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EFFECTS OF THE NORMAL AGING PROCESS AND SEX DIFFERENCES ON THE EVALUATION OF AUDIOLOGIC BRAINSTEM RESPONSES

by

Rochelle Lee Malinoff

A dissertation submitted to the Graduate Faculty
in Speech and Hearing Sciences in partial fulfillment
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The City University of New York.

1985

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The City University of New York

Abstract

EFFECTS OF THE NORMAL AGING PROCESS AND SEX DIFFERENCES ON THE EVALUATION OF AUDIOLOGIC BRAINSTEM RESPONSES

by

Rochelle Lee Malinoff

Adviser: Professor Michael Seitz

The objective of this study was to determine the changes and variations in BSER wave morphology which are associated with aging and with differences between the sexes. In particular, the study was undertaken to determine the effects of the normal aging process of males and females on the BSER as measured by absolute and interpeak latencies of waves I^+ through V^-, the amplitude ratios of waves V:I and general morphological patterns. Accordingly, 8Ø healthy men and women (4Ø of each) with normal hearing and falling into four age groups--18-34, 55-64, 65-74 and 75-82 were chosen as subjects for the study. All subjects were tested at 8Ø, 6Ø, 4Ø, and 2Ø dB SL using ipsilateral, contralateral, and horizontal recording montages whenever possible.

Results of the study indicate a general increase in absolute latencies with age through the first three age groups. IPLs also increased with age when recording at 8Ø and 6Ø db SL, but showed a decrease in transmission time at 4Ø dB SL. The relative amplitude of waves I and V decreases significantly with aging, although no effect was found on the amplitude ratios of waves V:I at any sensation level or montage.

Females subjects were found to have shorter absolute and interpeak latencies than males. The differences between male and female absolute latencies did not usually become significant however (at $p < .05$) until the later waves (III, IV, and V^+).

The results of the study indicate statistically significant effects of the aging process, and of differences between the sexes, on the normal variations of the BSER. The study clearly establishes the importance of accounting for the age and sex of subjects as a precondition for establishing normality and abnormality criteria for the interpretation of BSER in a clinical environment.

ACKNOWLEDGEMENTS

Writing a dissertation is a joint venture which makes it surprising that only one member of the team receives a degree. The person to whom I owe the most gratitude is my husband, Paul Dygert. He helped in the tangible ways of reading, editing and typing the manuscript; and in the intangible ways of encouraging me when I was depressed, listening to me talk about about BSER at three A.M. and loving me throughout. We are now looking forward to a life together without a dissertation.

Mike Seitz especially deserves thanks since he is the reason this dissertation exists in its present form. His arrival at the Graduate Center was extremely fortuitous for me, as he brought to the department a knowledge of BSER testing techniques which made feasible my undertaking the present study. Moreover, his discipline, intelligence and subtle sense of humor encouraged me, as surely it must have many of his students, to keep on working. His critiques were extensive and incisive, and served to improve both the analysis and the writing at every point; and his demanding standards of scholarship have made the study much better than it otherwise would have been.

To Arthur Boothroyd I give special thanks for his clear insightful thinking and quick mind. Every comment he made improved the final product.

Lou Gerstman richly deserves thanks for compassion, enthusiasm and especially for his habit of overextending himself. He came as close as anyone could to making the research, analysis and writing rewarding for itself as well as for the end product.

Dennis Kissel gave generously of his time to serve as the outside reader for this study. His contributions to the field of evoked potentials have been significant.

I also owe a debt of gratitude to the New York Veterans Administration Medical Center which was my source of equipment, subjects and income. It was here, too, that I first came to realize the special need for research on auditory testing methods for an aging population. In particular, the departments of Otolaryngology, Ophthalmology, Social Work, Speech Pathology, Volunteer Service, Medical Library and Medical Media all helped to make this task a little easier. Special thanks, too, to Laurie Volk in the Medical Media Department for drafting the multitude of graphs that appear in this document.

Finally, I thank my family and friends who have had the patience to bear with me for the last six years. It is nice, now that I am "coming out", to find them all still there waiting.

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Chapter 1

AUDIOLOGIC TESTING PROBLEMS IN AN AGING POPULATION

I. Introduction

The utility of any diagnostic test or physiologic measurement depends on knowledge of the systematic and random variables which are reflected in the test results. The results of audiologic testing reflect three sets of factors which must be separated to properly evaluate the meaning of the test results for a specific individual: population factors, subject factors and random factors.

First, the results reflect the influence of variables which are characteristic of the population from which the individual being tested is drawn. These population variables may include age, sex and environmental variables. Second, the results may reflect factors unique to the individual; factors which may indicate an audiologic normality, abnormality or pathology. Finally, the results reflect the influence of random variation. This random error term reflects both unexplained variation in the data generation process and effects of explanatory variables that have not been explicitly incorporated into any of the analyses.

It is the second set of factors (subject factors) which the clinical practitioner seeks to identify in any testing procedure. For the abnormalities or possible pathologies to be identified, however, it is necessary that the clinician know the normal variation in test results that are predictable from information on the population from which the patient comes. Thus it is important that population differences known, or suspected, of causing significant changes in audiologic test data be thoroughly investigated so that interpretation of test data can be as accurate as possible.

