normal group than for the presbycusic group. The type III (decay/recovery) pattern was equally distributed across the subject groups.

Further analysis was then done to determine if there were age effects (young vs. older normal) or hearing loss (older normal vs presbycusic) effects on the occurrence of certain patterns. The Test for the Significance of Differences between Porportions showed that there was a significant effect ($p < .05$) of age on the incidence of Type II (double plateau) and Type IV (rapid/slow decay) patterns. There were no significant hearing loss effects found for any of the four pattern types.

The frequency distribution of the four decay patterns as a function of stimulus type is illustrated in Figure 35. The Pearson Chi-Square test showed that the patterns were dependent on the stimulus type at the .01 probability level. As can be seen in the figure, the Type I (or classical pattern) was most frequent for 1000 Hz and 2000 Hz at 15 dB above acoustic reflex threshold.



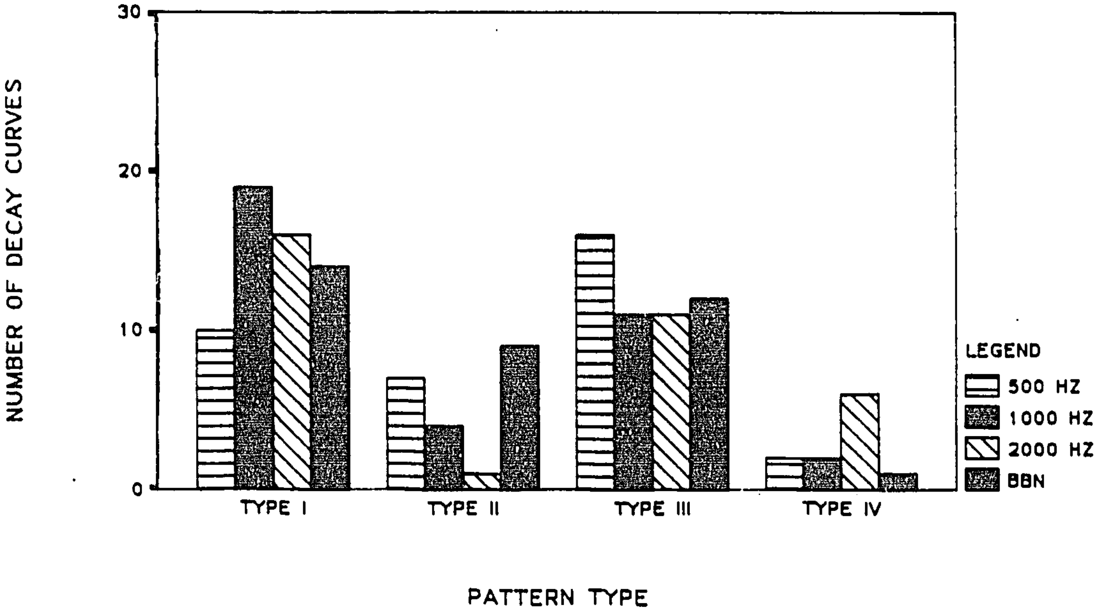


FIGURE 35: DISTRIBUTION OF PATTERN TYPES AS FUNCTION OF STIMULUS
TOP GRAPH: 10 DB SL; BOTTOM GRAPH: 15 DB SL

The type II (or double plateau) pattern was most frequent for 500 Hz, 1000 Hz, and broad band noise at 10 dB above acoustic reflex threshold. The type IV (or rapid decay/slow decay) pattern was most frequent for the 2000 Hz, 10 dB SL condition. Once again, the Type III (decay/recovery) pattern was equally distributed across stimuli.

V. RATE OF ACOUSTIC REFLEX ADAPTATION

The rate of acoustic reflex adaptation (i.e. the rate of magnitude change with increased time) has been quantified in past studies by using a half-life time. As mentioned earlier, there were problems with the half life approach in this study. For one thing, many subjects did not exhibit 50% decay when stimulated with 500 Hz or broad band noise within a reasonable stimulation time (>100 seconds). Furthermore, estimates of single points along the decay curve (i.e. 50% decay point) was difficult to make with precision since the decay patterns were often complex. The difficulty with choosing a half life was particularly evident for the decay/recovery pattern (Type III), which was the most common pattern type found.

A previous section presented data using the analysis of magnitude change at specific time intervals along the decay curve. From this approach, a significant interaction between group and time suggested a group effect on the rate of decay for 2000 Hz and broad band noise. However, this approach did not provide for a single measure of decay rate. In addition, the analysis of reflex decay data using this approach may be confounded by the variations in the decay form across subjects. For example, it is possible that the significant interaction between group and time was due to differences in the form of the decay curves between groups and not necessarily due to a differences in decay rate. Because of these factors, a second approach was adopted to analyze the data collected.

The second approach used an exponential curve fitting procedure on those portions of the individual decay function that appeared to reflect an unambigous decay process. From the exponential fitting procedure, a time constant was derived, which represents a single measure of decay rate. This approach assumed that the underlying function during decay was exponential, i.e. that the rate of decay (or slope of the magnitude vs. time function) was proportional to the current magnitude. This assumption is, of course, open to question, yet seemed to be justified for the following reasons:

First, the simplest assumption regarding decay would be to describe it as a linear function. Using this assumption, the rate of decay would need to be constant between the peak value and the baseline value. In reviewing the present data, this linear function was never observed. Even if a linear function was observed, it would violate common sense. As the resting baseline was approached, the function would have to be discontinous, requiring a sudden shift to a zero decay rate once baseline was reached.

The second simplest assumption is the exponential one. Like the linear assumption, it is described by a single parameter, in this case, the time constant. Unlike the linear assumption, it requires no discontinuity when baseline is approached since the exponential function predicts that baseline is only approached but never reached. More importantly, there were many instances in the present data, in which a single exponential curve gave an excellent fit to the complete decay function. In other instances, the fit to an exponential curve was excellent over significant portions of the decay function.

A more complicated alternative to the exponential assumption would have been to fit the decay data with polynomial functions. Such an approach would have provided several coefficients, none of which would have given an appropriate estimate of decay rate. Furthermore, it would have been difficult to explain the coefficients or express them in terms of groups means. While it is true that many of the subjects exhibited complex decay behaviour that would have been well fit by polynomial functions, the problem posed by these data was solved by fitting different portions of the data by an exponential function.

The equation relating admittance change to time for a simple exponential decay would be:

$$y = a * e^{-bt} \tag{5}$$

where y = admittance change re: baseline
a = value of admittance at t=0
b = a constant
e = base of natural logarithm (2.718)

The constant b gives a measure of rate of decay. In fact, 1/b is the time constant of the exponential curve, i.e. the time taken for y to decay to 1/e of its value at t = 0 (See Fig. 36).

The gradient of a linear relationship between log (y) and t was calculated in order to determine the value of b for each function. From equation (5) is derived the following:

$$\log y = \log a - bt \tag{6}$$

Thus, a plot of log (y) against t is a straight line with intercept log a and slope b (See Fig. 37).

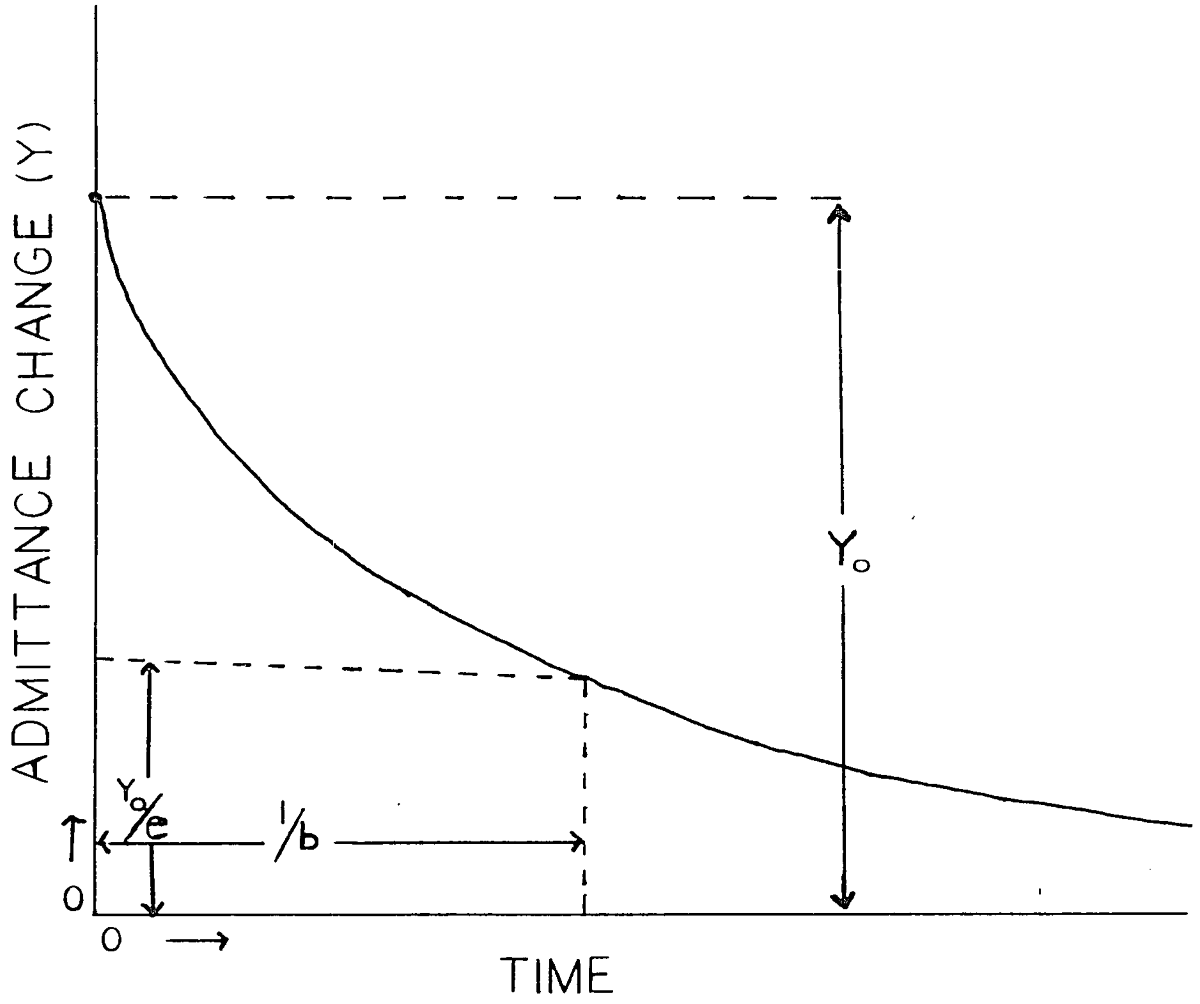


Figure 36: Relationship of Admittance Change to Time for a Simple Exponential Decay

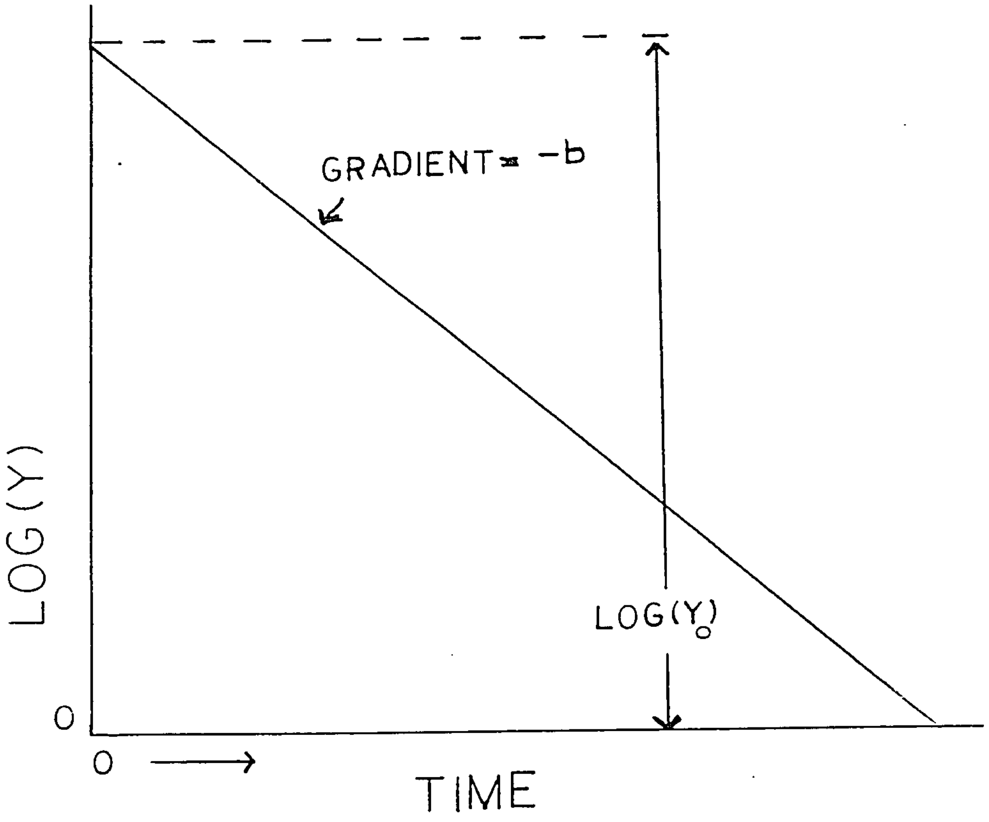


Figure 37. Plot of Log (y) vs. Time. The Line has Intercept Log a and Slope b.

The exponential fit was done on the entire decay data array of an individual curve or on sections of the array depending on the pattern type of the reflex adaptation curve (see Figure 38). For example, the entire data array was used to determine the best fit for the Type I (or classical) reflex adaptation curve. For the Type II (or double plateau) curve, the best fit was determined by using the data array after the second plateau of the admittance. For the Type III (decay/relaxation pattern) curve, the fit was determined by using 2 or 3 sections of the data array within the decay phases of the curve and calculating the mean time constants for the sections, while for the Type IV (or rapid/slow decay) curves, the best fit was done on the steepest initial portion of the adaptation curve.

For each value of t within the section of the data array chosen, the admittance change, after baseline correction, was converted to its log transform and a linear least squares fit was performed. This gave estimates of log (a) and b, and also a measure of goodness of fit, expressed as a correlation coefficient. The linear regression function was then re-transformed to admittance values by substituting each value of t into equation (4), using the values of log (a) and b determined from the analysis. The transformed function

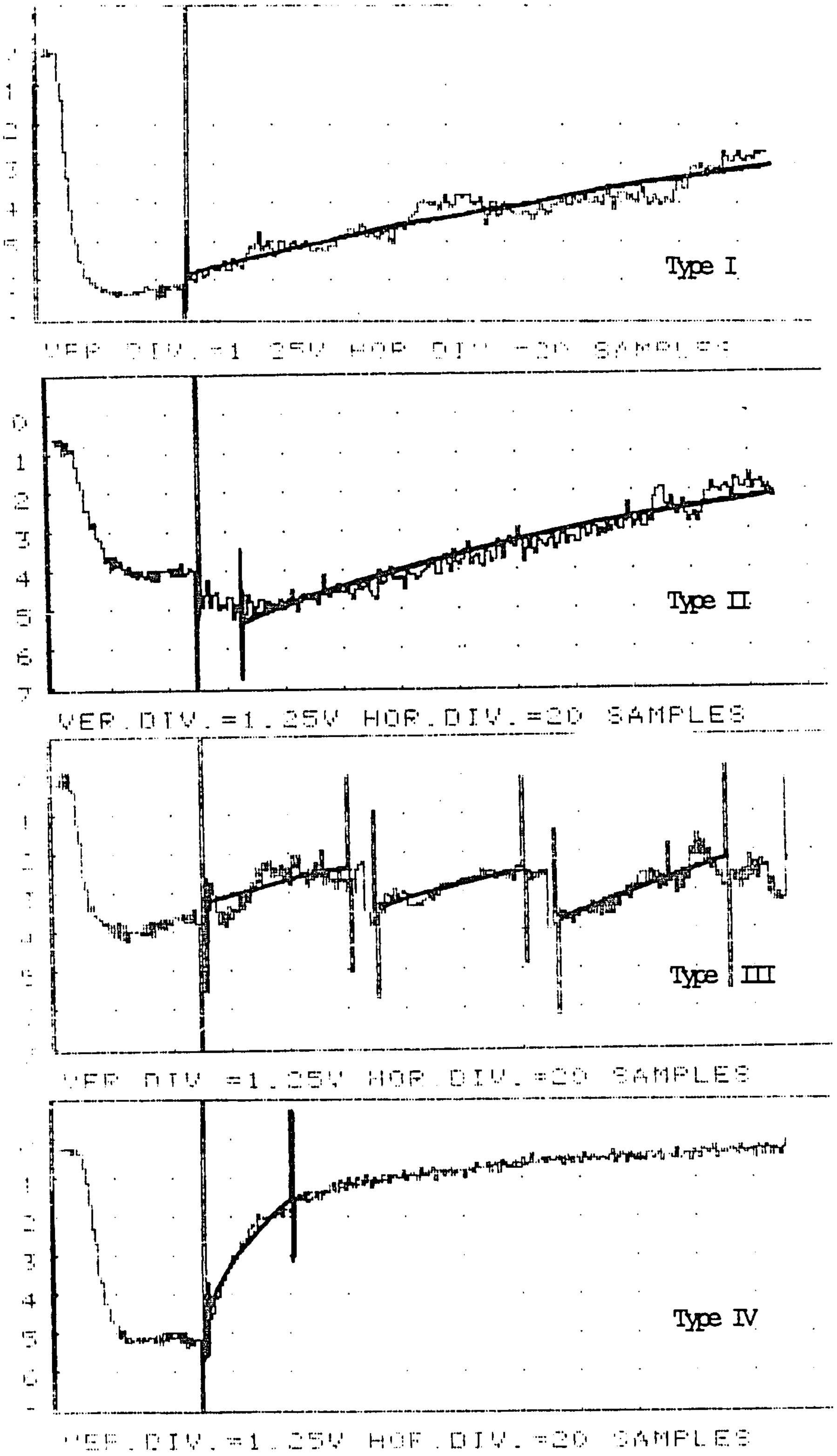


Figure 38: Examples of the Curve Fitting Technique for Each of the Four Pattern Types

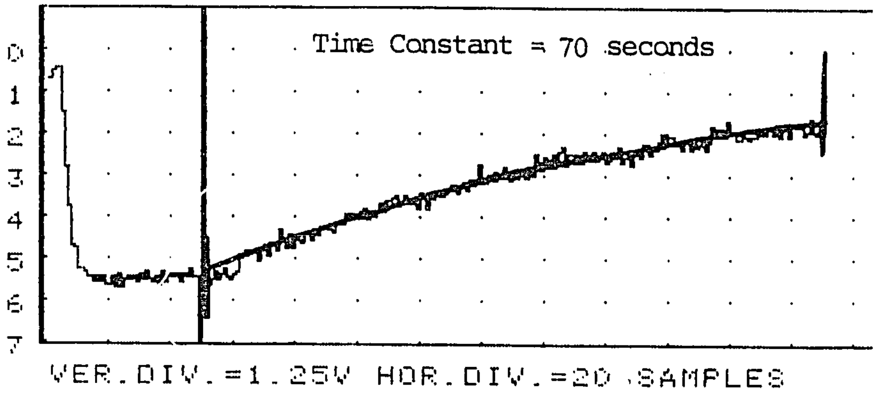
was then drawn over the initial decay function for visual confirmation of goodness of fit (See Fig. 39).