Many previous studies have documented changes in auditory acuity as a function of the normal aging process [Schuknecht, 1967; Hinchcliffe, 1962; Corso, 1963; Moller, 1981]. Recent studies of auditory brainstem evoked responses (BSER) have also suggested that biological aging may be reflected in changed BSER wave morphology. [Beagley and Sheldrake, 1978; Jerger and Hall, 1980; Patterson, et al., 1981]. Studies suggest, too, that there are differences between the wave morphology of males and females [Jerger and Hall, 1980; Michalewski et al. 1980]. Reliable BSER data are needed to help distinguish normal aging and sex effects from pathological effects on BSER wave morphology. It is with this need in mind that a large study was designed and undertaken to determine the effects of normal aging processes in males and females on the BSER wave morphology. In particular, 40 men and 40 women ranging in age from 18 to 82 were tested at four intensities to determine the variation in BSERs with increasing age.

II. The Normal Aging Process

DEMOGRAPHICS

The proportion of elderly persons (age 65 and above) in the U.S. population has been increasing steadily since 1900. In that year, only 4.1 percent of the population were elderly, whereas the proportion of elderly had increased to 11.3 percent by 1980. Demographic forecasts are for 13.1 percent of the population to be elderly by the end of the century [U.S. Census Bureau, 1983]. The auditory health care of this large and growing minority creates new challenges for otologists, audiologists and other health care professionals.

GENERAL CHANGES

The normal aging process entails changes in biological, sensori-perceptual, psychomotor and psychological processes; intellectual capacity and memory [Schow et al., 1978]. At the most basic level, many cells die, and replacement of them is reduced or absent. Remaining cells may not operate at peak efficiency, resulting in a reduced functional capacity in many organs of the body. The vascular, muscular, and nervous systems are all particularly susceptible to the effects of age.

One of the most common problems characteristic of aging persons is circulatory impairment, caused by cardiac insufficiency attributable to heart disease, hypertension, pulmonary, metabolic or infectious disease. These cardiovascular disturbances have an impact on other bodily systems, particularly the nervous system. The brain is highly susceptible to oxygen deprivation and therefore frequent temporary interruptions in the blood supply will likely result in the death of neurons.

A decrease in brain size as one ages is one of the most obvious changes in the gross anatomy of the nervous system and a number of studies have documented a decrease in central nervous system neurons with advancing age [Schow et al., 1978]. A recent study showed a decline in the number of neurotransmitters in the caudate nucleus, putamen and frontal cerebral cortex in the age span of 19 - 73 years [Wong et al., 1984].

RELEVANT SEX DIFFERENCES

Although life expectancy is increasing, a marked difference exists between the life expectancies of men and women. More baby boys are born than girls, and boys continue to outnumber girls until the age of 18, but females outnumber males in all age cohorts beyond 18 years. For every 100 persons over 65 years, 59 are women and 41 are men. The ratio changes to about 120:100 females to males for the age cohort 65-69 and 160:100 females to males for the 85 years and above cohort [Butler and Lewis, 1977].

There are many biological differences between the sexes, leading to different disease patterns, different physiological data (e.g., hemoglobin value), and differences in the central nervous system [Kjaer, 1979]. For example, males have been found to have advantages in certain visual-spatial activities, although females have documented advantages in auditory processing and linguistic skills. Females acquire language earlier than males and have better sound discrimination abilities [Seitz et al., 1980].

In 1967, Beard studied 270 male and female centenarians and found that although men experienced greater hearing loss than did women, women lost more vision with aging than did men. [Butler and Lewis, 1977]. Studies on perception have shown that pain tolerance at every age is greater for men than for women. Although pain tolerance decreases with age, it does so more for men than for women [Friedman, 1978]. The study by Wong, et al. [1984] found that the decline in neurotransmitters during the age span of 19-73 was greater for males than it was for females.

A study of smell identification ability shows that the average ability to identify odors reaches a peak between 20 and 40 years of age and declines monotonically thereafter.

Women of all ages are generally more accurate than men in identifying odors [Doty et al., 1984]. There are clear and documented differences between the sexes and the way they biologically age in these and other aging processes.

CHANGES IN THE AUDITORY NERVOUS SYSTEM

Substantial alterations occur in the entire auditory system of the elderly beginning at the external ear and extending to the brain. Attention has conventionally been focused on the inner ear, but anatomical changes also occur in the external meatus and middle ear [Willeford, 1971]. An obvious physical change is the enlargement of the pinna. Between the ages of 30 and 50, many subtle changes occur in the pinna, including a loss of skin elasticity, a loss of muscle tonicity, and a proliferation of hair growth [Hinchcliffe, 1962; Willeford, 1971; Schow et al., 1978; Maurer and Rupp, 1979]. The topographic changes of the aging pinna also appear to have a minor effect on the geriatric's hearing of the high frequencies and in his or her reduced ability to localize sound [Maurer and Rupp, 1979].

In the middle ear, the tympanic membrane becomes more rigid and transluscent, and the elasticity of the mouth of the eustachian tube may change, causing problems in appropriate dilation which can lead to an increase in negative middle ear pressure [Maurer and Rupp, 1979]. Other changes which have been suggested include ossicular atrophy, predominantly of the crura of the stapes, ossification of the incus-malleolar joint and degeneration of the middle ear muscles [Willeford, 1971]. Schuknecht [1964, 1967] undertook extensive study of human temporal bones to determine the effects of aging on the cochlea. He described degenerative changes in the stria vascularis, loss of hair cells and supporting cells in the organ of Corti, and atrophy of the spiral ligament and basilar membrane.

There is also evidence of age-related neuronal and structural changes within the human brainstem. Degenerative changes, such as cell size and cell shape irregularities, and degenerative changes in the myelin sheaths and axis cylinders have been observed in the auditory pathway. Affected regions include the ventral cochlear nucleus, superior olivary complex, inferior colliculus, medial geniculate and inferior olive [Patterson et al., 1981].

III. Hearing Problems in the Elderly

PREVALENCE OF HEARING LOSS

Among the many chronic medical conditions affecting the elderly, hearing impairment ranks secondly only to arthritis [Maurer and Rupp, 1979]. Estimates of the incidence of hearing loss in the elderly vary greatly according to the population tested, measurement techniques, and criteria for hearing loss. In 1971 the American Speech and Hearing Association reported that at least 2.5 million U.S. citizens over the age of 65 had significant bilateral hearing impairments [Alpiner, 1982].

AUDITORY MANIFESTATIONS

The set of auditory problems that accompany aging is known as presbycusis. The term presbycusis encompasses a multitude of problems associated with the elderly individual's auditory functions, including the pathology of the aging ear, the related auditory discrimination difficulties, and many other associated social-psychological problems encountered by the individual due to hearing difficulties [Hull, 1978].

The following are some of the many auditory problems that may be manifested in the elderly individual: impairment of auditory threshold sensitivity, impairment of speech discrimination and sound localization, impairment of auditory perceptual judgment, decrease in the ability to recall long sentences and problems with loudness tolerance caused by recruitment [Hinchcliff, 1962]. Not all features are necessarily found in each presbycusic individual.

More is known about the effects of aging on pure tone sensitivity than about any other hearing dysfunction of the elderly [Schow et al., 1978]. The measurement of sensitivity most often used is the pure tone threshold in dB. The pure tone threshold results obtained in the 1960-62 National Health Survey [U.S. Department of Health, Education and Welfare, 1965], as a function of age and sex, are shown in Figures. B.1-4. The initial deterioration in sensitivity occurs relatively early in life with measurable changes observable early in adulthood. Males experience hearing loss at an earlier age than females, with relatively large differences in threshold occurring between the sexes in the high frequencies by the third decade of life [Schow et al., 1978]. Hearing loss with age occurs predominantly in the high frequencies, and gradually extends to the lower frequencies as aging progresses. As one can observe, older males experience greater high frequency hearing losses than older females, although females show slightly greater losses in the low frequencies than do men.

IV. Audiologic Testing of the Aging

BEHAVIORAL AUDIOMETRY

The occurrence of age-related high frequency hearing loss and discrimination problems of the elderly is well documented [Bergman, 1980; Hinchcliffe, 1962; Schuchnecht, 1964; Corso, 1963]. Age is also a factor in impedance audiometry, with static compliance decreasing as a function of age and acoustic reflex thresholds elevating for noise signals and improving slightly for pure tone signals [Jerger and Hall, 1980].

Differences between males and females are also reflected in audiological testing. Sex is a factor in both behavioral and impedance audiometry. In older adults, pure tone sensitivity for higher frequency pure tone signals is usually better in women than in men, although sensitivity for low frequency pure tone signals is usually better in men than in women. Sex differences in performance of diagnostic speech audiometric procedures have also been reported. Sex is a factor in some impedance audiometric measures. Static compliance tends to be greater in male than in female subjects [Jerger and Hall, 1980].

AUDIOLOGIC BRAINSTEM EVOKED RESPONSE

Brainstem evoked potential audiometry, a relatively new procedure for recording and analyzing the electrical events occurring in the neural pathway as they proceed to the midbrain, has become an integral part of the audiologic test battery. Its results provide information for the diagnosis of audiologic and neurologic disorders.

BSER testing elicits neurological responses from successive portions of the auditory pathway, beginning with the hair cells within the cochlea, progressing to the auditory nerve to the brainstem and beyond. Brainstem responses reflect a relatively large volume of neural tissue as transmission occurs along the auditory pathway. The mass changes that occur within the peripheral and central auditory nervous system of the elderly, such as the reduction in the number of eighth nerve fibers, atrophy of the spiral ganglion, degeneration of the ganglion cells in the ventral cochlear nucleus and the medial geniculate body, and varying degrees of cellular degeneration in the cell population of the superior olivary complex and the inferior colliculus [Maurizi et al., 1982], could be expected to affect the functional neurological activity at one or more levels of the auditory pathway, resulting in a BSER that differs significantly from that of younger individuals.

It is also possible that differences between males and females (e.g., pure tone thresholds and impedances) that have been exhibited in other audiologic testing measurements will also be reflected in the BSER of the elderly. If so, the use of BSER techniques for the clinical evaluation of patients will depend on appropriate age and sex comparisons with normal response variation. The objective of this study was to determine the normal response range and variance in male and female subjects ranging in age from 18 to 82, so that one could begin to determine any age and sex changes in the BSERs that might occur during the normal aging process.

Chapter 2

AUDITORY BRAINSTEM EVOKED RESPONSE PROCEDURES

I. Introduction

In 1970, Jewett, Romano and Williston described a series of auditory evoked potentials that were recorded from the surface of the scalp in the first ten milliseconds after a click stimulus. This response is what is typically referred to as Auditory Brainstem Evoked Response (BSER). Subsequently, the recording of auditory brainstem responses has emerged as a vital adjunct to the clinical testing repertory of the audiologist, otologist, and neurologist.