The time constants for individual subjects, derived from the foregoing procedure, are listed in Tables 13 through 16. Time constants could not be calculated for some stimulus conditions for one of two reasons. First, some subjects were not tested at a 15 dB sensation level for certain stimuli due to loudness tolerance problems. Second, a time constant could not be derived for certain subjects due to the irregularities in the adaptation curve. If the data were missing for one sensation level, then the data for the other sensation level were excluded from the analysis.

Table 17 summarizes these mean time constants for each group and stimulus condition, derived from the exponential function. The mean time constant was based on 11 subjects per group for each stimulus and sensation level.

A three way analysis of variance was performed on the natural logarithm of each time constant, or log (1/b). The transformation to log (1/b) was done to stabilize the variance (i.e. for conditions with long time constants the inter- and intra-subject variability

Correlation: - .967
Gradient: -.01438
Timeconstant: 69.55 secs



Subject: JA
Stimulus: 1 kHz
Intensity: 100 dB SPL
Ear: R
Baseline Sampling Time: 20 msec
Decay Sampling Time: 350 msec

Figure 39: Example of an Adaptation Function. The least squares fit was performed on the curve. The transformed function is drawn over the original decay function.

Table 13.

Time Constants (in seconds) of the Individual Adaptation Functions for the Young Normal Subjects (Group I), Old Normal Subjects (Group II), and Presbycusic Subjects (Group III). Stimulus is 500 Hz presented at 10 and 15 dB above Acoustic Reflex Threshold. Arithmetic Means and Standard Deviations (S.D.) are Presented.

	Young Normal		Older Normal		Presbycusic	
	10 dB	15 dB	10dB	15 dB	10dB	15dB
1	68	169	282	173	106	94
2	-	-	60	87	54	57
3	69	69	64	111	82	65
4	203	277	106	125	75	75
5	72	95	200	166	144	135
6	114	144	28	69	54	44
7	187	197	102	115	137	190
8	78	108	53	53	45	62
9	169	165	134	127	82	74
10	118	186	171	194	155	328
11	126	128	65	79	-	-
12	226	241	-	-	71	74
N	11	11	11	11	11	11
MEAN	130	162	115	118	91	109
S.D.	58	62	76	45	37	84

Table 14

Time Constants (in seconds) of the Individual Adaptation Functions for the Young Normal Subjects (Group I), Old Normal Subjects (Group II), and Presbycusic Subjects (Group III). Stimulus is 1000 Hz presented at 10 and 15 dB above Acoustic Reflex Threshold. Arithmetic Means and Standard Deviations (S.D.) are Presented.

	Young Normal		Older Normal		Presbycusic	
	10 dB	15 dB	10dB	15 dB	10dB	15dB
1	120	70	23	43	49	44
2	-	-	52	33	14	21
3	49	39	36	55	83	57
4	66	103	57	63	38	41
5	41	51	81	60	31	51
6	44	86	51	28	46	38
7	138	63	60	98	51	36
8	128	115	15	22	17	27
9	33	52	84	85	61	76
10	24	37	59	71	245	121
11	70	86	21	42	-	-
12	59	50	-	-	82	81
N	11	11	11	11	11	11
MEAN	70	68	49	55	65	54
S.D.	40	26	23	24	64	29

Table 15

Time Constants (in seconds) of the Individual Adaptation Functions for the Young Normal Subjects (Group I), Old Normal Subjects (Group II), and Presbycusic Subjects (Group III). Stimulus is 2000 Hz presented at 10 and 15 dB above Acoustic Reflex Threshold. Arithmetic Means and Standard Deviations (S.D.) are Presented.

	Young Normal		Older Normal		Presbycusic	
	10 dB	15 dB	10dB	15 dB	10dB	15dB
1	41	62	21	10	18	17
2	-	-	4	2	6	6
3	8	7	20	22	62	72
4	18	21	22	26	7	12
5	18	16	37	36	27	32
6	11	37	39	26	16	16
7	9	8	26	18	18	9
8	15	18	8	14	9	7
9	16	13	25	26	27	30
10	5	5	44	57	46	44
11	21	20	18	13	-	-
12	5	11	-	-	23	18
N	11	11	11	11	11	11
X	15	20	24	23	24	24
SD	10	17	12	14	17	20

Table 16

Time Constants (in seconds) of the Individual Adaptation Functions for the Young Normal Subjects (Group I), Old Normal Subjects (Group II), and Presbycusic Subjects (Group III). Stimulus is Broad-band Noise presented at 10 and 15 dB above Acoustic Reflex Threshold. Arithmetic Means and Standard Deviation (S.D.) are Presented.

	Young Normal		Older Normal		Presbycusic	
	10 dB	15 dB	10dB	15 dB	10dB	15dB
1	127	88	61	89	154	154
2	-	-	93	109	97	110
3	120	103	68	91	100	116
4	93	161	35	153	116	100
5	47	81	136	124	57	170
6	32	142	115	107	34	89
7	94	149	95	84	126	99
8	215	209	73	45	105	91
9	90	105	115	103	96	115
10	67	154	168	186	71	91
11	86	87	64	121	-	-
12	133	151	-	-	106	67
N	11	11	11	11	11	11
MEAN	100	130	93	110	97	109
S.D.	49	40	38	37	33	30

Table 17

Arithmetic Mean of Time Constants (in seconds) for the Three Experimental Groups according to Stimulus and Sensation Level above Acoustic Reflex Threshold. Time Constants are Derived from the Exponential Fitting Procedure.

	Young Normal		Older Normal		Presbycusic	
SL:	10	15	10	15	10	15
Stimulus						
BBN	100	130	93	110	97	109
500 Hz	130	162	115	118	91	109
1000 Hz	70	68	49	55	65	54
2000 Hz	15	20	24	23	24	24

will be greater than for conditions with short time constants). The analysis of variance is shown in Table 18.

In order for the results of the analysis to be more meaningful, Table 19 shows data used in the analysis of variance but converted back into time units. Therefore, the table lists the antilogs of the mean log (1/b), together with the distribution (+/- 2 s.d.) for each group, stimulus, and sensation level.

The analysis showed that the factor of group is not significant as a main effect. The absence of a group effect indicates that neither the effect of age (young normals vs. older normals) nor the effect of hearing loss (older normals vs. presbycusics) is significant when the data are collapsed across the 500 Hz, 1000 Hz, 2000 Hz and BBN stimuli. To be more specific, the rate of acoustic reflex adaptation between the young normal hearing and older normal hearing subjects were not statistically different, when a time constant is used to quantify decay rate. The distributions of time constants for the young and old groups show considerable overlap and large variance, as shown in Table 19. Similiarly, the time constant data for the older normal hearing and presbycusic groups were not statistically different.

Table 18

Analysis of Variance in the Values of Log (1/b) for Young Normal Hearing, Older Normal Hearing and Presbycusic Subjects. Stimuli included 500 Hz, 1000 Hz, 2000 Hz and Broad band Noise at 10 dB and 15 dB re ART.

Source	Sum of Squares	d.f.	Mean Square	F	Prob.
Group	1.2861	2	0.6431	.61	.55
Error	30.6825	29	1.0580		
Stimulus	150.6666	3	50.2222	140.81	.00
Stimulus x Group	2.8360	6	.4727	1.33	.25
Error	31.0293	87	.3567		
SL	1.0101	1	1.0101	9.24	.01
SL x Group	.2487	2	.1244	1.14	.33
Error	3.1702	29	.1093		
Stim x SL	.4639	3	.1546	1.81	.15
St x SL x G	.1536	6	.0256	.30	.94
Error	7.4126	87	.0852		

Table 19.

Means and Distributions (+/- 2 s.d.) of the Time Constants for the Young Normal Hearing, Older Normal Hearing, and Presbycusic Subjects for the Eight Stimulus/ Sensation Level Conditions. Geometric Time Constant Used.

	Young Normal		Older Normal		Presbycusic	
SL re ART	10 dB	15 dB	10 dB	15 dB	10 dB	15 dB
BBN						
Mean	90	124	81	104	89	105
Range	(32-254)	(69-232)	(30-224)	(50-217)	(36-216)	(61-181)
.5kHz						
Mean	118	150	94	110	85	94
Range	(47-297)	(66-343)	(24-362)	(49-248)	(36-203)	(28-316)
1kHz						
Mean	61	64	43	50	46	47
Range	(19-189)	(30-138)	(14-136)	(19-126)	(9-229)	(16-136)
2kHz						
Mean	13	15	19	18	16	15
Range	(4-45)	(3-67)	(1-78)	(3-93)	(5-54)	(4-51)

*
The time constant values listed in the table are calculated by taking the antilog of the mean of log (1/b) used in the analysis of variance.

This finding indicates that there were no hearing loss effects of decay rate. Again from Table 19, it can be seen that there is overlap between the distributions of time constants for the two groups.

The main effect of sensation level was significant (F(1,29) =9.24; p=01). Figure 40 shows the mean time constants (antilog of the means of log(1/b)) for the two sensation levels for the three groups. The mean time constants for the 15 dB level are longer than those for the 10 dB level.

The interaction between sensation level and group failed to reach significance at the .05 probability level. This finding indicates that the change in mean time constant from 10 dB to 15 dB did not statistically differ with age or hearing loss.

The effect of stimulus on the rate of reflex adaptation is highly significant (F(3,87)=140.81, p<.01). Figure 40 illustrates the inverse relationship between the mean time constants with the frequency of the tonal stimulus. As the frequency of the tonal stimulus increases, the mean time constant decreases. However, the group x stimulus interaction was not significant, indicating that the mean time constants for the young

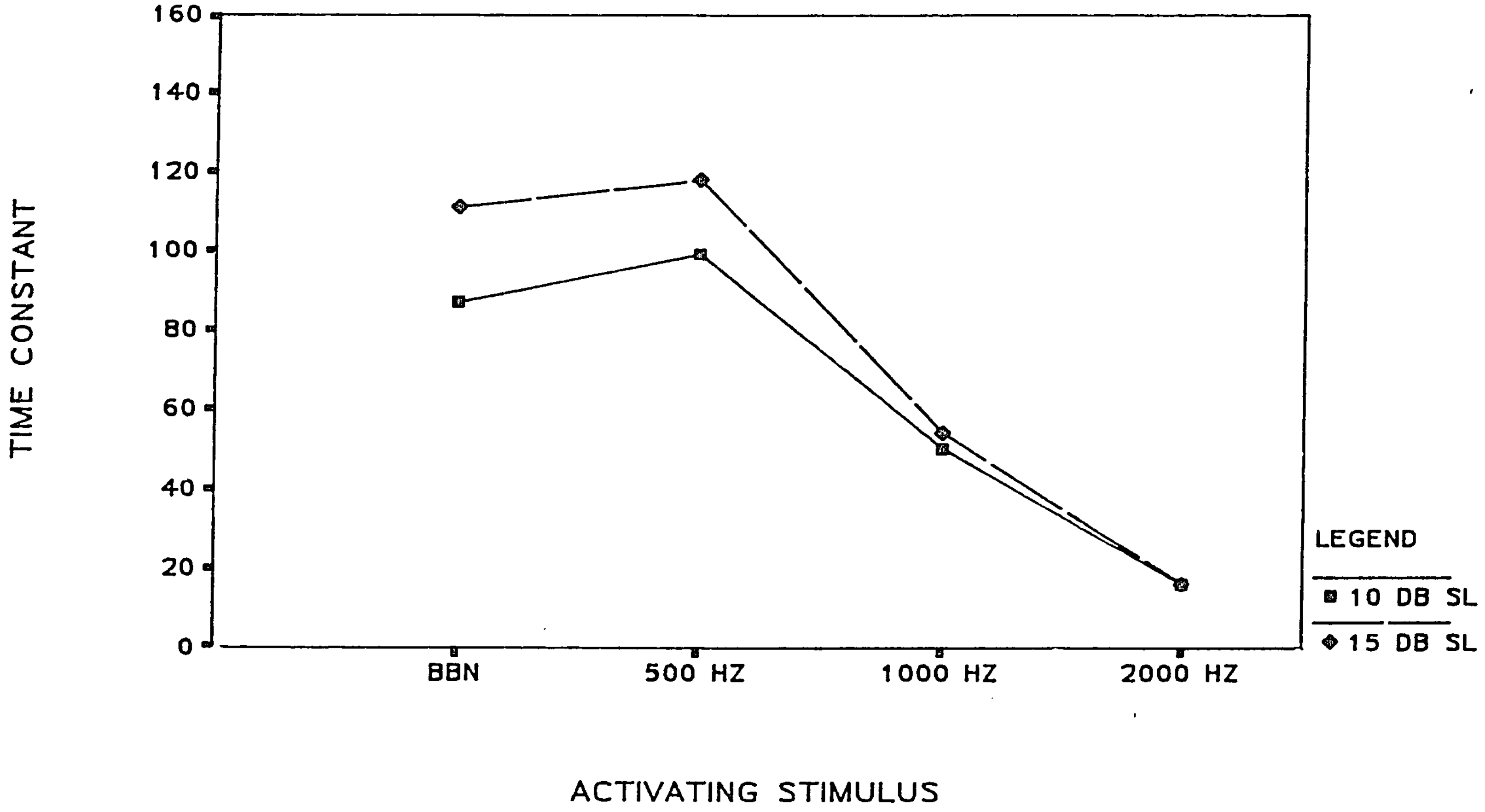


FIGURE 40: MEAN TIME CONSTANTS IN SECONDS COLLAPSED ACROSS GROUPS FOR 10 DB AND 15 DB SL RE: ART

normal, old normal and presbycusic group change uniformly with the frequency of the activator. There was also no significant interaction between stimulus, sensation level and group.

Chapter 6

DISCUSSION

The primary purpose of this study was to investigate the effects of age and presbycusic hearing loss on the rate of reflex adaptation. Originally, the rate of reflex adaptation was to be quantified in terms of a half life (i.e. the time taken for the reflex magnitude to decay to 50% of its maximum value). This method of quantification was based on the assumption that all subjects would demonstrate a classical decay pattern in which the reflex magnitude steadily and monotonically returns to pre-stimulus values. The data collected in this study demonstrated the fallacy of this assumption. The pattern of change in reflex magnitude during prolonged stimulation was often complex, varied from subject to subject, and even varied within a given subject as a function of stimulus type and level.

Given the complexity of the adaptation functions, the data were examined in several ways. The discussion of the methods and results will be discussed in the following order: (1) the form of the decay curve was categorized into four pattern types and the distribution of the types was studied in relation to subject group and stimulus type; (2) the general pattern of reflex magnitude change was examined across time for each function; and (3) the rate of reflex adaptation was quantified by measuring the gradient of the individual adaptation function during periods of maximum adaptation.

The answers to the research questions turned out to be different, depending on the particular aspect of the function that was being examined. For instance, for some stimuli, the pattern of reflex magnitude change over time and the form of the adaptation curves were signficantly affected by age. However, the gradient (or time constant) of the function was not affected. With this in mind, we can return to the issue of age and presbycusic hearing loss.

AGE EFFECTS

Age Effects on Reflex Decay Form

It was shown that age had a significant effect on the form of the adaptation curves. The age effect on form was demonstrated by statistically analyzing the distribution of the four pattern types with respect to group. An age dependency was shown for two out of the four pattern types. The incidence of the Type II or double plateau pattern was significantly higher for the older normal hearing group than for the young normal hearing group. This pattern occurred most frequently for broad band noise. In contrast, the incidence of the Type IV or fast/slow exponential decay pattern was significantly higher for the young normal hearing group than for the older normal hearing group. Again, this pattern was stimulus-type dependent, occurring most frequently for 2000 Hz than any other stimuli. No age effects were found for the distribution of the Type I (classical) or Type III (decay/recovery) patterns.

Possible explanations for the occurrence of different pattern types and their relationship to aging have little basis in the existing literature on reflex adaptation. In the first place, although the characteristics of the adaptation phenomenon in relation to stimulus variables have been widely described in young normals, there is little information available regarding the different forms of the adaptation functions across subjects. Secondly, there have been no past studies which have examined the effects of age on any aspect of adaptation behavior.