Brainstem evoked potentials are small amplitude changes superimposed on the EEG scalp potentials that occur as a result of some transient auditory stimulus. A typical BSER has a maximum amplitude of .1 to .5 uV. This response is often hidden in the background noise of ten to 30 times the magnitude of the response. Until the mid 1960s, recording evoked potentials was possible only through the use of invasive electrodes placed in or near the tissue generating the responses [Glatke, 1983]. With the advent of the averaging computer, which can algebraically sum events, separating stimulus related electrical potentials from the larger non-time locked spontaneous EEG activity [Hecox, 1984], and with advances in filter and differential amplifying systems, the detection of evoked potentials at sites remote to the neuronal activity is now possible [Jewett and Williston, 1971]. With advances in technology and refinements in recording techniques, the study of auditory evoked potentials detected at the vertex has become more commonplace in the practice of audiology.

The BSER recorded from adults with electrodes on the vertex and earlobe or mastoid is a series of four to seven vertex positive peaks occurring at about 1.0 msec. intervals during the first 10 msecs. after a moderately loud (60-80 dB) stimulus presentation. A typical configuration of a BSER is shown in Figure 1.

The present study concerned the first five waves after stimulus presentation, including the negative peaks of the first and fifth waves. The presence of waves six and seven is often quite variable. Wave six has consistently been considered hardest to recognize of the BSER waves in a normal population [Chiappa et al., 1979]. Waves six and seven are so often irregularly present and variable among individuals in cross sectional studies of normal populations that they are useful only in longitudinal studies of individuals for whom the waves are well-defined [Stockard and Sharbrough, 1978].

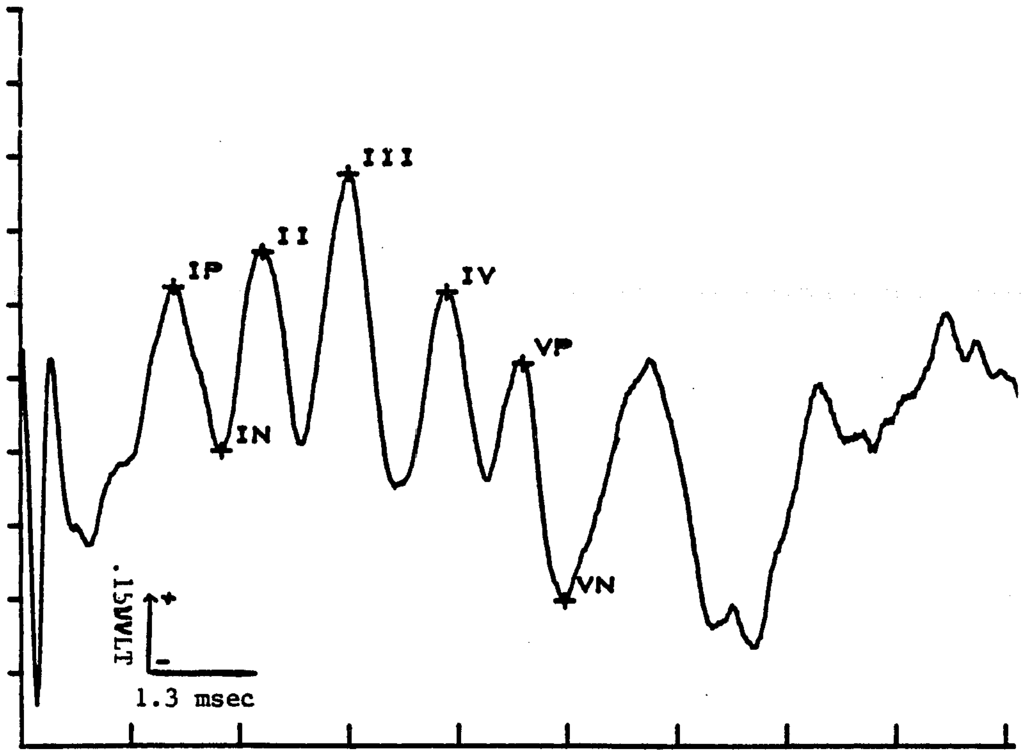

Figure 1. Typical BSER for normal hearing, 34 year old female: ipsilateral montage, 60 dB SL, summed response to 4000 rarefaction clicks.

There are presently many different nomenclatures describing the various wave peaks. Jewett et al. [1970] named the first five waves I-V (in Roman numerals), whereas Pratt and Sohmer [1976] numbered the same waves 1-3 and 4a + 4b. Other authors, such as Davis [1976], report waves based on their latencies. Thus the same peak may be labeled differently by different authors. For example, wave V (Jewett), N_4 (Thornton) and P_6 (Davis) all refer to the identical peak [Hall, 1984]. The Jewett et al. [1970] nomenclature, using Roman numerals to sequentially denote waves I-V is the most common and will be used in this study.

II. Generation of the Response

NEURAL GENERATION OF WAVES

Initially, researchers believed each wave to be correlated with a single specific generator.[1] This simplistic association of single wave components with successive neural regions in the auditory system developed despite the early cautioning by Jewett and Williston [1971] that the neural origins of the BSER wave components are not known, and their suggestion that there are multiple generators of waves III to V.

Studies investigating the neural origins of the BSER waves have usually been either lesion studies [e.g. Buchwald and Huang, 1975; Stockard and Rossiter, 1977] or in-depth intra-cranial recordings on animals [e.g. Achor and Starr, 1980; Moller et al., 1981]. These studies have shown that a complexity of generators produce each wave. Data from these studies strongly suggest that the combined sequential and simultaneous activation of generators, and the overlapping of transient and sustained activity from multiple sites,

[1] The following correlations have often been cited in the literature: wave I: eighth nerve; wave II: cochlear nucleus; wave III: superior olivary complex; wave IV: nucleus of the lateral lemniscus; and wave V: inferior colliculus [see, e.g. Borg, 1981].

preclude any specific correlation between a single brainstem site and a particular response peak. Nonetheless, peaks can be assigned to certain regions in the brainstem, which is the basis of their usefulness in neurologic testing [Rowe, 1981].

There is fair agreement and good support for accepting that wave I is the far field representation of the compound action potential of the eighth (auditory) cranial nerve [Hall, 1984; Buchwald and Huang, 1975]. Recent data also suggest that wave II is generated by the intracranial portion of the eighth cranial nerve [Hall, 1984] and perhaps the cochlear nuclei as well [Buchwald, 1983]. Moller et al. [1981] argued that waves I and II both originate from the auditory nerve. Wave I arises from the peripheral part of the auditory nerve, whereas wave II originates from the auditory nerve close to its entrance into the brainstem. The latency between waves I and II in the human brainstem corresponds to the travel time from the peripheral part of the auditory nerve to its entrance into the brainstem.

There is some disagreement concerning the generator sites for waves III, IV and V. Correlative recordings of surface BSERs and depth intracranial evoked potentials in the same animal have shown that a potential of maximum amplitude in the superior olivary complex (SOC) of the ipsilateral and contralateral brainstem auditory pathways has a latency which coincides with that of wave III. Additional support for the importance of SOC contributions to wave III generation is provided by lesion studies. Taken together, the depth-recording and lesion studies portray wave III as a potential which derives from both uncrossed input to the ipsilateral SOC and crossed input to the contralateral SOC [Buchwald, 1983].

Hall [1984], nonetheless, cites a study in guinea pigs by Gardi and Bledsoe which concludes that wave III arises from the contralateral medial nucleus of the trapezoid body. Thus, wave III generation can only safely be attributed to activity in the brainstem auditory regions, probably in the pons [Hall, 1984].

Wave IV often merges with the more pronounced wave V in clinical recordings, and thus it has attracted less clinical and experimental attention. An origin in the vicinity of the lateral lemniscus is often cited [e.g. Rowe, 1981] but conclusive evidence supporting this location is still missing.

The neural origin of the fifth wave component is still not clear. The auditory midbrain, particularly the inferior colliculus, is often suggested as the primary generaton site as the result of correlations between wave V abnormalities and lesion studies [Buchwald and Huang, 1975; Stockard and

Rossiter, 1977], but there is also evidence that wave V may be recorded following total destruction of the inferior colliculus [Achor and Starr, 1980]. Thus it seems possible only to identify the primary generators of wave V in the midbrain region.

The origins of waves VI and VII have not been studied extensively. The source of these two waves may be in the medial geniculate and the auditory cortex, respectively [Seitz et al., 1980].

NEUROPHYSIOLOGY

Since the neurophysiologic basis of BSER is not well developed, the following is a very generalized and simplistic description of what occurs. The neuron is the important electrical generator in the central nervous system. Each neuron is composed of two distinct generators: axons and dendrites. The axons (tubes) conduct nerve impulses. The axon potentials are all-or-none in character and each is followed by a refractory period. The dendritic system (cell body and branches other than axon) undergoes changes in polarity (post-synaptic potentials) when chemical mediators are released at the synaptic junctions. These potentials are graded [Davis, 1976], and similar potentials from neighboring sources are additive. Aside from the eighth cranial nerve compound action, potentials (waves I and II) axonal impulses contribute little to the BSER [Davis, 1976]. In the brainstem, axonal activity is relatively weak and poorly synchronized. The BSERs are thought to mainly "reflect the graded post-synaptic potentials rather than the all-or-none action potentials discharged at the cell soma or transmitted along the axonal projection" [Buchwald, 1983, p. 159]. More knowledge of the neurophysiologic principles underlying BSER is still necessary.

III. Clinical Use of BSER

The use of BSER as a diagnostic tool has focused on two principal areas:

1. Evaluation of the transmission of auditory information through the brainstem. This is used most often with children or adults who cannot be tested subjectively, but where some indication of "hearing" sensitivity is required.

2. Evaluation of the neurological integrity of the acoustic nerve and the brainstem pathway. Many clinicians see this as the primary role of BSER in an adult population [Hecox, 1984].

When evaluating the hearing sensitivity of subjects using BSER, clinicians determine the lowest intensity at which wave V^+ is seen, resulting in one type of threshold estimate. A difference between measured and normal response thresholds represents the amount of high frequency hearing loss. A second technique is to create a latency-intensity function by mapping the latencies of a subject's wave (say wave V) onto several intensities and comparing that function with one generated by subjects with normal hearing. The amount of displacement from the normal range and any differences in the slope of the latency-intensity function are used to estimate the amount of loss and the site of lesion [Hecox and Jacobson, 1984].