Studies on the age-related changes on other acoustic reflex parameters may provide some clues as to why the form of the reflex decay curve would be affected by age.

For instance, Mangham and Miller (1979) have suggested that adaptation occurs more rapidly for those subjects who have short reflex rise times (or short reflex latency). Based on their hypothesis, the high incidence of the Type IV could be related to differences in reflex onset behavior between the young and old. Past research has shown that the latency values for young subjects are slightly shorter than those for older subjects (Bosatra, 1984). The design of the present experiment did not lend itself for the accurate measurement of reflex latency, and so data on reflex latency in the young and old could not be analyzed. Future research would need to be conducted to determine if there is any relationship between reflex onset times and the age-related incidence of the Type IV reflex decay pattern.

The reason for the age-related incidence of the double plateau (Type II) pattern is not clear. Sandow (1944) observed that there is a relaxation of muscle tension following muscle contraction, which is generally referred to as the latency relaxation. Studies could be done to investigate whether the double plateau decay pattern is related to the relaxation latency of the middle ear muscles. One approach would be to determine the contribution of the stapedius muscle to the double plateau pattern. Along this line one may ask; does the stapedius muscle initially contract, relax, and then contract for a second time? And, if so, does this phenomenon occur more frequently in older subjects? A second approach would be to investigate any possible contributions of the tensor tympani muscle to the double plateau pattern. Although some studies have found that the tensor tympani is not active in most humans except at high intensity levels (Jepsen, 1963; Moller, 1964), other studies have suggested that the tensor tympani can contribute to a biphasic reflex response at the beginning of acoustic stimulation in certain individuals (Love and Stream, 1978; Mangham and Stream, 1978). One could ask "Is the double plateau pattern caused by the contraction of the tensor tympani muscle or the combined interaction of the stapedius and tensor tympani muscles?" Additionally, are the effects of the tensor tympani muscle revealed by a change in admittance which is more pronounced as a subject ages?

Age Effects on the Magnitude vs. Time Analyses

It was found that age affects the general pattern of change of the reflex magnitude over time for 2000 Hz and broad band noise. The significant Group x Time interactions for these stimuli indicated that the change in reflex magnitude was different across time for the young normal hearing and the older normal hearing groups.

The Group x Time interaction for 2000 Hz is clearly seen in Figure 24. The young normal hearing group demonstrated a fast change in magnitude at the beginning of stimulation. After approximately 9 seconds the change in magnitude between the young and older normal hearing groups were essentially the same. This observation was statistically supported by the fact that no Group x Time interaction was found when the analysis of variance was performed on data which excluded the initial three data points.

The manner in which the general magnitude change differs between the young subjects and old subjects at 2000 Hz has a relation to the distribution of pattern types mentioned earlier. There was a signficantly greater incidence of the fast/slow (Type IV) pattern for the young normal hearing group than for the older normal hearing group, and this pattern occurred most frequently for 2000 Hz. It is not suprising, then, that a age-related effect was found for this frequency when the overall reflex magnitude change is examined across time. As a group the young normal hearing subjects demonstrated faster decay at the beginning of stimulation to a 2000 Hz activator than their old normal hearing counterparts. This faster decay was evidenced by the high incidence of the fast/slow exponential (Type IV) pattern as well as in the magnitude vs. time analysis.

The significant Group x Time interaction for broad band noise is also related to the distribution of pattern types. The high incidence of the double plateau (Type II) pattern for the older group is one reason why there are age effects when the magnitude change over time is statistically analyzed. The older normal subjects, as a group, show a different pattern of magnitude change during the first few seconds of stimulation compared to the young group (Figure 25-26).

Age Effects on the Time Constant Analyses

No age effects were found when the rate of reflex decay was expressed by the gradient (or time constant) of the reflex adaptation function. The absence of a signficant age effect on the time constant data for 500 Hz and 1000 Hz is consistent with the findings of the magnitude vs. time analysis. There are no significant age-related findings for these stimuli whether one expresses decay rate as a change in the logarithmic magnitude vs. time or by the overall magnitude change over time using a linear scale of admittance.

The time constant findings for 2000 Hz and broad band noise are somewhat counter to those of the magnitude vs. time analysis for these stimuli. There are two reasons for the difference in age-related findings for these two approaches. First, the magnitude vs. time analysis was influenced by differences in the shape of the adaptation curve. Since this analysis examined the overall magnitude change across 14 data points at evenly spaced time intervals, a difference in magnitude change over a few data points could produce a significant group x time interaction. This was not the case with the time constant analysis. The time constant for a given curve was calculated by using a large number of data points from the data array. Consequently, the time constant approach minimized the influence of curve shape on the calculation of decay rate. Second, this approach also involved obtaining an estimate of decay rate only from those portions of the individual functions that appeared to reflect an unambigous decay process. For example, an average time constant was calculated for the Type III pattern (decay/recovery pattern). This was done by measuring the time constant for several portions of the curve; portions that showed clear evidence of decay. The mean of the time constants was then used as the average time constant for that curve. For the Type II (double plateau) pattern, the time constant was calculated from the second plateau. The time constant for the Type IV (fast/slow decay) pattern was measured during the fast portion of the decay curve. In each of these cases, this method of calculation resulted in a decay rate measure that was less contaminated by curve shape differences and the "best fit" possible to an exponential curve. However, it is important to keep in mind that had a single time constant been calculated for the entire adaptation function, the time constant value would have been different. The way in which the time constant was derived could partially account for the difference in age-related findings between the time constant analysis and the magnitude vs. time analysis.

EFFECTS OF PRESBYCUSIC HEARING LOSS

No significant presbycusic effects were found by any of the three methods for examining the adaptation data. There were no significant differences found between the older normal hearing and presbycusic group on the distribution of pattern types, the overall magnitude change across time, or the gradients of the adaptation curves. The present findings indicate that, as a group, the presbycusic subjects were very much like the older normal hearing subjects.

Comparison of the present data on presbycusic subjects with the literature is not possible. There are no previous studies which have investigated adaptation behavior using this population. It should be keep in mind that the present results apply only to the effects of presbycusis. The results also apply only to older subjects who exhibit a mild to moderate degree of cochlear hearing loss which is restricted to the high frequency region. The findings can not be taken as evidence that a cochlear hearing loss has no effect on adaptation behavior. In fact, the existing literature suggests that cochlear hearing loss can affect adaptation behavior. For example, Chiveralls et al (1976) reported data on 58 clinical cases with sensorineural hearing loss. Their study included patients with hearing losses as great as 95 dB HL. Using the typical clinical criterion (greater than 50% decay within 10 seconds), it was found that the cochlear hearing loss subjects showed a faster rate of decay than normal hearing young subjects in a similiar study. Oviatt and Kileny (1984) also suggested that subjects with sensorineural hearing loss exhibit greater reflex adaptation that that found in normal ears. Both of these studies included subjects with varying degrees of cochlear hearing loss; many of whom had hearing loss exceeding 50 dB. It is possible that the present study could have demonstrated differences between the old normals and presbycusic groups had it included subjects with a hearing loss which exceeded a moderate degree. In order to test this hypothesis, future research in this area would need to be conducted.

STIMULUS TYPE AND GROUP INTERACTION

The effect of stimulus type on adaptation rate was found to be significant for all three groups. The time constants for tonal stimuli decreased with an increase in the frequency of the activating stimulus. This relationship between the rate of reflex adaptation and the frequency of the signal is consistent with previous studies (Djupesland et al, 1967; Kaplan et al, 1977; Wilson et al, 1978). For the broad band noise stimuli, the time constants for the three groups fell between those for the 500 Hz and 1000 Hz stimuli. A similar result was found by Wilson et al (1978) for their broad band noise stimuli presented at three different sound pressure levels in young normal subjects using a measure of half life.

The effect of stimulus type on the rate of adaptation did not significantly interact with subject group.The time constants changed in a similiar manner across stimuli for all three groups (young normal, older normal and presbycusic). This finding does not support the third experimental hypothesis that age and/or presbycusic effects were be different for different stimuli.

There are no studies which have reported the effects of age on the rate of reflex adaptation across different stimuli. However, at the beginning of this research it was hypothesized that there would be a age-stimulus type interaction with age differences being most prominent at high frequencies. This supposition was based on findings reported for reflex magnitude growth in elderly subjects. For instance, several investigators have found that reflex magnitude growth functions becomes asymptotic at high intensity levels for high frequency stimuli (Silman and Gelfand, 1981; Wilson et al, 1981). At high levels the function saturates (i.e. further increases in intensity do not produce a corresponding increase in magnitude). Saturation in the mean reflex growth functions has been found in normal hearing elderly subjects for 1000 Hz and 2000 Hz (Silman and Gelfand, 1981). This is in contrast to the group finding of no saturation among young normals reported by Wilson (1979). Thus, in normal elderly, saturation occurs and is frequency dependent.

Wilson et al (1981) hypothesized that the age-related saturation noted for high frequency activators may be due to the effects of adaptation. In other words, Wilson speculated that older normal hearing elderly show saturation due to a faster rate of reflex adaptation for this group compared to a young group for high frequency activators. The present data do not support Wilson's hypothesis since there was no age-stimulus type interaction. However, it may be worthwhile for a future researcher to examine adaptation rate and reflex magnitude growth in the same groups of young and old subjects to determine if the findings are correlated in any way.

SENSATION LEVEL AND GROUP INTERACTION

Sensation level was found to be a significant main effect for all three groups. In general, the time constants were longer for the 15 dB SL than for the 10 dB SL (Figure 40). This effect is consistent with past research. Several studies have shown that the rate of adaptation, measured by a half life, decreases as the intensity of the signal increases, for 500 Hz, 1000 Hz and broad band noise activating signals (Dallos, 1964; Djupesland et al, 1967; Givens and Seidemann, 1979; Rosenhall et al, 1979; Wilson et al, 1978). For 2000 Hz, however, it has been reported that rate of adaptation does not systematically change with the intensity of the activating signal (Givens and Seidemann, 1979; Wiley and Karlovich, 1979; Wilson et al, 1978).

Although there were sensation level effects, there were no age-related or presbycusis-related effects on adaptation behavior as a function of sensation level. When the overall magnitude change was examined across time, there was no significant three way interaction between group, sensation level, and time. Likewise, there was no significant group x sensation letel interaction revealed by the time constant analysis. The time constants changed in the same manner for the three groups as a function of sensation level. This finding does not support the fourth experimental hypothesis that age and/or presbycusic effects would be different at different sensation levels.

There have been no studies which have examined the effects of sensation level on adaptation behavior in older normal hearing subjects or subjects with a presbycusic hearing loss. The closest research to the presbycusic issue are studies which have dealt with the effects of sensation level on adaptation rate in subjects with a cochlear loss resulting from Meniere's Disease or other etiologies. For instance, Mangham et al (1980) measured reflex decay in Meniere's subjects by using a time constant. They found that the rate of decay decreased with an increase in intensity from 10 dB to 20 dB above acoustic reflex threshold. The inverse relationship between the rate of decay and sensation level in these cochlear subjects was similiar to that found for young normal hearing subjects (Wilson et al, 1984). The absence of an interaction between presbycusis with sensation level in this study is consistent with Mangham's results for the cochlear loss subjects.

ADAPTATION PATTERNS TYPES

Before concluding this chapter with a discussion of the limitations of the study, it is worthwhile to return to the discussion of pattern types. The two of the four pattern types were discussed briefly in relation to age and presbycusic issues. All four types can now be discussed in a more general fashion.

The classical or Type I pattern is the only pattern of decay that has been discussed in past studies. In this pattern the reflex response shows a steady exponential decay from the peak of the response following stimulation to the resting baseline. The classical pattern occurred most frequently for the 1000 Hz and 2000 Hz activator signals, when they were presented at 15 dB SL. This pattern type was not related to subject group. That is, no group was significantly more likely to provide a classical decay pattern than any other.

The basis for the classical pattern is not evident. The fact that it occured more frequently for the mid-frequencies (i.e. 1000 Hz and 2000 Hz) may be related to the sensitivity of the reflex response. It has been shown that the reflex threshold is most sensitive to tonal stimuli centered at 1000 Hz and 2000 Hz (Peterson and Liden, 1972; Popelka, 1981).

Type II was the "double plateau" pattern in which the magnitude increased to a higher value after reaching what appeared to be a peak. It was observed that the first peak occurred in the expected time frame of 1 second and the second peak occurred during that portion of the function in which decay began. This was most common for 500 Hz and broad band noise. The possible basis of this pattern type was discussed in relation to the effects of age on the rate of reflex adaptation since it was more common for the young normal group than the older groups. It was suggested that future research be done to determine if one or both of the middle ear muscles were responsible for the double plateau pattern. The mechanism used to explain the occurrence of the double plateau pattern would also have to explain why this pattern was more common in older subjects.

The Type III pattern was the irregular "decay/ recovery" pattern of repeated decay and recovery. This was the most common pattern, accounting for over 1/3 of the total, and was equally distributed across groups, stimulus type and sensation level. It is a pattern of response that is familiar to engineers dealing with servo systems. It occurs for certain relationships among gains and time constants in the elements of complex feedback systems. The only reference to oscillation in the reflex decay functions known to this writer is by Moller (1984). He points out that the frequency, amplitude and rate of decay of the oscillation of the reflex response are all determined by the dynamics properties of the different elements of the reflex system. The basic explanation is that the reflex contraction that is initiated by an input sound reduces the efficiency of the middle ear and therefore attenuates the sound at the level of the cochlea. This attenuation may cause a partial relaxation of the reflex response. If this relaxation is too great and/or too fast, the sound level in the cochlea may rise enough to cause reactivation of the reflex. On the basis of this explanation we would expect the decay/recovery phenomenon to be most apparent for stimulus frequencies at which stapedius muscle contraction has the greatest effect on middle ear transmission, i.e. the lower frequencies. The results of the present study do not support this prediction because Type III patterns were equally common for all stimulus types. It appears, therefore, that the full explanation for this phenomenon is more complex and requires further investigation.

Type IV was the rapid/slow pattern showing a rapid decay followed by a slower exponential decay. This type occurred most frequently for the 2000 Hz activating signal. It also occurred more frequently for the young group than for the older groups. A discussion of this pattern type was presented in relation to the effects of age on the rate of reflex adaptation. It was hyothesized that the higher incidence of the Type IV for the young group than for the older groups may be related to differences in reflex onset times. Whether the results of a future study would support this hypothesis needs to be demonstrated.

In conclusion, the existence of different pattern types of the reflex decay curves was a novel and exciting finding. The reasons for the dependency of pattern type on subject group and stimulus type are not known. At the present time, one can only speculate on the underlying mechanisms for the decay patterns. Certainly, future research needs to be done in this area.

LIMITATIONS OF THE STUDY

Three out of the four experimental hypotheses were rejected based on the findings of the present study; there were no significant differences between old normal hearing subjects and subjects with a presbycusic hearing loss; age and presbycusic effects were not different for different stimuli; and age and presbycusic effects were not different for different sensation levels. Only the first experimental hypothesis was supported by the findings (i.e. there were significant differences between young normals and older normals). These age-related differences were found when the distribution of pattern types and the overall magnitude change vs. time data were examined. Had only the time constant approach been used in this study, the first hypothesis would have been rejected as well.

The level of confidence by which a hypothesis is accepted or rejected directly hinges on the limitations of the experiment. Like any piece of research, there were several limitations of this study:

1) **Experimental Design.** The experimental design used in this experiment could have precluded the demonstration of a significant age or presbycusic effect.

The experimental design was a randomized one in which the variability between groups was compared to the variability within groups. A different experimental design could have increased the chances of finding a significant age or presbycusic effect. For example, if an intrasubject design was used, the rate of adaptation would be measured in a given subject at different ages. The problems with such a design are obvious, since adaptation measurements would be made at different time intervals across a span of many years.

Besides using an intersubject design, the findings of this study were based on data collected on a small number of subjects within each group (n=12). It was observed that the inter-subject variability in the adaptation data within each group was extremely large. The large variability was noted in the overall magnitude values and in the time constant data. Such large inter-subject variability in adaptation data is not unique to this study. For example, Wilson et al (1984) have pointed out in their review of the adaptation literature that the majority of studies have observed large inter-subject variability. The large variability can pose a problem when one is dealing with small samples. There is always the possiblity that the large inter-subject variability can obsure any inter-group differences. For this reason, caution needs to be exercised when generalizing the findings where the effects of age and presbycusic hearing loss were not statistically significant. A study which included large numbers of young, old and presbycusic subjects could have demonstrated significant differences between the groups.

2) Elevated Acoustic Reflex Thresholds. The findings of the present study may have been influenced by the intensity levels at which adaptation functions were obtained. The adaptation measurements were taken at an intensity level which was 10 dB or 15 dB above the acoustic reflex threshold. The acoustic reflex threshold was defined as the lowest sound pressure level over two consecutive ascending trials that produced a .01 mmhos change between the mean baseline admittance of 50 pre-stimulus samples and the mean admittance of 50 post-stimulus samples. Because the reflex threshold served as the reference, it is important to compare the threshold data to those of previous studies.

It was found that the mean acoustic reflex thresholds (in dB SPL) were generally higher than those reported in the literature for both young and old normal hearing subjects. Specifically, the mean acoustic reflex threshold for tonal stimuli (.5, 1, and 2 kHz) were 6-8 dB higher for both groups compared to previous laboratory studies (see Tables 21 and 22). The mean acoustic reflex threshold for broad band noise was approximately 13 dB higher for the young group and 8 dB for the older groups. There are three possible sources for the elevation of the reflex threshold. These include: poor sensitivity of the reflex measurement system; calibration error; and different criterion used to define the threshold of the reflex.

The first possible source for the elevation of the reflex threshold is poor sensitivity of the reflex measurement system. As noted in the review of the literature, Popelka (1981) pointed out that a low sensitivity measurement system could result in elevated acoustic reflex thresholds. According to his estimation, a measurement system that was capable of detecting changes in impedance on the order of 60 acoustic ohms instead of 10 acoustic ohms would result in an elevation in threshold as large as 3 dB for tonal stimuli and 10 dB for noise stimuli. The measurement system used in the present study was capable of detecting less than a .001 mmhos change in admittance. The sensitivity was far below that needed to detect the .01 mmhos change which was used as the criterion for determining threshold. In addition, the change in mmhos (which directly corresponds

Table 20.

Summary of various studies on young normal hearing subjects. Mean ARTs (standard deviation) in dB SPL.

Study	Criterion/ Ms. device	500Hz	1000Hz	2000Hz	BBN
Flottorp et al. (1971)	JNC GLR	93	89	88	-
Beedle & Harford[a] (1973)	JNC SCR	94	90	89	-
Margolis & Popelka[b] (1975)	JNC OR	98 (3)	91 (2)	90 (2)	77 (5)
Margolis & Fox[b] (1977)	JNC P	94	90	92	75
Handler & Margolis (1977)		94 (6)	90 (5)	92 (5)	75 (8)
Silman et al (1978)	JNC SCR	93 (6)	91 (6)	93 (4)	76 (6)
Silman & Gelfand (1979)		91	89	91	77
Thompson et al (1980)	.01 mmHos SCR	100	93	96	-
Wilson (1981)	.01 mmHos C	91 (5)	90 (5)	91 (5)	72 (9)
Wilson et al (1984)	.01 mmHos C	97 (6)	91 (5)	92 (5)	76 (9)
Oviatt & Kileny (1984)	JNC OR	100 (6)	97 (5)	97 (5)	-
Present Study	.01 mmHos	101 (6)	97 (4)	99 (4)	88 (5)
Present Study	JNC	92 (4)	91 (4)	93 (3)	79 (5)

Table 21

Mean Acoustic Reflex Thresholds (standard deviations) in dB SPL for Tonal and Noise Stimuli for Normal-Hearing Older Subjects Reported in Laboratory Studies.

	Ages (in yrs)	ART			
		500 Hz	1000 Hz	2000 Hz	BBN
Handler & Margolis (1977)					
Silman (1979)	60-76	94 (4)	90 (6)	93 (6)	83 (11)
Thompson et al. (1980)	60-69[a]	100	93	98	-
Silman & Gelfand (1981)	61-76	91	88	92	82
Gelfand & Piper (1981)	60-76	95 (7)	91 (8)	92 (8)	84 (8)
Silverman (1981)	60-69[a]	95 (8)	90 (7)	92 (7)	85 (7)
Wilson (1981)	50-60	96 (7)	93 (6)	95 (5)	81 (9)
Present Study (.01 mmhos)	60-69	104 (4)	97 (6)	99 (6)	91 (8)
Present Study (jnc criterion)	60-69	98 (4)	92 (7)	95 (7)	85 (8)

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[a] Study reported data from subjects for other decades

to milliliter change in a syringe) was found to be linear as a function of digital unit change. Thus, the measurement system was not only capable of detecting a minute change in admittance (less than .01 mmhos) but that change was directly porportional to the change noted by the computer in digital units. A measurement error resulting from poor measurement sensitivity was considered unlikely.

The second source of error in estimating the threshold of the reflex response relates to the calibration of the stimuli used to elicit the reflex and/or the calibration of the system used to monitor the reflex response. The possiblity of a calibration error was explored at length in this study. Complete calibration of the measurement system and stimuli was conducted before data collection and it was carried out periodically throughout the course of the experiment, as outlined in Chapter 3. At the end of the experiment, the measurement system and stimuli were again checked for any calibration error. No error was discovered. A measurement problem resulting from an error in calibration was also considered unlikely.

A third source, the methods used to estimate the threshold, is the most probable one. The acoustic reflex threshold was defined as the lowest sound pressure level over two consecutive ascending trials that produced a .01 mmhos change between the mean baseline admittance of 50 pre-stimulus samples and the mean admittance of 50 post-stimulus samlple. In this criterion, there are two components. One component is the amount of admittance change needed to determine if a reflex response is present. The second component is the method by which the pre- and post-stimulus admittance values are specified.

Consider the first component, or the amount of admittance change needed to define reflex threshold. An admittance change of .01 mmhos used in this experiment was the same as that used by a few researchers (Thompson et al, 1980; Wilson and colleagues, 1978, 1981). For example, in the study on reflex growth by Thompson et al (1980), the criterion for reaching threshold was .01 mmhos. The mean thresholds for the tonal stimuli of the present study are in good agreement with theirs. These researchers used low passed filter noise, so a comparison can not be made between the reflex thresholds for noise due to the spectral differences. The admittance change used to define threshold by Wilson et al (1978) was also .01 mmhos. The thresholds for tonal and noise stimuli were higher than those obtained by Wilson et al. However, their study had an important drawback. Each participant was required to have a measureable reflex at 90 dB HL for the tonal stimuli and at 95 dB SPL for the broad band noise. Because of this requirement, the subjects were not chosen at random. The selection of subject was biased towards subjects with lower acoustic reflex thresholds. Because of the biasing in subject selection, a comparison between the data of the two studies should be made with caution.

The most worthwhile study for comparison purposes is the 1981 study by Wilson and colleagues. In this study, the researchers did not bias the selection of subjects. A .01 mmhos admittance change was used to define threshold and mean thresholds were reported for young and old normal hearing subjects. Despite the use of the same admittance change criterion and similiar subject selection, the present results are still significantly higher than those obtained by Wilson. The largest differences were observed for 500 Hz and the broad band noise stimuli for the young normal group (amounting to 10 dB at 500 Hz and 16 dB for broad band noise). This observation suggests that the first component of the threshold criterion (i.e. the amount of admittance change required) is not the cause of the disparate threshold findings.

The second component of the threshold definition (i.e. the method for comparing pre and post stimulus baseline) may have more to do with the elevation of the reflex thresholds. This component is different than that used in the past. In the study by Wilson et al (1981) just discussed, the sampling time and sampling techniques were different. The admittance output was sampled over three 100 msec periods for each stimulus presentation. The first sample was taken 150 msec before the onset of the activating stimulus to provide a measure of baseline admittance. Two additional samples were taken at 600-700 msec and 900-1000 msec post-stimulus. The average of these two samples was used as a measure of the admittance during the reflexive state. In the present study, the average of 50 samples over a period of 1500 msec before stimulus onset provided a measure of baseline admittance. The average of 50 samples over the last 1500 msecs of a 2000 msec signal was used as a measure of admittance during the reflexive state. The criterion used in the present experiment were more conservative than those used in the past in that a greater and more consistent change in immittance was required before deciding a reflex response at occurred. This could well account for the higher reflex thresholds across groups.

Differences in threshold criterion may help to explain the higher acoustic reflex thresholds for all groups. However, it does not explain why the threshold for the noise stimulus was more elevated than that for the tonal stimuli, particulary for the young normal subjects. This finding can be explained by the characteristics of the magnitude of the immittance change which occur just above the reflex threshold for noise activators in young normal subjects (Gelfand and Piper, 1981; Popelka, 1981). The amount of the immittance change near threshold is very small and the growth of this change with intensity is relatively slow until levels of 10 dB above the threshold for noise stimuli. In other words, the reflex growth function for broad band noise in young subjects has a curvilinear tail within a 10 dB range above threshold (Silman et al., 1978). Since reflexes were evaluated by using a strict threshold criterion in the present experiment, an elevated estimate of the noise threshold was obtained because larger reflex changes were needed to meet the threshold requirement. Therefore, the threshold was estimated at levels which were considerably higher on the normal reflex growth function. This would not affect the acoustic reflex thresholds to the same degree for tonal stimuli or for the older subjects because the growth function for these do not have a curvilinear tail near threshold (Gelfand and Piper, 1978).

The differences in ARTs cited above may have important implications for the reflex adaptation measurements. Because higher ARTs were obtained on average, the sound pressure levels used in this study may be higher than those used by other researchers, especially for the broad band noise stimulus. This means that the presentation levels were approximately 15 to 25 dB above the typical laboratory thresholds rather than at the nomimal levels of 10 and 15 dB. It is possible that age or presbycusic effect would have been shown had the reflex thresholds been consistent with those reported in the literature.

3) **Correction of Baseline Shift.** The procedure used to correct the baseline shift could have influenced the outcome of the present experiment. Recall from Chapter 2 that the baseline shift is a drift in the measured admittance from pre-stimulus baseline to post-stimulus baseline that is not related to the activation of the reflex. The shift can be measured during the resting state (or reflexive state) and is presumed to be due to negative pressure that develops

over time in the middle ear (Wilson et al, 1984). In this study, the assumption was made that the baseline shift is a linear function (Antablin et al, 1980). The baseline shift correction procedure involved calculating the gradient of the linear function between the mean admittances of 50 pre-stimulus and 50 post-stimulus samples over time.

The assumption of a linear shift in baseline has been supported by recent studies (Wilson et al, 1978; Antablin et al, 1980). However, it is possible that this assumption was erroneous in the present experiment for three reasons. First, it is not known whether baseline shift is identical during silent trials (no reflex activation) and stimulus trials (with reflex activation). Wilson et al (1978) and Antablin et al (1980) studied baseline shift in young normal subjects during silent trials over a long period of stimulation (210 seconds). The assumption of a linear shift during the reflexive state is based on the observation of baseline shift during the non-reflexive state. There is no reason to suspect that the baseline shift is altered by activation of the reflex. However, future studies need to be done to clarify this issue.

Second, the present study used the same correction procedure for both the young and older subjects. It is possible that the mean rate of baseline shift for the two age groups is different during silent trials. There may be muscular tonis differences as a function of age which would affect eustachian tube patency. The result would be differences in the rate of pressure buildup in the middle ear space for older subjects compared to their young counterparts. Future research would be required to investigate this aspect.

Third, the recovery time chosen in the present study may have influenced the calculation of post-stimulus baseline. Recall from Chapter 4 that a 3 minute recovery time was used to allow for the relaxation of the reflex response following stimulation. Immediately following the recovery phase, the computer calculated the mean of 50 sample as a measure of the post-stimulus baseline level. It is not known whether a 3 minute phase would allow for complete recovery of the reflex response following prolonged stimulation. Dallos (1964) reported that, for most individuals, the reflex returns to the resting baseline level after a period of 2 to 5 minutes after the activating stimulus is switched off. To date, there are no studies which have investigated the recovery of the reflex response after prolonged stimulation of several minutes. There are also no studies which have examined the reflex recovery phenomenon in older subjects. In the present experiment, the time allowed for reflex recovery was the same for the young and older groups. It is possible that the reflex recovery times are different as a function of age. Differences in the recovery of the reflex between the two groups would result in a miscalculation of the true post-stimulus baseline and hence result in the over- or under-correction of baseline shift. Additional research appears warranted to determine if the reflex recovery phenomenon is altered as a function of aging.

CONCLUSIONS

The following conclusions can be drawn from the results of the present study:

(1) Older subjects with normal hearing sensitivity do not exhibit reflex decay rates that are different from those of younger subjects when the rate of decay is defined by a time constant; however, there are different patterns of decay for the young and old normal hearing subjects for 2000 Hz and broad band noise activators.

(2) Four distinct patterns of decay were observed for young normal, older normal and presbycusic subjects that were related to both stimulus type and age.

(3) Presbycusic individuals with a mild to moderate hearing loss do not exhibit reflex decay rates that are different from those of young or old normal hearing individuals.

(4) The distribution of the four pattern types was not related to presbycusic hearing loss. The presbycusic subjects exhibited patterns of decay similiar to the older normal hearing subjects.

(5) The rate of decay was affected by stimulus type for the young normal, older normal and presbycusic subjects; however, there were no interactions between the age or presbycusic hearing loss and stimulus type.

(6) The rate of decay was affected by sensation level for the young normal, older normal and presbycusic subjects; however, there were no interactions between age or presbycusic hearing loss and sensation level.

Chapter 6.

CLINICAL IMPLICATIONS AND FUTURE DIRECTIONS

CLINICAL IMPLICATIONS

The usefulness of the acoustic reflex decay test in identifying neurotologic pathology such as acoustic tumors is determined by the ratio of correctly identified cases to incorrectly identified cases. Typically, the clinical reflex decay test involves the measurement of the reflex response over a 10 second period to tonal stimuli at 500 Hz and/or 1000 Hz presented at 10 dB above the acoustic reflex threshold. The criterion for abnormal decay is defined as 50% or greater decay occurring within this 10 second period. The present study was concerned with the effects of age and presbycusic hearing loss on the rate of reflex decay. Clinically the question must be asked, "does aging or presbycusic hearing loss affect the criterion that is presently in use for determining abnormal decay ?"

Before attempting to answer this question, the issue related to the reflex threshold elevation needs to be addressed. It was noted in the previous chapter that the reflex thresholds were elevated compared to past laboratory studies. It was further pointed out that because higher reflex thresholds were obtained on average, the sound pressure levels used in this study may be higher than those used by other researchers. This means that the presentation levels were approximately 15 to 25 dB above the typical laboratory thresholds rather than at the nominal levels of 10 dB and 15 dB. This issue is not critical when we discuss the adaptation results in relation to clinical data. The acoustic reflex thresholds obtained in this study, although measured under laboratory conditions, are in good agreement with past clinical studies. The data at 500 Hz and 1000 Hz at a sensation level of 10 dB is comparable to that obtained in the clinical situation (see Gelfand, 1984).

The present study showed that the rate of reflex decay was not significantly different for old subjects compared to young subjects, when the rate was quantified by a time constant. As pointed out in the previous chapter, the time constant approach taken in this study was very different from that used in the clinical test of reflex decay. There are three important differences. First, the time constant was calculated using portions of the adaptation curve depending on the pattern type of the curve. For instance, the time constant for the Type II (double plateau) curve was calculated by using the portion of the curve following the second plateau. For the Type III (decay/recovery) pattern, the mean time constant value was derived by averaging the time constants for two or more portions of the curve. In the clinical test of reflex decay the half life is calculated by using the entire decay curve regardless of the its morphology. Second, the time constant is mathematically derived by fitting an exponential curve to the adaptation function. The clinical half life measure is derived by using a linear function. Third, each adaptation function was corrected for baseline shift in the present study. To date, a baseline correction technique has not been applied in the clinical test of reflex decay.

Despite the above differences in the methods used to derive a measure of decay rate, it is interesting to look at how the time constant values obtained here would compare to a half life measure. By using a mathematical equation, the time constant values can be converted into half lives. This can be done by multiplying the mean time constant by log (2). The converted values are shown in Table 24. Of interest clinically, are the half lives at 500 Hz and 1000 Hz.

Table 22. Mean half life times (in seconds) and confidence limits (+/- 2 s.d.) for young normal hearing, old normal hearing, and presbycusic groups for 500 Hz and 1000 Hz at 10 dB SL and 15 dB SL. The half life times were converted from the mean time constant multiplied by log (2). (Note that the original means and time constants were calculated from log (1/b) and then converted back to time units).

		500 Hz	1000 Hz
Young Normal Hearing			
	10 dB SL	81 (32-175)	42 (13-130)
	15 dB SL	104 (46-237)	44 (21-95)
Old Normal Hearing			
	10 dB SL	65 (17-250)	30 (11-94)
	15 dB SL	76 (34-171)	35 (13-87)
Presbycusic			
	10 dB SL	59 (25-140)	32 (6-158)
	15 dB SL	65 19-218	32 (11-94)

The results indicate that the lower confidence intervals (- 2 s.d.) of converted half life times for both young and old normals exceed 10 seconds. This finding suggests that the currently-employed clinical criterion does not need to be modified when testing a young subject or an older subject who has normal hearing sensitivity.

The situation is a little different for the presbycusic group. The results indicate that for these subjects the lower confidence interval (- 2 s.d.) exceeds 10 seconds for the 500 Hz stimulus, but falls below 10 seconds for the 1000 Hz stimulus. This implies that the present clinical criterion may need to be modified when testing a subject with a presbycusic hearing loss. Use of a 10 second criterion would result in a number of false positive cases because of an abnormal finding at 1000 Hz.

Whether or not the clinical criterion should be modified for the presbycusic subjects depends on the degree of specificity (correction rejection of VIII n. pathology) or sensitivity (correction identification of VIII n. pathology) a clinican wishes. Based on the present results, one can suggest modifications of the existing criterion to reduce the number of false positive cases among older subjects with a cochlear hearing loss related to aging.

One way to reduce the number of false positive cases among the presbycusic subjects (and thus increase the specificity of the decay test) would be to use a 5 second criterion rather than the 10 second criterion. The use of a 5 second criterion has been advocated by several researchers, based on reflex decay findings in patients with cochlear and eighth nerve lesions (Anderson et al, 1969; Kurdziel et al, 1979; Olsen et al, 1981).

Kurdziel et al (1979) presented data on 59 patients with Meniere's disease, 149 patients with cochlear hearing loss of various etiologies, and 48 subjects with VIII nerve pathology. Acoustic reflex decay was recorded for 500 Hz and 1000 Hz using a 10 second tone. Their results were then analyzed according to the presence of abnormal decay within a 10 second period and within a 5 second period. Abnormal decay occurred for 25% of the Meniere's disease patients and 20% of the other cochlear patients when a 10 second criterion was used. Reflex decay was less frequent than absence of reflexes for the VIII nerve tumor group. However, when reflex decay could be measured, 15% of this group exhibited abnormal decay within 10 seconds. Using a 5 second criterion, the percentage of persons with cochlear hearing loss showing abnormal results dropped to 22 % and 14 % for the two cochlear groups, while the percentage of tumor patients showing abnormal decay remained the same. These researchers suggest that use of a 5 second criterion can increase the specificity of the decay test without sharply reducing its sensitivity.

Another way to reduce the number of false positives among presbycusic subjects, based on present data, would be to perform the reflex decay test at 15 dB above the acoustic reflex threshold. The lower confidence level for 1000 Hz at 15 dB SL for the presbycusic group is 11, so the majority of presbycusic subjects would not show an abnormal decay result using a 10 second criterion here.