When using BSER to look for neuro-otologic pathology, testing is usually done at fairly high stimulus levels so as to best see all waves of the BSER. With low stimulus levels, the number of identifiable waves decreases. The remaining sections of this chapter will discuss techniques used for the interpretation of BSER when using it as a tool for the evaluation of neuro-otologic pathology.

RESPONSE MEASURES

Criteria for BSER interpretation are usually based on the ability of the BSER to replicate itself on repeated runs, the absolute latency of individual peaks, their interpeak latencies and the general morphology of the waveform. The ratios of the amplitudes (peak to trough) of waves V and I are also used as criteria for a normal response, but have not proven to be as clinically significant as waveform replication or absolute and interpeak latencies.

Response Latency

Absolute wave latency is the time period in milliseconds (msec.) between stimulus onset and the positive or negative peak of a given wave. Latency is highly reliable with very little intrasubject and intraaural variability [Davis, 1976]. Two methods of measuring the absolute latency of a wave are commonly used. One measure is the maximum positive voltage (the highest point, or peak of the wave), the other measure is the wave shoulder immediately preceeding the subsequent trough. The first method was used in this study. The two methods are illustrated in Figure 2.

Interpeak Latencies

The difference in time between two wave peaks is called the interpeak or interwave latency (or IPL). In neurological applications, IPL has greater diagnostic import than does the absolute latency. Since it is generally agreed that wave I reflects the eighth nerve activity, the latency between wave I and subsequent waves is a measure of auditory brainstem transmission or conduction time.[1] As with absolute latency values, IPLs are highly reliable and do not vary significantly from clinic to clinic under similar testing conditions. Proper identification of the different waves is obviously crucial to their diagnostic usefulness.

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[1] Interpeak (like absolute) latencies are referred to by different names: brainstem transmission time [Sohmer, 1983], central transmission time [Salamy and McKean, 1976] or central conduction time [Rowe, 1978].

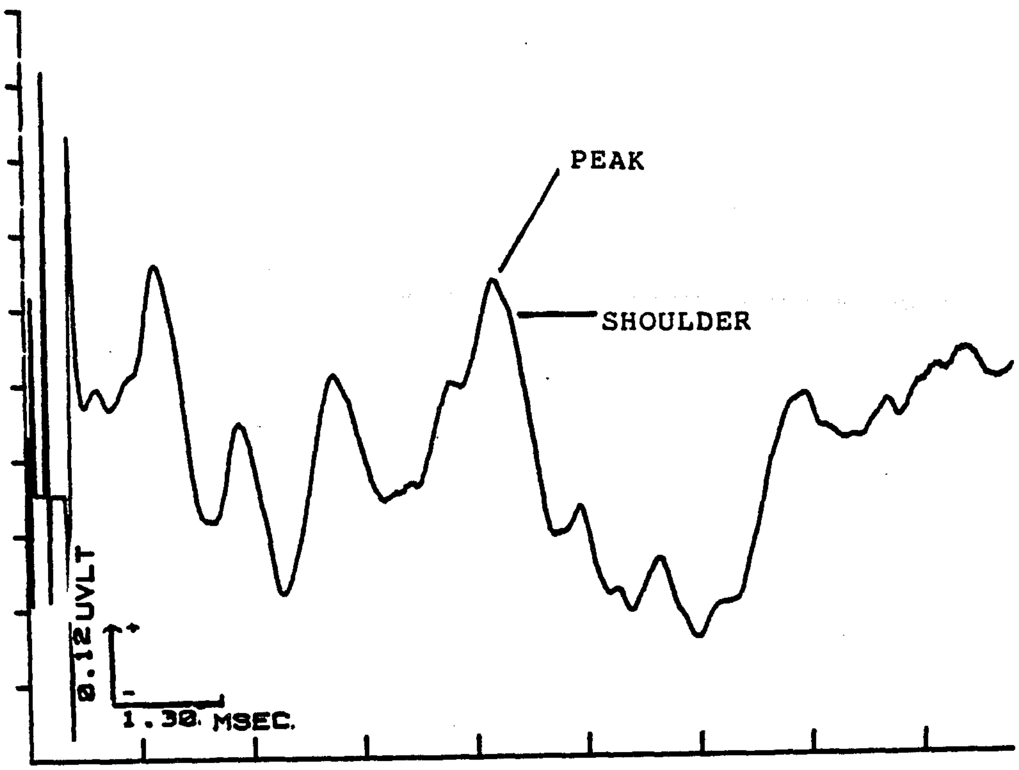

Figure 2. Peak and shoulder of wave V. BSER of a 32 year old normal hearing male: summed response to 4000 rarefaction clicks, 80 dB SL, ipsilateral montage.

Wave identification is not, however, a wholly objective task. It is important to avoid labelling a wave on the basis of when it occurs (latency) or its location in the waveform (position). Experience in knowing how the waves react to different intensities, stimulus repetition rates and recording parameters (e.g., contralateral, ipsilateral, or horizontal) and stimulus phase is needed for the proper identification of the various waves.

Response Amplitude

Relative amplitude is expressed in microvolts from the peak (or shoulder) of a wave to the most negative peak of the following trough. Wave amplitude is characterized by high inter- and intrasubject variability and has been found to be of limited use for clinical diagnosis. Absolute amplitude cannot be used to identify abnormalities since often specific waves (e.g., II and IV) may often be absent for non-pathological reasons [Stockard and Sharbrough, 1978]. The use of the relative amplitude ratio (between waves V and I) has proven to be more clinically useful than has the amplitude of individual waves. Even this measure shows considerable variability and is susceptible to momentary contamination by muscle activity and other electrical or mechanical artifact.

For the average subject, the amplitude of wave V exceeds that of wave I, resulting in a wave V/I amplitude ratio >1.0 [Hall, 1984]. The ratio varies with age but is considered to have diagnostic significance when the wave V amplitude is <0.5 of the Wave I amplitude [Hecox and Jacobson, 1984].

Wave Morphology

The morphology of the brainstem response refers to the visual appearance of the sequence of five to seven waves. This aspect of BSER interpretation is largely subjective, and not easily quantifiable. Nonetheless, there may at times be alterations in the morphology of the waveform even though the latency and amplitude measure are within normal limits. One might see broad and poorly defined waves with no distinct peak or with multiple peaks or lack of good replication between two or more BSERs at the same stimulus intensities (Figure 3). Although all measurements of absolute and interpeak latency have a subjective element, morphology is the most subjective.

VARIABLES AFFECTING RESPONSE

The ideal stimulus for evoking the BSER has long been a subject of considerable interest. The most widely used stimulus for brainstem evoked response testing is the acoustic transient, or click. It has an essentially

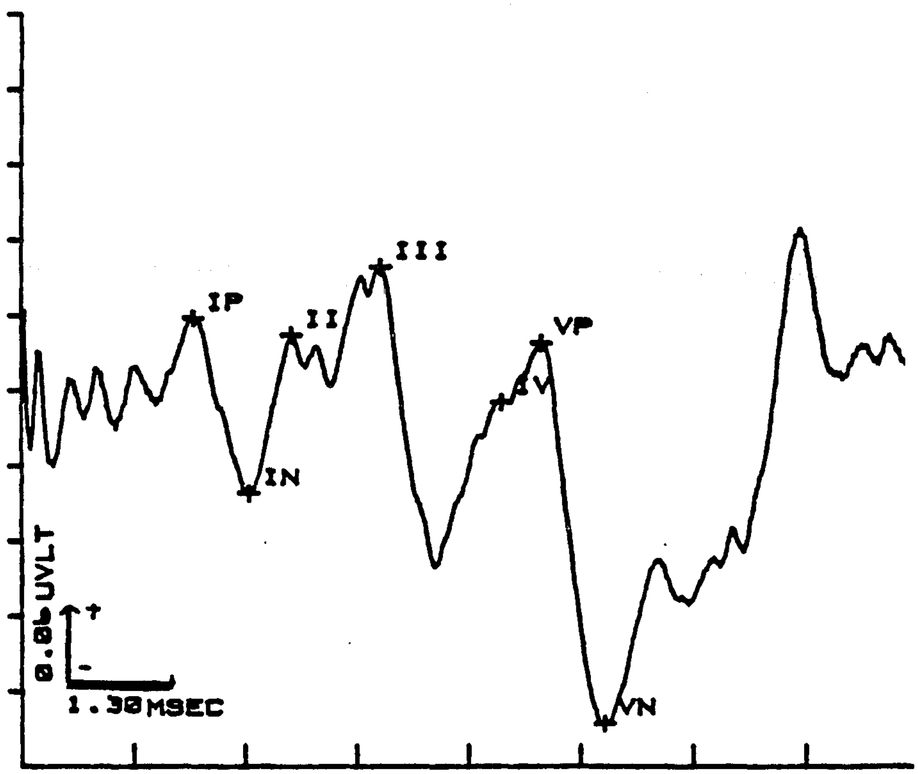

Figure 3. BSER with poorly defined waves, multiple peaks; 75 year old male, 60 dB SL, summed response to 4000 rarefaction clicks, ipsilateral montage.

instantaneous onset and a very brief duration. Since the brainstem evoked potential is an onset response, the click is well suited for generating the necessary synchronous neuronal firing that appears to be essential for eliciting a repeatable BSER [Hall, 1984].

As the recording of BSER has become clinically common in audiology, neurology, otology and pediatrics, the range of normal variation in the response has become evident. The response is affected by a number of stimulus variables, including polarity, intensity, rate and phase; and recording parameters such as filter settings and electrode placement [Chiappa et al., 1979; Stockard and Stockard, 1979; Weber et al., 1981; Klein and Teas, 1978; Jewett and Williston, 1971; and Don et al., 1977]. The response is also affected by subject variables such as temperature, sex, age and hearing loss [Stockard and Sharbrough, 1978; Coats and Martin, 1977; Seitz et al., 1980; Jerger and Hall, 1980].

Chapter 3

REVIEW OF THE LITERATURE

I. Age Effects on BSER

INTRODUCTION

There are two periods of time in which age has been shown to affect the latencies, amplitudes and morphology of BSERs: that of birth to two years of age and after about 50 years of age. There is, however, more understanding and agreement of the effects of the earlier maturational process on the BSER than the effects of the normal or biological aging process.

BIRTH TO TWO YEARS

Although analyses of age-related changes in BSER are inconclusive, the age range from birth to two years is clearly a period in which the brainstem response reflects the maturational changes occurring in the auditory nervous system. Numerous studies exist documenting maturational changes in the BSER of infants as they mature. Principal among these are Galambos [1978]; Galambos and Schulman-Galambos [1975, 1979]; Galambos and Despland, 1980; Hecox [1975]; Hecox et al. [1976, 1981]; Hecox and Galambos, 1974; Kaga and Tanaka [1980]; Salamy and McKean [1976]; Cox et al. [1981], Fria and Doyle [1984] and Jacobson et al. [1981].