Mangham et al (1980) suggested that the combined use of 10 dB and 20 dB SL may enhance the diagnostic value of the reflex decay test. They found that the rate of decay for cochlear hearing loss subjects decreased with an increase in intensity from 10 dB to 20 dB above acoustic reflex threshold. Conversely, the rate of decay for their retrocochlear subjects increased with an increase in intensity level. Thus, they suggest that the clinical use of two sensation levels can help reduce false positive findings among cochlear subjects while increasing the sensitivity of the test by correctly identifying eighth nerve pathology.

As Jerger and Jerger (1983) point out, there is nothing sacred about the criterion currently in use in the clinic. The choice of criterion depends on whether the clinican wishes high specificity or high sensitivity. For example, many clinicans will place greater emphasis on an abnormal decay finding which occurs within the first 5 seconds than one that occurs at 9 seconds. Jerger and Jerger (1983) argue that, for a test like reflex decay, sensitivity is a more important property than specificity. This is because the reflex decay test serves as a screening procedure for eighth nerve site. A positive reflex decay finding would lead to more extensive studies, such as brainstem evoked potential testing and/or radiographic followup. A false positive finding would be discovered by these additional tests. However, if the reflex decay test yields a negative result in a patient with an acoustic tumor, there is danger that further diagnostic testing would not be performed and so the false negative finding is not found out.

There are at least two important implications of the reflex decay rate results for the three groups in this study. First, based on these results, there is no need to modify the currently accepted clinical criterion when testing young or older normal hearing subjects. Second, the clinical criterion may need to modified when testing subjects with a mild to moderate presbycusic hearing loss. The proposed modifications in the existing criterion at 1000 Hz (i.e. use of a 5 second time period or use of a 15 dB SL) could improve the specificity of the reflex decay test. However, caution must be exercised in accepting these modifications. It is not known how such modifications would alter the sensitivity of the reflex decay test. Additional research is necessary to determine which response criteria result in the lowest numbers of false-positive and false-negative responses. In particular, decay rate data, similiar to that presented in this study, needs to be obtained for subjects with eighth nerve pathology.

Another important implication of the present study relates to the different forms of decay. It is conceivable that an abnormal decay finding could be the result of defining a half life in the presence of an ambigous decay pattern. For example, the most frequent pattern noted for all subjects and conditions was the Type III, or the decay/recovery pattern. It has already been discussed how this pattern can create problems in the calculation of a half life. Specifically, a half life could be measured within 10 seconds if the decay portion of the curve is considered without attention to the recovery portion.

The age dependency of certain pattern types may further compound the problem of defining abnormal decay in older subjects. For instance, the Type II, or "double plateau" pattern occurred most frequently for older subjects stimulated with a 500 Hz tone (and broad band noise). If the half life time is calculated from the first plateau, an abnormal decay finding may be obtained within the first 10 seconds of stimulation.

The results imply that a consideration of pattern types, particularly for elderly patients, might enhance the clinical value of the reflex decay test in differential diagnosis. Future studies should investigate the different pattern types found during the 10 second period used clinically and make recommendations for defining half life in the presence of these, often ambigous, patterns.

Finally, the issue of baseline shift correction has clinical relevance. Ideally, corrections for the baseline shift should be made whenever there is a substantial difference between the pre- and post-stimulus baselines. Corrections for baseline shift are not routinely done in the clinical test of reflex decay. It has been shown by Antablin et al (1980) that the admittance can shift by

.002 mmhos or greater within a 10 second period. Therefore, it is expected that baseline shift occurs more often than not within the 10 second period used in the clinical reflex decay test. Without correcting for baseline shift, the clinican could easily underestimate or overestimate the amount of reflex decay that is present and fail to correctly identify abnormal decay behavior. Additional work is needed to explore the consequences of baseline shift in the clinical situation and to devise ways of dealing with its correction. Certainly, the baseline correction procedure used in the present study could be easily adopted for clinical use.

FUTURE DIRECTIONS

The rate of reflex adaptation, defined by a time constant, was not significantly different between groups of young normal hearing, older normal hearing, and presbycusic subjects. However, one of the limitations of the study was that adaptation data were not collected at levels close to acoustic reflex thresholds, as defined by typical laboratory studies. A future study should collect similar data using levels close to reflex threshold (e.g. 5, 10, 15, and 20 dB). Additionally, the study should include a larger number of subjects within each group.

A promising area for future research is the study of the morphological differences in the adaptation functions. In the present study we found that the form of the decay curve was clearly a function of age and stimulus type. The reasons for these differences are not known. Therefore, future investigations should be done to examine the form of the adaptation functions of young normals, older normals, and subjects of all ages with different degrees of cochlear hearing loss in greater detail.

There was large intersubject variability in the time constant data. Such large intersubject variability has also been present in past adaptation studies but the source is not known. The large variability within subject groups clouds the statistical inter-group differences and weakens the use of the reflex decay test in the differential diagnosis of auditory pathology. Therefore, the possible factors which contribute to the variability should be examined in young normal subjects. For instance, a future study could examine differences in baseline admittance, reflex latency or maximum reflex magnitude across subjects to determine the relationship of these factors to decay rate.

The presence of large intersubject variability in the decay rate data necessitates the need to establish confidence limits for various clinical populations. Confidence intervals were measured for a small group of young normal, old normal and old subjects with a mild to moderate cochlear hearing loss in the present study. Similiar data need to be generated on subjects typically seen in the clinical situation. Most importantly, in order to strengthen the sensitivity of the reflex decay test, confidence intervals should be determined for a group of subjects with confirmed eighth nerve lesions.

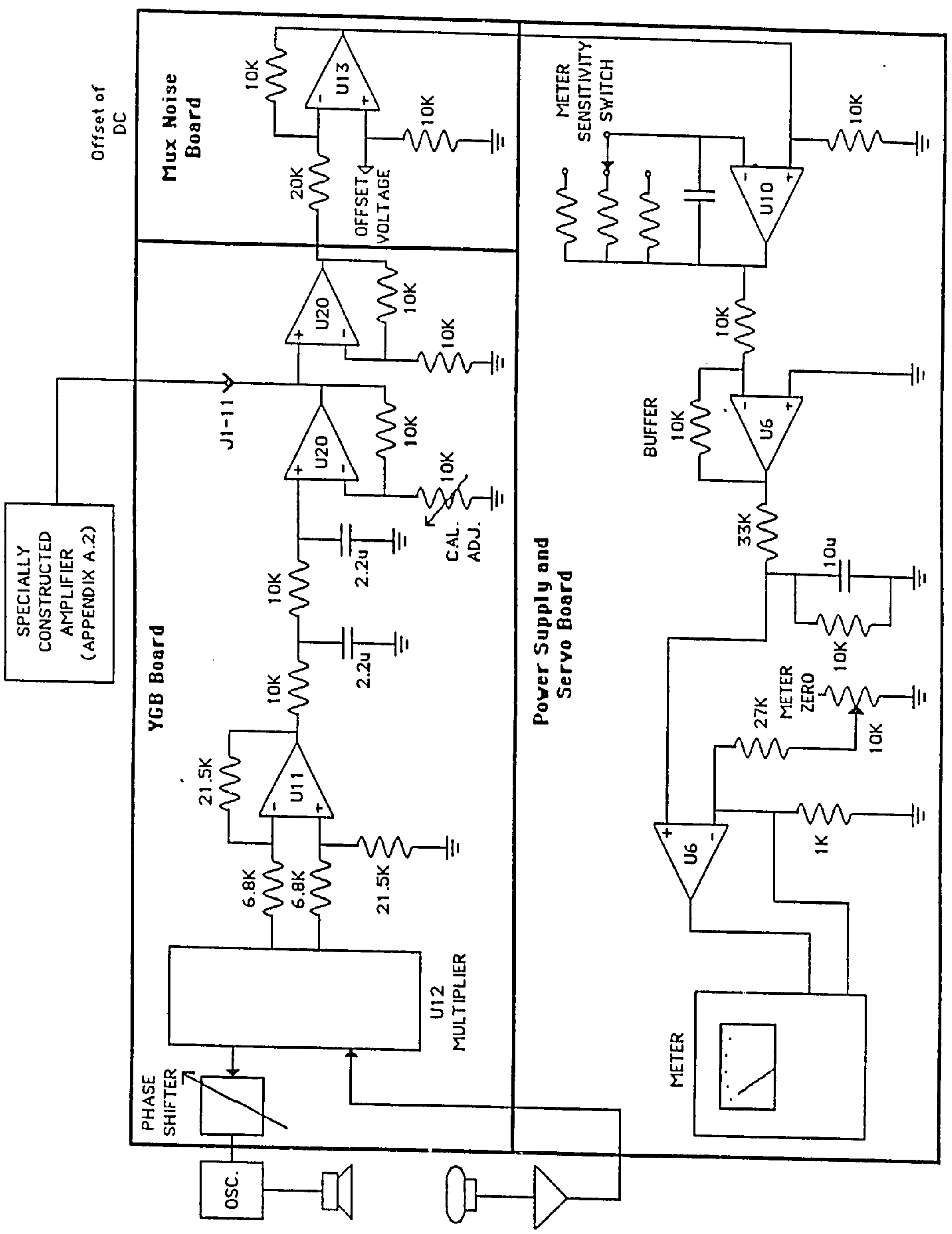
It was mentioned that acoustic reflex adaptation measurements reflect different physiologic mechanisms than that for the other reflex measurements (e.g. threshold, latencey, magnitude growth). Therefore, a subsequent study should be conducted that examines the various reflex measurements within the same groups of young and old normal hearing subjects.

In past studies, the acoustic reflex threshold was found to be unchanged by cochlear hearing loss, unless the hearing loss exceeded 50 dB HL. The rate of adaptation for the presbycusic subjects with a mild to moderate hearing loss were not significantly different than for the subjects with normal hearing. It is possible that hearing loss greater than this could alter the rate of adaptation. Additional research should be carried out which examines the rate of adaptation in subjects with varying degrees of cochlear hearing loss.

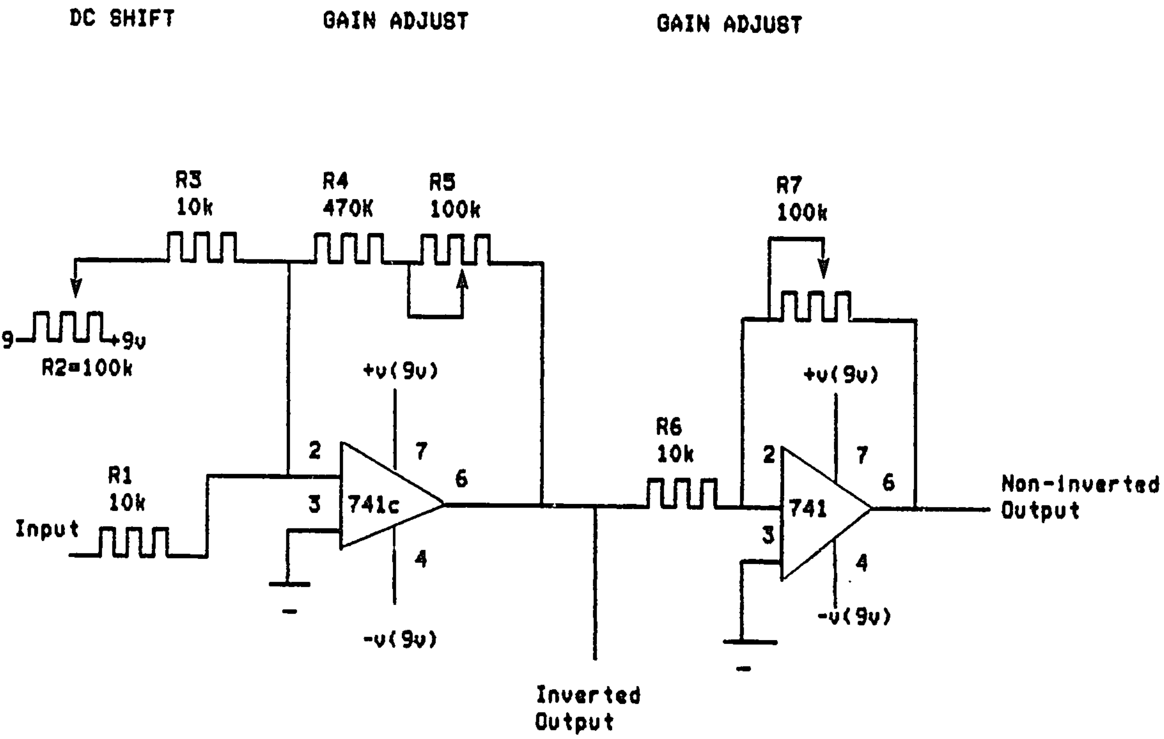
The baseline correction procedure used in this study could easily be applied to the clinical measurement of reflex decay. Whether the baseline shift within the 10 second period used clinically warrants such a technique remains to be seen. A subsequent study could examine the degree of baseline shift exhibited in the different patients typically encountered in the clinic.

The most striking conclusion is that some of the basic assumptions underlying the clinical application of reflex decay are open to serious question. In particular, the form of the reflex decay functions and the factors contributing to the differences among functions can result in an inaccurate diagnosis of pathological decay, especially in the older subject.

Appendix A. 1


Offset of DC
Mux Noise Board
10K
U13
10K
20K
OFFSET VOLTAGE
METER SENSITIVITY SWITCH
10K
U10
SPECIALLY CONSTRUCTED AMPLIFIER (APPENDIX A.2)
J1-11
U20
10K
10K
U20
10K
10K
CAL. ADJ.
10K
2.2u
10K
2.2u
10K
BUFFER
10K
U6
33K
10u
10K
Power Supply and Servo Board
YGB Board
21.5K
U11
6.8K
6.8K
21.5K
METER ZERO
27K
10K
1K
U6
U12 MULTIPLIER
PHASE SHIFTER
METER
OSC.

APPENDIX A.2
SCHEMATIC DIAGRAM OF MIXER AMPLIFIER



Non-inverted gain: 47-57
Inverted gain: 47-470

Appendix B.1

Ages (in years) and Hearing Threshold Levels (in dB HL) for Young Normal Subjects.

Subject	Age	250Hz	500Hz	1000Hz	2000Hz	4000Hz	8000Hz
1.	27	10	10	10	5	10	5
2.	23	0	5	5	5	5	5
3.	20	5	0	5	0	5	5
4.	29	5	10	5	5	10	10
5.	23	5	0	5	5	0	5
6.	24	5	5	10	5	5	5
7.	29	5	0	0	0	5	15
8.	27	0	10	5	0	5	5
9.	26	5	0	5	0	15	5
10.	26	5	5	0	0	5	5
11.	29	5	5	0	0	5	5
12.	20	5	5	5	0	5	5

Appendix B.2

Ages (in years) and Hearing Threshold Levels (in dB HL) for Old Normal Subjects.

Subject	Age	250Hz	500Hz	1000Hz	2000Hz	4000Hz	8000Hz
1.	61	10	10	10	5	15	20
2.	69	5	10	10	10	20	10
3.	63	5	5	5	5	10	10
4.	63	5	5	5	5	10	10
5.	69	5	5	15	15	15	20
6.	67	20	20	20	15	20	20
7.	64	15	10	5	5	15	15
8.	62	5	0	5	5	15	10
9.	64	10	5	5	10	5	10
10.	60	5	10	10	5	20	20
11.	68	5	10	20	20	15	20
12.	64	10	15	15	5	20	15

Appendix B.3

Ages (in years) and Hearing Threshold Levels (in dB HL) for Presbycusic Subjects.

Subject	Age	250Hz	500Hz	1000Hz	2000Hz	4000Hz	8000Hz
1.	66	10	5	10	20	35	40
2.	64	10	10	15	25	35	45
3.	60	15	5	10	15	35	40
4.	69	5	10	10	15	30	40
5.	61	5	0	0	10	40	35
6.	68	10	10	5	20	30	35
7.	62	20	15	10	25	35	40
8.	69	15	15	15	35	50	50
9.	69	15	15	20	30	45	50
10.	66	10	15	20	25	45	35
11.	64	15	15	20	25	40	45
12.	64	15	20	15	30	40	45

Appendix C.1

CASE HISTORY FORM

Name: ______________________ D.O.B.: ______ Age: ____

Date: _________ Sex: ______

A. Complaint of Hearing Problem

____

____

B. Date of Onset ___________________________

C. What was Onset Related to?

____

____

D. Better Ear ____________ Fluctuate Hearing ____________

E. History of Noise Exposure

____

____

F. History of Ear Pathology or Surgery

____

____

G. History of Ototoxic Drugs

____

____

H. History of Medical Problems

____

____

I. History of Muscular Disorders

____

____

Appendix C.2

INSTRUCTIONS TO SUBJECTS

Acoustic Reflex Adaptation Study

This is a test to measure the amount of time it takes for a small muscle in your ear to contract and then relax. A plug will be placed in one ear and an earphone will be place over the opposite ear. You will feel a slight sensation of pressure in the beginning of the test. Then you will hear some loud tones or noise, that may last a few seconds or may last up to a minute or so. The tones will be very loud, but if the tones are ever at an intolerable level, please let me know.

To get good results, you must sit very still. Between each test run, I will let you have a rest. But during the test, please relax. Don't move, swallow, chew or yawn. At the end of each test run, please do not move until I tell you, even if the tone goes off. The recording is still running before the tone goes on and after the tone goes off.

REMEMBER: TRY NOT TO MOVE DURING EACH TEST RUN

TRY NOT TO CHEW, SWALLOW, OR COUGH DURING THE TEST

LET ME KNOW IF THE SOUND BECOMES UNCOMFORTABLE

Appendix C.3

Consent to Act as a Research Subject in a Dissertation Project at the Graduate Center of the City University of New York.

The purpose of this study is to determine the effects of various tones and noise on the amount of time it takes for a small muscle in your ear to contract and then relax. It is hoped that the results of this study will give us information on certain aspects of normal hearing and aid in the diagnosis of hearing loss.

In order to measure the reflex response, it is necessary to place a small probe (earplug) in one ear canal and present sounds to the other ear through an earphone. Some of the sounds will be loud, but never at a hazardous level. There are no known adverse effects from this test.

The researcher is a licensed and certified Audiologist (New York State License #480, (CCC-A, 1979). Before your participation in the study, the researcher will test your hearing and visually inspect your ear canal for abnormalities.

While the results of this study will be published, no personal information on you will be disclosed to anyone unless it is made anonymous.

You are free to withdraw your consent and discontinue your participation in this study at any time.

AUTHORIZATION: I have read the above and agree to participate in the study described with the understanding that I may withdraw at any time, without penalty.

Appendix D.1

Acoustic Reflex Thresholds (in dB SPL) for Young Normal Hearing Subjects

Subject	500 Hz	1000 Hz	2000 Hz	BBN
1.	108	98	101	84
2.	105	94	107	98
3.	90	96	99	90
4.	94	90	95	86
5.	100	92	95	88
6.	94	92	101	84
7.	108	102	97	91
8.	100	98	99	80
9.	104	100	99	84
10.	108	100	101	92
11.	96	100	93	86
12.	102	96	99	92

Appendix D.2

Acoustic Reflex Thresholds (in dB SPL) for the Older Normal Hearing Subjects

Subject	500 Hz	1000 Hz	2000 Hz	BBN
1.	102	100	107	101
2.	106	94	107	101
3.	100	86	95	76
4.	108	104	113	84
5.	104	84	97	86
6.	96	98	91	92
7.	108	94	97	94
8.	102	100	99	94
9.	104	96	105	86
10.	108	98	95	88
11.	102	102	103	84
12.	110	104	103	102

Appendix D.3

Acoustic Reflex Threshold (in dB SPL) for the Presbycusic Subjects

Subject	500 Hz	1000 Hz	2000 Hz	BBN
1.	96	90	95	90
2.	106	98	105	96
3.	104	94	89	80
4.	110	94	105	101
5.	90	94	105	86
6.	104	100	108	84
7.	108	100	89	94
8.	104	104	107	101
9.	104	98	101	94
10.	100	98	101	94
11.	100	96	101	100
12.	104	98	91	84

Appendix E.1

Individual Admittance Values (in digital units) for a 500 Hz Activator During the Reflex Onset Period. Top Line: 10 dB SL; Bottom Line: 15 dB SL.

Time (sec)	.08	.16	.24	.32	.40	.48	.56	.64	.72	.80	.88	.96
Young Normals												
1	40	166	435	605	761	787	829	846	940	930	872	895
	91	416	920	1145	1256	1189	1165	1222	1143	1095	1079	1122
2	42	307	322	312	317	389	312	322	290	371	335	326
	23	325	454	512	525	552	533	566	610	535	613	576
3	11	99	725	1078	1175	1204	1233	1238	1217	1131	1105	1121
	35	29	575	855	893	908	929	931	967	987	957	965
4	182	197	403	523	679	766	810	803	814	888	886	875
	34	603	1070	1133	1233	1335	1366	1356	1362	1406	1396	1368
5	77	321	442	782	767	984	942	944	1037	1048	1128	986
	55	682	859	1243	1244	1378	1342	1345	1336	1372	1367	1359
6	135	671	875	898	921	998	1008	974	957	1028	1002	982
	74	623	929	1147	1223	1234	1249	1285	1262	1258	1306	1316
7	94	335	637	717	757	672	666	715	677	655	648	720
	137	752	1081	1148	1145	1109	1091	1031	1062	1077	1068	1078
8	10	210	424	488	525	539	508	477	467	459	475	487
	33	404	704	776	778	763	768	787	793	787	759	715
9	160	400	685	683	636	689	767	738	680	754	730	706
	195	379	639	792	835	784	829	926	912	837	827	893
10	73	393	620	599	623	567	648	601	583	620	621	574
	100	238	466	651	690	737	743	692	669	692	633	621
11	234	1350	1279	1178	1231	1119	1069	1106	1121	1093	1074	1127
	510	1362	1447	1414	1397	1367	1368	1330	1282	1313	1260	1264
12	120	344	650	745	759	815	888	862	849	913	934	858
	81	667	921	1079	1122	1108	1124	1157	1133	1129	1150	1174
Older Normals												
1	26	523	638	811	661	786	407	567	637	471	601	513
	10	356	391	466	417	455	327	545	390	439	410	395
2	95	255	365	406	421	396	412	415	356	345	380	385
	108	297	439	487	517	462	479	516	486	473	495	496
3	47	257	514	629	659	710	758	740	745	793	790	753
	106	655	1010	1128	1231	1228	1280	1320	1305	1233	1267	1321
4	55	267	453	511	536	590	595	574	566	597	489	483
	122	242	504	560	475	559	594	502	523	553	584	601
5	19	266	583	607	593	574	538	474	469	465	482	478
	147	391	702	792	815	809	815	766	714	628	621	579
6	169	115	351	467	516	505	575	548	565	642	654	645
	245	398	625	809	849	867	873	936	944	878	888	874
7	104	228	296	360	460	494	468	473	521	503	471	487
	78	316	507	560	456	542	607	555	543	565	558	517
8	213	555	748	784	751	787	857	765	762	787	823	857
	714	999	1109	1046	990	1035	1032	986	1023	1000	1027	1001
9	114	197	271	357	403	410	453	511	485	462	485	520
	89	319	466	485	509	561	609	565	562	607	624	581
10	171	120	210	291	314	260	371	461	371	398	350	441
	72	133	311	331	328	363	390	322	331	353	376	359
11	215	410	681	724	855	799	769	741	782	797	769	791
	132	400	609	690	690	716	666	651	740	723	742	744
Presbycusic												
1	103	276	458	428	454	503	541	473	483	503	468	451
	179	567	696	789	875	876	831	855	898	842	826	852
2	102	853	2073	2325	2430	2273	2318	2397	2366	2314	2415	2402
	91	916	2188	2553	2696	2647	2595	2659	2669	2599	2599	2640
3	155	312	338	257	354	352	324	375	393	435	470	417
	253	335	444	467	472	436	449	499	510	495	470	557
4	80	397	475	619	729	739	704	733	787	746	680	707
	66	434	711	733	852	890	809	828	858	848	801	891
5	186	130	112	142	288	390	427	487	489	509	537	531
	52	25	278	451	496	549	565	614	579	605	617	581
6	126	166	238	319	386	363	409	443	413	375	422	431
	60	208	482	484	450	558	606	540	517	617	613	555
7	40	350	592	575	579	651	683	643	658	700	647	664
	102	401	617	693	722	708	722	776	794	734	741	764
8	97	364	597	649	709	651	678	678	624	673	731	712
	151	518	682	698	768	766	718	740	779	719	713	771
9	106	135	341	365	397	440	483	514	445	473	444	488
	107	417	590	578	637	661	628	592	604	623	623	591
10	93	51	123	201	275	315	282	292	326	359	370	355
	119	145	261	328	392	419	427	446	489	509	514	501
11	10	28	61	75	84	126	159	155	155	142	190	199
	187	236	299	352	375	390	376	386	407	429	419	405
12	10	179	388	330	300	284	266	279	297	286	286	320
	10	344	731	733	704	747	739	749	760	760	728	750

Appendix E.2

Individual Admittance Values (in digital units) for a 1000 Hz Activator During Reflex Onset Period. Top Line: 10 dB SL; Bottom Line: 15 dB SL.

Time (sec)	.08	.16	.24	.32	.40	.48	.56	.64	.72	.80	.88	.96
Young Normals												
1	124	75	153	336	522	584	559	568	607	633	586	551
	130	617	1215	1348	1372	1429	1409	1330	1231	1245	1269	1210
2	41	89	203	252	292	259	285	289	277	261	300	358
	15	233	385	452	474	452	484	475	431	438	490	482
3	106	86	426	1193	1074	1193	1253	1277	1282	1331	1345	1305
	94	144	685	1177	1345	1373	1366	1417	1431	1381	1378	1350
4	149	107	393	658	822	913	1052	1118	1094	1141	1213	1232
	115	130	488	780	952	1082	1213	1213	1255	1294	1314	1352
5	187	129	332	544	766	856	896	976	1047	1111	1059	1172
	131	244	511	811	1051	1193	1291	1350	1349	1375	1321	1320
6	161	314	625	1114	1079	1114	1159	1210	1272	1281	1291	1336
	112	611	1054	1331	1447	1464	1545	1593	1588	1569	1612	1648
7	172	576	875	1129	1224	1179	1155	1214	1208	1185	1205	1233
	144	674	1073	1229	1304	1341	1295	1313	1390	1364	1335	1381
8	37	412	646	636	628	638	633	628	592	586	533	537
	12	522	808	838	822	782	748	726	739	719	702	682
9	138	160	505	735	745	777	793	873	818	872	843	875
	78	270	681	866	951	929	890	1017	1012	842	941	959
10	114	110	161	372	661	705	721	745	785	741	634	664
	133	264	540	791	859	942	962	925	958	991	995	915
11	62	1254	1193	1249	1135	1147	1096	937	1004	1034	1028	1009
	91	1219	1328	1356	1340	1322	1343	1329	1371	1324	1346	1374
12	100	156	514	801	859	907	961	947	928	960	990	968
	136	468	1010	1193	1217	1275	1304	1270	1210	1261	1259	1215
Older Normals												
1	76	531	679	667	655	646	695	756	714	690	696	669
	107	518	696	777	745	764	792	780	752	726	746	778
2	157	227	340	354	392	440	416	399	433	420	408	366
	52	225	314	368	408	457	428	411	473	418	388	387
3	148	373	670	803	885	957	936	946	1004	1026	1007	977
	35	536	970	1265	1194	1184	1269	1259	1239	1272	1298	1301
4	128	263	490	591	627	677	639	630	708	733	681	620
	55	271	693	885	874	834	831	805	768	806	763	750
5	37	87	227	265	298	432	316	344	396	449	391	371
	194	226	375	483	540	500	530	538	533	509	552	539
6	198	181	535	679	779	888	775	799	817	803	814	879
	147	83	341	600	761	861	898	933	887	823	834	916
7	189	284	346	462	498	475	451	525	471	473	506	542
	92	256	316	402	426	406	443	413	471	435	457	439
8	174	710	883	616	655	754	761	716	740	749	714	685
	300	1183	1309	1201	1055	938	1013	1015	918	963	1001	1001
9	124	213	309	424	499	464	474	534	556	497	523	555
	172	332	417	552	628	652	633	663	697	638	649	676
10	128	113	104	165	246	356	329	441	437	364	367	447
	134	137	239	271	339	437	454	433	469	465	431	397
11	170	362	650	766	812	825	902	930	941	933	974	946
	134	397	692	835	916	969	940	958	1003	1022	976	994
12	195	446	770	512	538	518	516	560	616	629	640	654
	88	587	1017	1036	1044	1075	1126	1082	1038	1125	1198	1168
Presbycusic												
1	167	360	563	621	741	776	781	825	772	752	773	805
	111	433	593	597	633	681	682	664	722	741	677	675
2	87	157	1077	1872	2261	2440	2482	2447	2477	2585	2620	2596
	107	434	1673	2366	2655	2742	2711	2730	2788	2792	2757	2773
3	229	285	333	337	484	473	462	468	550	498	478	469
	183	234	478	468	453	404	496	448	529	557	624	577
4	165	202	396	436	462	495	535	529	501	480	490	442
	93	260	521	596	655	724	702	686	709	700	600	610
5	207	94	135	202	505	687	641	697	820	892	832	830
	214	140	295	594	880	1076	1192	1134	1161	1266	1246	1189
6	62	238	478	544	600	600	560	587	634	635	584	625
	127	405	591	711	816	830	806	832	880	828	813	847
7	120	361	617	743	751	753	802	822	808	814	795	849
	160	180	438	612	701	647	645	712	695	657	673	728
8	112	404	559	620	669	617	544	528	561	548	513	563
	211	483	748	851	882	801	744	725	705	669	661	658
9	205	368	574	587	694	669	642	673	685	609	766	725
	157	372	559	689	738	730	694	735	774	721	713	785
10	104	74	186	288	325	309	370	406	421	408	426	497
	86	132	303	337	409	491	524	562	568	610	670	660
11	108	250	392	469	548	627	665	657	659	695	717	712
	66	288	492	549	591	607	645	634	679	693	714	765
12	10	431	453	474	479	543	487	442	440	443	437	447
	10	900	1061	1054	981	947	926	934	956	957	984	970

Appendix E.4

Individual Admittance Values (in digital units) for a Broad band Noise Activator During Reflex Onset Period.
Top Line: 10 dB SL; Bottom Line: 15 dB SL.

Time (sec)	.08	.16	.24	.32	.40	.48	.56	.64	.72	.80	.88	.96
Young Normals												
1	63	68	245	454	641	784	852	834	839	867	919	880
	113	361	1021	1307	1428	1450	1450	1506	1481	1477	1465	1491
2	0	119	289	303	268	304	410	288	389	488	280	263
	13	251	440	544	487	510	463	455	440	446	420	472
3	15	41	684	1142	1282	1279	1328	1404	1363	1354	1417	1443
	75	118	799	1228	1362	1352	1330	1381	1428	1410	1385	1380
4	76	165	499	732	858	986	1083	1101	1115	1088	1148	1193
	67	367	799	1072	1201	1264	1297	1328	1387	1365	1412	1428
5	76	165	499	732	858	986	1083	1101	1115	1088	1148	1193
	58	590	1108	1271	1369	1457	1474	1476	1487	1541	1499	1470
6	185	323	645	884	1015	1050	1122	1072	1043	1051	1076	1031
	90	523	979	1278	1415	1503	1482	1411	1398	1424	1390	1343
7	47	386	863	1063	1106	1132	1238	1216	1196	1256	1241	1157
	31	467	1123	1379	1423	1486	1529	1454	1412	1432	1498	1496
8	17	228	480	574	592	618	625	607	584	552	539	541
	20	442	704	771	806	795	778	754	750	784	773	807
9	177	287	440	497	535	580	635	616	651	653	649	625
	104	495	719	591	683	892	569	622	670	750	700	703
10	196	125	316	557	707	828	736	746	786	764	717	734
	63	117	528	749	819	919	898	839	893	897	858	770
11	79	1052	1192	1088	1101	1091	1027	1045	1104	1032	992	1011
	111	1194	1347	1379	1433	1441	1380	1352	1430	1368	1372	1386
12	112	416	915	1089	1180	1256	1268	1260	1300	1309	1292	1282
	60	346	962	1185	1292	1366	1377	1369	1361	1405	1414	1341
Older Normals												
1	129	549	576	666	754	679	681	675	697	688	637	700
	76	602	713	713	744	816	806	722	754	727	753	675
2	51	177	294	354	379	429	432	368	365	404	397	389
	30	156	373	408	378	438	412	372	333	385	415	449
3	173	362	576	608	748	771	828	885	955	910	833	942
	168	540	930	1063	1065	1071	1165	1190	1138	1174	1233	1208
4	198	187	288	435	490	448	427	452	445	424	472	516
	90	144	375	547	560	548	568	595	586	557	579	582
5	161	243	387	491	531	526	489	492	535	464	462	431
	145	382	677	700	711	717	729	734	707	758	731	749
6	266	204	483	702	817	790	811	880	924	881	909	962
	47	29	147	305	471	465	516	491	537	499	519	564
7	202	380	327	333	397	449	489	375	471	569	545	517
	182	294	325	439	524	487	462	516	545	491	513	558
8	195	596	939	884	799	779	814	848	825	808	833	801
	241	1025	1507	1515	1351	1277	1274	1307	1354	1162	1209	1301
9	79	238	395	440	493	563	596	565	593	650	622	620
	150	356	545	667	729	731	750	798	778	773	786	805
10	148	197	232	233	263	351	449	429	433	501	520	504
	180	225	303	469	561	619	626	644	670	678	669	699
11	177	141	298	411	400	451	536	544	447	464	485	466
	143	200	395	502	539	629	638	597	616	649	612	561
12	158	368	743	652	722	725	792	776	835	829	776	721
	100	421	685	709	720	735	732	756	816	854	810	810
Presbycusics												
1	65	178	405	516	545	573	644	608	587	630	648	617
	87	265	569	788	782	821	850	890	863	885	936	935
2	94	325	1412	2340	2651	2675	2692	2756	2770	2748	2687	2756
	30	487	1780	2413	2625	2680	2716	2735	2779	2767	2818	2834
3	216	194	321	427	461	485	506	545	522	504	524	536
	182	306	368	409	484	482	443	442	503	495	465	532
4	88	362	666	700	772	859	801	839	887	869	824	853
	80	380	570	724	940	888	788	880	968	988	924	988
5	211	34	168	312	286	310	437	433	378	565	523	457
	357	265	278	329	645	560	639	768	859	881	800	787
6	154	157	235	346	402	402	459	462	481	476	504	485
	66	41	233	373	465	457	476	524	532	517	526	548
7	119	176	324	436	534	582	568	550	576	596	572	564
	170	472	705	796	855	935	926	919	928	974	965	941
8	46	342	704	792	732	662	679	597	605	646	650	629
	18	470	694	692	707	630	683	578	578	556	610	557
9	163	221	409	539	666	664	675	714	716	669	641	682
	162	336	445	618	669	671	664	706	707	671	673	744
10	70	80	126	227	267	321	381	392	415	482	518	525
	120	31	107	279	397	382	372	448	544	511	493	510
11	67	48	176	279	277	304	405	397	365	363	389	430
	53	40	377	515	522	541	618	604	598	598	704	693
12	21	569	870	834	849	840	814	889	918	896	893	923
	19	622	1056	1160	1250	1317	1349	1338	1356	1339	1300	1284

Appendix E.3

Individual Admittance Values (in digital units) for a 2000 Hz Activator During Reflex Onset Period. Top Line: 10 dB SL; Bottom Line: 15 dB SL.

Time (sec)	.08	.16	.24	.32	.40	.48	.56	.64	.72	.80	.88	.96
Young Normals												
1	88	76	381	755	927	1035	1144	1209	1215	1189	1216	1268
	42	681	1290	1505	1579	1627	1630	1608	1577	1654	1600	1556
2	122	84	105	194	308	336	291	279	313	304	253	269
	0	36	234	322	314	309	361	379	365	272	288	391
3	72	48	372	678	892	994	1132	1191	1143	1179	1183	1225
	60	3	191	484	674	812	905	927	962	872	1018	985
4	76	13	92	231	381	492	671	752	778	826	868	883
	76	100	399	699	899	1045	1174	1190	1181	1190	1235	1218
5	23	237	842	1092	1242	1366	1393	1375	1358	1376	1415	1401
	75	37	484	860	996	1039	1083	1157	1191	1235	1319	1322
6	136	460	943	1371	1638	1779	1794	1798	1851	1865	1849	1835
	83	670	1376	1719	1856	1975	2040	2033	2039	2070	2092	2093
7	67	77	280	369	489	615	751	715	674	734	776	738
	95	106	242	390	574	618	592	732	734	749	781	821
8	7	72	293	500	610	662	793	674	645	658	690	710
	0	146	475	664	734	763	757	748	722	722	710	719
9	244	336	632	1006	987	945	1001	1040	960	903	889	948
	107	207	477	647	776	748	784	732	747	751	697	774
10	135	102	200	550	713	802	883	872	800	706	800	807
	87	101	284	598	784	898	918	828	843	886	818	730
11	57	1045	1268	1247	1216	1186	1155	1201	1184	1165	1200	1207
	71	1057	1278	1288	1291	1327	1281	1264	1298	1271	1249	1240
12	132	130	381	859	1144	1257	1318	1326	1302	1278	1306	1263
	52	82	586	1075	1219	1297	1335	1302	1265	1306	1361	1324
Older Normals												
1	83	617	805	814	766	831	820	782	790	725	753	720
	95	624	834	892	877	831	851	845	855	761	675	793
2	93	155	305	403	383	389	429	380	322	424	386	332
	41	30	192	288	336	316	310	298	256	250	192	199
3	5	233	769	1012	1176	1213	1305	1362	1276	1217	1315	1306
	157	489	1033	1288	1349	1374	1418	1479	1464	1450	1483	1533
4	105	395	713	856	962	988	975	971	986	941	925	894
	83	377	747	978	948	1026	1009	1047	1010	1033	954	906
5	242	211	450	626	681	827	880	866	973	924	953	892
	108	87	377	645	730	817	920	886	866	918	948	909
6	102	74	202	237	246	232	283	281	217	293	353	302
	117	144	260	244	298	278	344	311	311	301	325	351
7	212	723	1246	1351	1270	1241	1249	1161	1126	1158	1146	1062
	94	603	1169	1318	1226	1272	1181	1136	1066	1097	1028	1001
8	49	181	443	627	663	644	676	731	706	712	733	741
	59	307	522	609	634	690	708	694	726	756	745	728
9	229	160	153	217	321	393	461	536	532	558	569	651
	192	205	219	341	477	610	593	572	609	706	618	659
10	76	52	176	258	348	405	399	319	353	390	430	433
	83	101	241	377	529	623	608	537	507	552	527	551
11	80	374	774	837	937	997	918	950	998	1012	1043	1011
	60	331	813	1002	1111	1189	1070	1230	1235	1259	1418	1514
Presbycusic												
1	115	124	246	298	339	407	439	410	377	415	388	321
	108	371	650	725	780	850	892	875	869	858	881	889
2	63	0	175	696	1229	1626	1749	1951	2074	2109	2079	2101
	87	0	234	875	1474	1881	2089	2167	2169	2245	2318	2318
3	157	237	317	423	518	492	566	674	700	707	698	682
	191	262	436	579	628	638	758	818	772	820	801	800
4	64	186	455	616	670	698	782	718	682	639	747	708
	71	251	522	644	665	712	714	690	668	696	634	604
5	80	104	193	342	477	519	511	566	600	617	605	633
	7	29	141	227	358	404	353	369	449	477	458	477
6	123	132	150	182	216	215	193	236	272	222	227	256
	50	175	328	366	402	478	527	487	483	525	487	473
7	170	180	341	449	473	453	468	507	486	403	460	486
	47	223	475	552	585	610	567	543	537	560	572	522
8	146	289	562	645	674	744	769	727	734	766	796	770
	24	208	487	528	535	641	645	618	597	665	671	642
9	65	33	5	57	120	140	223	321	345	299	303	355
	151	69	81	165	251	307	312	301	363	397	441	407
10	180	161	194	303	398	428	397	409	442	448	439	435
	162	188	261	377	456	492	498	515	532	589	553	552
11	0	197	510	632	683	698	666	643	636	634	649	665
	0	450	813	938	967	928	932	889	927	960	954	947

Appendix F.1

Mean Admittance Change (in microliters) for the Three Experimental Groups during the Reflex Onset Period. Reflex Activator was 500 Hz presented at 10 dB and 15 dB above acoustic reflex threshold.

Time (secs)	Group: Young		Older		Presbycusic	
SL:	10	15	10	15	10	15
.08	5.6	6.5	6.3	9.4	5.2	6.5
.16	22.5	30.7	16.5	23.3	15.3	21.5
.24	35.5	47.7	26.4	34.5	27.4	37.5
.32	40.8	56.3	30.7	38.0	29.8	41.9
.40	43.3	58.4	31.9	37.6	33.1	44.7
.48	45.6	59.0	32.6	39.2	33.6	45.7
.56	45.8	59.2	32.0	39.6	34.4	44.8
.64	45.6	59.8	32.4	39.6	35.4	45.9
.72	45.6	59.1	32.3	38.5	35.2	46.3
.80	46.8	59.1	32.3	38.5	35.6	46.3
.88	45.7	58.8	32.8	39.2	36.3	45.8
.96	45.7	59.5	32.8	38.6	36.3	46.7

Appendix F.2

Mean Admittance Change (in microliters) for the three Experimental Groups during the Reflex Onset Period. Reflex Activator was 1000 Hz presented at 10 dB and 15 dB above acoustic reflex threshold.

Time	Group:	Young		Older		Presbycusic	
(sec)	SL:	10	15	10	15	10	15
.08		6.6	5.6	8.2	7.1	7.5	7.2
.16		16.4	25.5	17.9	22.5	15.3	20.2
.24		28.5	46.3	28.4	34.9	27.3	36.7
.32		42.7	57.6	29.8	41.1	34.1	44.6
.40		46.4	62.2	32.6	42.3	40.3	49.2
.48		48.6	64.3	31.9	43.0	42.6	51.6
.56		50.0	65.6	34.1	44.3	42.5	51.0
.64		51.1	66.1	35.9	44.0	43.0	51.0
.72		51.7	65.4	37.1	43.6	44.2	53.0
.88		52.2	66.1	36.6	44.0	44.7	52.8
.96		53.2	65.8	36.5	44.3	45.3	53.2

Appendix F.3

Mean Admittance Change (in microliters) for the Three Experimental Groups during the Reflex Onset Period. Reflex Activator was 2000 Hz presented at 10 dB and 15 dB above acoustic reflex threshold.

Time (sec)	Young		Older		Presbycusic	
SL:	10	15	10	15	10	15
.08	5.5	3.5	6.6	5.6	6.0	4.6
.16	12.7	15.3	16.4	17.0	8.5	11.5
.24	27.4	34.6	31.2	33.1	16.3	22.9
.32	41.9	48.5	37.4	41.2	24.0	30.9
.40	49.9	55.4	40.0	44.0	29.9	36.7
.48	54.3	59.0	42.1	46.6	33.2	41.0
.56	58.4	60.9	43.4	46.5	34.9	42.8
.64	58.9	61.1	43.1	46.7	37.0	42.8
.72	57.9	61.2	42.8	46.0	38.0	43.2
.80	57.7	61.4	43.2	46.9	37.5	45.4
.88	58.9	62.3	44.5	46.0	38.2	45.3
.96	59.4	62.4	43.1	47.2	38.3	44.6

Appendix F.4

Mean Admittance Change (in microliters) for the Three Experimental Groups during the Reflex Onset Period. Reflex Activator was Broad band Noise Presented at 10 dB and 15 dB above Acoustic Reflex Threshold.

Time	Group:	Young		Older		Presbycusic	
(sec)	SL:	10	15	10	15	10	15
.08		4.9	3.8	9.2	7.3	6.2	6.4
.16		16.0	25.0	17.2	20.7	12.7	17.6
.24		33.5	49.9	26.2	33.0	27.5	34.0
.32		43.2	60.4	29.8	38.1	36.5	43.1
.40		48.0	65.0	32.2	39.6	39.9	49.0
.48		51.6	68.3	33.0	40.4	41.1	49.1
.56		54.0	66.4	34.8	41.1	42.9	49.8
.64		53.5	64.5	34.5	41.3	43.5	51.3
.72		54.4	66.0	35.6	41.8	43.7	53.1
.80		54.5	67.7	35.9	41.2	44.7	52.9
.88		54.1	67.2	35.5	41.8	44.4	53.1
.96		53.8	66.7	35.8	42.4	44.8	53.8

Appendix G.1

Individual Admittance Values (in digital units) for a 500 Hz Activator During Reflex Decay Period. Top Line: 10 dB SL; Bottom Line:15 dB SL.

Time (sec)	.96	4.5	12.5	20.5	28.5	36.5	44.5	52.5	60.5	68.5	76.5	84.5	92.5	100.5
Young Normals														
1	895	846	1017	1036	919	844	782	671	522	520	466	392	357	342
	1122	974	967	898	837	860	918	839	696	676	625	585	653	541
2	326	250	239	221	226	275	278	311	276	251	283	249	233	234
	576	485	507	417	325	375	309	336	308	332	257	320	238	276
3	1121	1001	1059	1139	1171	931	848	644	606	629	1152	730	317	291
	965	986	1151	1160	1024	894	884	634	466	571	465	528	330	373
4	875	863	867	798	839	794	744	707	657	640	545	594	590	560
	1368	1383	1374	1437	1304	1360	1335	1233	1240	1171	1111	1057	1059	1035
5	986	1053	960	882	672	638	587	539	521	411	413	345	305	250
	1359	1351	1249	1257	1168	1164	976	984	890	744	644	618	606	493
6	982	1043	1080	1055	957	903	831	833	745	770	601	583	462	446
	1316	1364	1262	1316	1238	1205	1154	1142	981	859	817	813	785	751
7	720	660	513	539	457	504	463	604	517	489	543	441	408	384
	1078	1008	829	893	788	753	734	786	736	714	713	646	569	559
8	487	456	290	314	295	400	359	331	383	447	343	352	360	411
	715	623	573	462	482	433	400	353	359	476	466	415	347	427
9	706	715	597	557	566	538	482	527	467	445	410	392	382	342
	893	787	746	725	655	627	551	572	530	552	502	499	441	373
10	574	568	491	500	529	407	362	349	326	303	343	342	266	235
	621	608	483	478	502	478	571	505	537	392	337	298	275	325
11	1127	698	685	617	617	558	527	494	451	424	411	410	353	341
	1264	1015	962	903	810	753	667	645	590	609	510	499	518	514
12	858	847	829	873	785	710	743	722	719	714	578	630	601	515
	1174	1092	1045	998	1001	979	964	891	895	823	852	804	717	701
Older Normals														
1	513	483	446	363	410	410	376	382	343	348	328	246	269	289
	395	433	456	402	384	403	361	358	368	396	365	302	315	275
2	385	273	181	171	194	136	154	90	122	148	186	153	151	147
	496	397	369	343	275	253	266	214	218	187	193	213	185	154
3	753	803	923	746	557	589	437	506	476	410	316	288	210	176
	1321	1301	1255	1163	1007	990	791	760	870	679	705	594	520	624
4	483	480	598	562	593	552	588	572	468	417	327	371	280	231
	601	471	533	557	520	427	463	476	431	355	317	314	250	223
5	478	443	428	435	455	441	412	479	385	310	317	349	332	412
	579	564	514	456	451	422	402	352	393	407	391	299	285	321
6	645	658	593	469	373	269	218	161	85	56	111	111	138	152
	874	933	983	893	838	748	687	599	505	465	390	340	312	261
7	487	530	527	472	447	400	371	385	319	299	286	239	223	194
	517	596	524	502	455	445	354	350	322	312	323	309	283	233
8	857	884	896	681	617	499	453	427	282	239	174	208	173	171
	1001	815	716	492	432	440	489	284	337	235	255	223	275	306
9	520	381	333	307	302	274	247	238	221	207	194	189	196	180
	581	546	485	457	420	364	342	327	332	321	298	278	251	221
10	441	387	474	456	473	382	458	385	406	343	352	328	273	244
	359	381	414	450	419	420	376	354	372	367	294	284	297	213
11	791	870	910	823	657	565	485	476	444	477	329	293	214	223
	744	810	856	784	721	568	461	379	551	519	349	313	306	297
Presbycusics														
1	451	439	436	417	419	403	369	300	312	279	227	231	181	181
	852	655	684	664	659	573	523	507	460	427	445	377	274	294
2	2402	2360	2098	1543	1224	1117	994	912	889	780	636	503	415	321
	2640	2760	2554	2165	1915	1665	1539	1165	1062	933	704	723	624	565
3	417	382	408	388	391	427	415	596	569	628	515	374	274	198
	557	429	586	584	564	552	575	521	369	448	349	276	258	260
4	701	644	641	641	592	471	496	396	392	371	334	290	133	201
	891	746	809	787	669	615	588	526	520	417	375	287	273	280
5	531	508	738	610	544	612	537	607	567	504	340	466	339	288
	581	1042	1030	1083	1063	989	877	699	726	767	654	628	491	589
6	431	353	306	205	148	130	194	135	137	173	150	159	106	102
	555	541	418	353	307	279	323	228	184	139	126	94	94	43
7	664	731	677	652	693	614	737	564	547	483	453	438	394	341
	764	757	749	735	659	645	629	566	570	515	550	482	506	468
8	712	810	944	924	935	843	774	700	597	473	386	310	194	149
	771	889	944	872	821	800	705	566	481	435	377	306	251	212
9	488	571	599	571	553	479	445	418	450	405	304	293	190	168
	591	708	783	722	710	706	693	683	453	400	361	291	239	248
10	355	456	454	365	361	369	360	364	367	407	379	404	353	330
	501	604	576	547	525	514	521	524	538	497	522	541	531	525
11	199	321	353	316	316	323	321	246	314	271	236	317	288	409
	405	447	526	560	456	490	476	446	479	488	379	451	401	469
12	320	370	357	273	206	178	179	173	170	133	133	127	105	81
	750	831	907	759	700	578	541	521	466	377	301	313	269	263

Appendix G.2

Mean Admittance Change (in microliters) for the Three Experimental Groups during the Reflex Decay Period. Reflex Activator was 500 Hz presented at 10 dB and 15 dB above acoustic reflex threshold.

Time (msec)	Group:	Young		Older		Presbycusic	
	SL:	10	15	10	15	10	15
.96		46	59	33	39	36	47
4.5		43	55	32	37	38	49
12.5		41	52	32	37	38	49
20.5		40	52	28	34	33	47
28.5		38	48	26	31	30	42
36.5		36	47	23	28	28	40
44.5		33	45	22	26	28	38
52.5		32	42	21	23	26	33
60.5		29	39	18	24	25	30
68.5		29	37	17	22	23	28
76.5		29	35	15	20	19	24
84.5		26	34	14	18	19	23
92.5		22	31	13	17	14	20
100.5		21	30	12	16	13	20

Appendix G.3

Individual Admittance Values (in digital units) for a 1000 Hz Activator during the Reflex Decay Period. Top Line: 10 dB SL; Bottom Line: 15 dB SL.

Time (sec)	.96	3.6	9.2	14.8	20.4	26.0	31.6	37.2	42.8	48.4	54.0	59.6	65.2	70.8
Young Normals														
1	551	665	719	650	610	489	570	485	475	461	425	494	464	380
	1210	1143	1070	969	907	842	747	782	685	565	497	493	511	449
2	358	315	281	195	187	176	136	136	149	137	99	130	100	62
	492	418	389	317	291	233	255	227	183	169	149	110	147	133
3	[illegible]	1203	1224	1199	1038	843	754	598	402	161	152	66	173	85
	1350	1281	1224	1108	892	627	394	323	235	165	143	99	70	41
4	1232	1262	1255	1066	1066	1038	953	829	719	691	663	543	585	380
	1352	1349	1318	1253	1089	901	891	856	794	830	870	701	758	818
5	1172	999	949	897	932	686	636	588	476	406	309	291	265	182
	1320	1220	1259	1127	1073	1036	1028	923	857	758	574	531	439	268
6	1336	1291	1365	1342	1252	1112	1118	903	1080	763	492	440	364	282
	1648	1566	1614	1480	1403	1403	1245	1163	1052	1035	1034	842	776	760
7	1233	1314	1136	1059	1162	1103	1058	1009	933	795	753	863	784	791
	1381	1461	1395	1386	1274	1359	1118	1049	889	863	804	630	516	590
8	537	502	407	398	369	312	329	338	332	353	299	294	268	226
	682	666	546	577	562	523	481	476	465	415	402	387	362	357
9	875	747	519	483	370	333	344	276	281	242	249	230	209	201
	959	786	731	696	580	524	471	347	352	312	293	265	256	228
10	664	534	448	227	201	247	148	95	151	148	80	103	113	76
	915	704	435	361	407	364	290	250	215	198	199	149	208	176
11	1009	973	882	824	776	740	721	666	579	530	478	421	413	397
	1374	1196	1085	1059	1023	952	924	854	825	749	661	642	582	577
12	968	869	800	661	592	599	490	459	363	299	326	305	339	270
	1215	1107	919	753	651	665	620	547	472	435	383	329	308	264
Older Normals														
1	669	531	501	395	312	215	151	130	142	172	66	165	211	262
	778	615	527	475	401	337	283	222	243	187	239	131	134	161
2	366	323	281	243	208	189	182	143	122	125	100	97	90	82
	387	387	334	361	224	230	181	183	177	93	110	112	83	54
3	977	983	1017	658	573	651	533	556	380	287	265	203	173	158
	1301	1209	1314	1195	944	950	775	826	638	541	504	496	507	354
4	620	635	454	403	378	406	377	311	330	296	268	209	174	143
	750	563	525	562	459	466	454	439	373	348	265	245	235	203
5	371	368	405	322	327	260	247	266	210	200	183	193	214	172
	539	514	446	448	404	364	327	302	287	255	238	261	223	143
6	879	888	935	808	797	773	631	577	540	495	491	346	222	271
	916	929	749	690	543	545	517	389	271	232	124	5	23	2
7	542	563	569	561	457	409	406	349	321	318	275	223	213	205
	439	445	492	450	470	426	385	379	300	272	296	282	281	235
8	685	492	428	229	99	74	117	52	0	44	20	0	36	0
	1001	968	888	748	522	470	349	199	193	133	175	93	44	61
9	555	449	349	349	298	302	266	252	243	232	216	214	190	166
	676	599	512	457	435	416	384	370	374	330	302	303	250	236
10	447	418	469	484	432	429	451	288	270	287	261	193	197	153
	397	462	452	465	452	427	404	369	321	310	222	249	184	177
11	946	918	788	683	553	411	295	203	174	154	80	10	93	127
	994	1004	884	749	584	490	390	349	300	212	270	310	245	200
12	654	774	842	864	909	880	941	872	925	935	930	949	947	829
	1168	1301	1375	1375	1319	1323	1312	1244	1211	1163	1116	1049	1009	873
Presbycusics														
1	805	704	678	599	528	488	473	441	363	348	289	249	220	171
	675	721	630	574	513	428	466	383	348	279	245	205	168	125
2	2596	2329	2160	1480	533	437	448	420	228	252	248	170	166	161
	2773	2577	2454	1489	1084	751	682	590	533	420	423	312	272	267
3	469	349	400	365	364	299	257	179	158	156	225	192	241	109
	577	630	673	629	623	572	499	470	378	322	249	279	268	294
4	442	487	468	405	306	267	226	198	175	158	124	119	102	98
	610	517	509	387	286	249	235	212	196	176	161	149	115	109
5	830	956	1110	886	527	557	564	326	311	277	154	167	197	128
	1189	1276	1347	1342	1086	1185	1053	795	562	617	490	391	604	415
6	625	522	454	364	288	222	179	181	175	143	191	156	117	113
	847	856	818	727	639	544	450	364	293	322	255	204	252	168
7	849	788	745	693	585	452	407	395	367	290	278	262	299	215
	728	782	683	488	414	380	309	336	285	257	168	146	117	124
8	563	432	411	336	203	136	59	5	0	12	0	0	0	0
	658	434	520	406	320	230	142	118	112	105	125	121	109	144
9	725	782	781	765	697	679	629	603	548	430	423	378	305	258
	785	810	806	754	733	652	637	614	639	529	464	469	383	304
10	497	540	611	617	552	478	525	502	510	531	556	465	443	414
	660	785	800	822	705	650	658	649	612	608	543	530	483	436
11	712	673	625	555	522	524	534	476	458	437	359	293	356	227
	765	640	716	673	624	610	557	554	535	577	455	436	519	379
12	447	653	750	735	679	621	578	549	538	482	391	354	379	342
	970	915	974	911	824	724	720	697	647	601	505	493	457	460

Appendix G.4

Mean Admittance (in microliters) for the Three Experimental Groups during Reflex Decay Period. Reflex Activator was 1000 Hz presented at 10 dB and 15 dB above Acoustic Reflex Threshold.

Time	Group:	Young		Older		Presbycusic	
(msec)	SL:	10	15	10	15	10	15
.96		53	66	37	44	45	53
3.6		51	61	35	43	44	52
9.2		47	57	33	40	44	52
14.8		43	52	28	38	37	44
20.4		41	48	25	32	27	37
26.0		36	45	24	31	24	33
31.6		34	40	22	27	23	30
37.2		30	37	19	25	20	27
42.8		28	33	17	22	18	24
48.4		24	31	17	19	17	23
54.0		20	28	15	18	15	19
59.6		20	25	13	17	13	18
65.2		19	23	13	15	13	18
70.8		16	22	12	13	11	15

Appendix G.5

Individual Admittance Values (in digital units) for a 2000 Hz Activator During Reflex Decay Period. Top Line: 10 dB SL; Bottom Line: 15 dB SL.

Time (sec)	.96	2.7	5.9	9.1	12.3	15.5	18.7	21.9	25.1	28.3	31.5	34.5	37.9	41.1
Young Normals														
1	1268	1207	1154	1139	1108	921	784	811	828	726	680	602	559	395
	1556	1474	1332	1297	1227	1225	1030	1060	1096	1000	968	987	789	683
2	269	187	64	52	16	117	150	183	138	71	60	18	47	81
	391	221	45	24	58	51	49	78	88	66	35	54	37	5
3	1225	1181	699	511	329	341	177	54	103	106	51	25	60	21
	985	698	313	208	139	120	78	50	48	205	128	38	31	19
4	883	660	782	584	462	327	321	290	213	191	164	131	120	90
	1218	1065	684	566	645	528	400	394	328	230	247	218	138	126
5	1401	1320	1232	1118	1230	675	632	543	444	370	282	226	242	150
	1323	1105	803	689	493	469	359	236	234	258	211	189	159	174
6	1835	1732	1035	782	586	468	374	264	175	214	261	292	180	324
	2093	2075	2021	1988	1835	1697	1578	1309	1223	1137	1107	979	859	802
7	738	695	529	392	586	582	438	315	250	149	48	70	68	23
	821	800	492	220	238	258	247	260	185	182	135	71	75	30
8	710	662	408	360	359	255	198	141	202	139	110	132	132	79
	719	631	536	512	466	418	341	253	220	139	118	136	128	65
9	948	777	544	484	435	415	409	353	332	333	307	248	246	227
	774	542	378	364	319	303	275	276	217	230	216	205	185	212
10	1207	998	780	834	814	770	584	445	342	327	268	218	205	207
	1240	1053	1034	927	836	682	628	490	311	291	253	269	225	179
11	807	519	244	204	207	177	152	117	130	87	99	100	90	37
	730	645	328	189	197	154	176	162	136	120	112	124	56	92
12	1263	958	569	497	486	401	355	301	237	210	191	165	166	126
	1324	964	509	382	270	232	208	163	133	122	118	107	78	71
Older Normals														
1	720	559	506	404	336	261	222	222	179	121	106	123	133	105
	793	582	384	249	201	115	113	90	79	112	79	93	98	104
2	332	194	95	61	28	0	0	0	0	0	0	0	0	0
	199	92	20	-13	-09	2	-4	29	18	15	-9	27	74	34
3	1306	1292	919	917	627	534	420	391	365	315	275	271	220	128
	1533	1429	1375	1305	1043	968	548	671	507	460	390	355	323	308
4	894	897	857	794	732	559	528	479	495	423	362	403	341	262
	906	978	822	753	688	629	535	556	445	392	424	395	383	375
5	892	946	857	751	604	636	565	499	456	459	429	423	359	369
	909	934	862	823	718	543	499	436	458	355	313	254	260	285
6	302	350	361	436	346	251	197	200	215	179	34	76	95	98
	351	317	317	291	241	211	149	139	133	107	110	84	54	106
7	1062	882	701	518	416	192	165	151	46	86	54	4	42	0
	1001	888	795	447	354	295	248	142	119	174	64	104	65	77
8	741	720	671	602	493	460	405	326	310	271	253	214	192	180
	728	728	677	640	572	507	424	410	367	338	255	235	202	139
9	651	706	703	646	611	647	591	519	459	412	395	384	336	342
	659	715	674	698	708	622	577	541	524	524	475	461	404	367
10	433	374	376	393	384	336	304	243	197	177	151	48	45	0
	554	529	415	328	242	203	210	207	200	69	51	47	93	106
11	1011	1133	1228	1297	1363	1355	1327	1323	1319	1251	1234	1171	1032	1081
	1541	1305	1385	1366	1388	1355	1326	1300	1269	1233	1213	1186	1173	1080
Presbycusics														
1	321	200	192	151	132	143	114	130	126	103	85	89	91	61
	889	789	481	547	347	370	255	203	181	144	146	118	98	117
2	2101	1799	1080	513	223	176	155	53	83	66	62	51	60	50
	2318	1586	1238	819	245	161	145	74	68	58	78	31	58	60
3	682	625	513	531	522	528	516	585	494	574	532	522	495	429
	800	672	644	627	603	629	572	601	577	534	503	473	450	403
4	708	337	210	238	220	170	135	96	103	99	100	89	93	59
	604	388	187	188	155	115	105	91	64	83	73	48	57	69
5	633	529	452	373	396	300	264	205	166	123	96	72	94	132
	477	477	366	310	242	223	173	148	126	92	54	39	14	43
6	256	212	186	156	140	121	111	97	66	56	67	75	68	69
	473	435	247	167	129	88	99	107	98	40	169	167	165	109
7	486	301	184	130	140	82	78	18	53	32	28	25	49	61
	522	270	222	195	155	82	13	17	29	1	6	32	17	66
8	770	780	817	801	741	704	631	532	487	405	361	321	332	269
	642	676	696	648	624	587	570	521	469	373	343	306	291	307
9	355	418	438	426	407	356	348	312	287	257	242	209	233	235
	407	441	434	433	410	631	298	255	252	262	261	234	216	163
10	435	398	435	384	312	154	133	106	145	101	15	3	42	70
	552	567	541	498	435	345	281	234	207	265	153	94	198	161
11	665	661	548	505	430	366	333	293	241	194	163	148	162	128
	947	856	672	490	458	403	306	250	226	211	172	118	111	116

Appendix G.6

Mean Admittance (in microliters) for the Three Experimental Groups during Reflex Decay Period. Reflex Activator was 2000 Hz presented at 10 dB and 15 dB above acoustic reflex threshold.

Time (msec)	Group:	Young		Older		Presbycusic	
	SL:	10	15	10	15	10	15
.96		59	62	43	47	38	45
2.7		51	53	41	43	32	37
5.9		38	40	37	39	26	30
9.1		33	34	35	35	21	25
12.3		31	31	30	31	19	20
15.5		26	29	27	28	16	19
18.7		21	25	24	24	15	15
21.9		18	22	22	23	12	13
25.1		16	20	21	21	10	12
28.3		14	19	19	19	10	11
31.5		12	17	17	17	9	10
34.7		10	16	16	17	8	9
37.9		10	13	14	16	9	9
41.1		8	12	13	15	8	8

Appendix G.7

Individual Admittance Values (in digital units) for a Broad Band Noise Activator During Reflex Decay Period. Top Line: 10 dB SL; Bottom Line: 15 dB SL.

Time (sec)	.96	4.5	12.5	20.5	28.5	36.5	44.5	52.5	60.5	68.5	76.5	84.5	92.5	100.5
Young Normals														
1	880	922	1012	883	868	726	519	660	538	500	547	525	506	432
	1491	1565	1453	1387	1090	1031	905	877	822	735	710	670	553	606
2	263	312	132	165	94	160	83	110	96	75	111	73	55	75
	472	391	295	191	129	215	350	213	188	211	196	150	256	214
3	1443	1361	1402	1154	1074	1057	946	992	994	923	736	753	593	566
	1380	1395	1384	1308	1228	1216	1275	1146	802	843	712	730	643	531
4	857	771	904	868	656	508	466	504	488	466	367	375	319	317
	1428	1413	1470	1260	1161	1101	1091	1102	1113	980	859	786	818	806
5	1193	1223	936	679	497	523	488	432	501	425	452	430	351	320
	1470	1509	1415	1304	1155	1046	931	770	816	673	542	583	568	493
6	1031	977	677	496	466	315	383	406	345	291	180	204	188	173
	1340	1433	1379	1245	1128	1101	1047	879	909	841	920	881	791	613
7	1157	1200	1245	973	846	871	829	792	716	571	483	434	457	472
	1496	1427	1375	1035	1156	829	953	877	885	909	976	678	733	603
8	541	525	555	525	470	471	516	476	409	471	434	388	336	323
	807	814	747	761	732	661	674	619	638	570	578	568	524	516
9	625	614	674	638	521	459	448	419	361	304	298	266	277	221
	703	735	622	572	492	506	460	444	440	412	372	317	272	243
10	734	473	336	298	331	291	203	244	195	187	207	134	113	95
	770	553	384	539	575	532	588	394	413	521	360	370	361	242
11	1011	1015	882	755	698	610	544	547	487	440	416	407	332	336
	1386	1374	1207	1099	1007	908	821	761	652	640	533	489	470	484
12	1282	1172	1031	944	800	771	727	701	659	670	601	591	552	534
	1341	1187	1060	970	929	840	800	773	713	709	662	650	624	577
Older Normals														
1	700	590	518	390	277	329	314	265	179	230	281	200	178	233
	675	582	476	366	382	328	264	292	269	230	213	212	213	196
2	942	649	768	659	567	538	518	397	331	385	279	202	281	215
	1208	1116	1145	875	851	854	796	764	628	553	429	461	468	429
3	516	403	190	235	206	155	141	146	196	91	18	23	32	1
	582	505	552	643	566	610	531	646	510	531	496	370	298	381
4	431	415	460	400	458	452	500	543	523	438	397	422	369	450
	749	748	782	782	729	664	593	622	537	582	513	471	476	272
5	962	1025	918	932	881	800	742	707	635	631	550	473	515	430
	564	607	526	562	482	388	409	406	415	323	245	293	257	280
6	517	575	507	468	423	384	356	330	325	338	256	224	235	193
	558	543	593	503	425	380	339	289	290	289	245	257	200	174
7	801	847	688	521	437	457	328	411	280	348	415	525	525	411
	1301	1218	989	697	515	484	460	396	301	276	169	253	320	303
8	620	574	544	498	470	414	395	363	369	314	306	295	274	253
	805	774	736	636	604	544	514	458	444	401	381	361	341	290
9	504	648	668	683	666	654	627	619	537	527	456	452	399	377
	699	695	745	736	732	685	674	644	625	561	548	539	483	440
10	466	524	246	194	80	25	141	182	126	93	43	25	32	63
	567	687	753	502	332	252	363	499	435	357	263	221	288	360
11	721	1080	1125	1182	1219	1239	1331	1278	1295	1179	1102	1024	950	964
	810	1062	1070	1025	1081	990	1007	998	922	908	820	754	720	625
Presbycusics														
1	617	649	677	659	614	602	522	510	503	487	429	422	380	365
	935	934	977	880	830	830	805	757	692	642	641	577	610	516
2	2756	3001	2925	2677	2460	2495	2318	1842	1638	1626	1514	1194	1289	1137
	2834	2913	2973	2497	2299	1957	2228	2060	2006	1750	1870	1533	1259	1056
3	536	538	478	591	604	625	583	555	482	342	187	239	75	182
	522	551	536	420	318	221	78	38	205	303	299	382	426	333
4	853	960	990	915	844	770	814	767	693	656	554	537	450	412
	988	935	1016	934	714	749	583	582	524	466	438	443	615	414
5	457	656	746	677	600	475	385	496	398	479	362	209	180	107
	787	786	1193	903	799	729	602	631	569	597	611	724	669	733
6	485	501	442	372	335	262	158	141	120	103	88	71	21	42
	548	592	559	444	441	414	361	331	300	252	262	251	238	209
7	564	690	681	607	557	478	433	370	338	482	463	381	397	324
	941	995	981	918	843	778	732	690	619	543	516	473	444	374
8	629	517	499	434	474	360	390	358	343	385	270	252	211	172
	557	562	550	476	369	323	296	343	266	274	220	221	209	227
9	682	806	826	797	763	730	649	609	559	522	479	412	324	356
	744	779	919	832	794	710	669	609	641	541	519	454	413	380
10	525	711	812	760	612	581	483	440	384	258	301	278	292	205
	510	633	724	683	536	518	446	449	409	362	316	287	306	263
11	430	626	597	575	498	516	454	486	428	415	374	348	256	253
	693	728	727	660	630	629	537	481	501	450	467	402	359	270
12	923	956	864	808	799	706	652	677	554	564	479	468	413	389
	1284	1379	1148	1036	915	825	662	700	528	462	455	386	369	353

Appendix G.8

Mean Admittance (in microliters) for the Three Experimental Groups during the Reflex Decay Period. Reflex Activator was Broad Band Noise presented at 10 dB and 15 dB above Acoustic Reflex Threshold.

Time (msec)	Group:	Young		Older		Presbycusic	
	SL:	10	15	10	15	10	15
.96		52	67	37	44	45	54
4.5		50	65	38	44	50	56
12.5		46	61	34	43	50	58
20.5		40	55	32	38	47	51
28.5		35	51	29	35	43	45
36.5		32	47	28	32	41	41
44.5		29	47	28	31	37	38
52.5		30	42	27	31	34	36
60.5		27	40	25	28	30	34
68.5		25	38	24	26	30	31
76.5		23	35	21	22	26	31
84.5		22	33	20	22	23	29
92.5		19	31	20	21	20	28
100.5		18	28	19	19	19	24

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