Since the infant age range is not the principal focus of this study, the following material will provide only a broad sketch of infant BSER within the first two years of birth.

Infant BSER waveform is very different from that of the adult. In normal newborns, waves I, III and V are generally the only peaks present. The amplitude of wave I is approximately twice that of the adult, whereas wave V amplitude does not reach that of adults until at least 9-12 months of age [Hecox, 1984].

In general, the BSER latencies depend on maturation so the younger the infant the longer are the latencies of all waves, the smaller the amplitude ratios (of waves I and V) and the larger the effects of a change in the stimulus repetition rate. [Hecox and Jacobson, 1984]. Wave V latency decreases by .4 msec. per week during the age period from 34 to 48 weeks. Thereafter, there is a reduction in the rate of decrease until adult value is reached around 18 to 24 months [Hecox and Jacobson, 1984]. Kaga and Tanaka [1980] found that waves III, IV and V are not differentiated in neonates and young infants, but reach a mature pattern by two years of age.

Although there is disagreement on the exact time the infant BSER morphology, absolute latencies and IPLs approximate those of adults, it generally occurs by two years. Wave I tends to mature sooner than the others, decreasing to normal latency by about 8-10 weeks [Fria and Doyle, 1984], while there is a progressive shortening in the latency of wave V until about two years of age [Kaga and Tanaka, 1980; Hecox and Galambos, 1974; Fria and Doyle, 1984]. The different maturation time between waves I and V is thought to reflect the different rates of neurological development by the infant, with the peripheral auditory system maturing earlier than the more central auditory mechanisms [Salamy and McKean, 1976]. Peripheral neural functioning, as measured by the absolute latency of wave I is thought to mature earlier as a result of an improved middle ear system, more developed cochlear sensitivity and acoustic nerve transmission [Hecox and Jacobson, 1984]. The reduction of absolute latencies of the later waves may be delayed until more progressive myelinization can occur in the infant auditory tract providing greater synchronization among neural impulses from higher brainstem generators [Kaga and Tanaka, 1980]. Hecox [1975] suggested that increases in dendritic organization and fiber diameter growth might also underlie earlier developmental changes that are reflected in the brainstem evoked response of newborns.

Accordingly, it appears that infant BSER undergoes changes with maturation reflecting changes in the peripheral and central auditory nervous system. This observation suggests that changes caused by biological aging in the peripheral and central nervous system of the geriatric individual may also be reflected in the BSER.

BSER IN THE ELDERLY

There is a fairly extensive body of literature concerned with the effect of biological aging on the BSER [Jerger and Hall, 1980; Otto and McCandless, 1982; Allison et al., 1983; Beagley and Sheldrake, 1978; von Wedel, 1979; Harkins, 1981; Michalewski et al., 1980; Patterson et al., 1981]. Results of the research on aging and BSER have not always agreed despite the general agreement that changes do occur in an aging auditory nervous system. These differences have been based, in part, upon a lack of standardization of recording procedures and differences in subject variables, such as age and sex.

One of the first studies to find aging effects in the BSER of older subjects was done by Fujikawa and Weber [1977]. They were investigating the effects of increasing rate of click presentation on the BSER of three age groups of subjects and reported the effect of different rates of click presentation on the latency of wave V. Clicks were presented at 50 dB SL at four different click rates: 13, 33, 50 and 67 per second.

Three groups of eight subjects each were tested: infants (7-8 weeks), young adults (18-24 years) and geriatric adults (69-81 years). Pure tone audiograms were obtained on the two adult groups using Hinchcliff's [1958] hearing levels for normal aging as the criteria for inclusion in the study. Infants tested were at low risk for hearing loss.

Using the latency of wave V at the slow rate of 13 per second as a baseline, three latency shift scores were obtained for each of the three faster rates. Latency shift scores at each of the rates were compared for the three groups. The wave V latency increase of infants and young adults were similar for the 33 per second and 50 per second stimulus presentation. At the click rate of 67 per second, infants show a .79 msec. latency increase from the slowest rate, while young adults show a shift of .44 msec. Fujikawa and Weber [1977] suggest that the fast rate of presentation stresses the infant's developing nervous system with its lack of complete myelin development.

Differences between the geriatric adult and the younger adults' responses were more extensive. The older adult shifted .91 msec. from the baseline rate of 13 per second to 33 per second; while the young adult shifted only .26 msec. during the same rate increase. The older adult continued to show much larger shifts in latency with increased stimulus presentation rates than does the young adult. Evidently the geriatrics' auditory nervous system is more sensitive to increased stress in the form of increased click rate than that of the young adult.

The underlying neurological mechanism of this latency shift is not clear, but Fujikawa and Weber [1977] speculated that with the increased rate of stimulation, there is possibly a reduction in neuronal firing rate and increased asynchrony or decreased efficiency at the synaptic junction. An aging nervous system, such as that of the geriatric adult, can be expected to manifest itself more dramatically under stress than does a normal system. This study was one of the first to show differences between the BSER of a healthy geriatric adult and that of a normal young adult.

A year later, Rowe [1978] studied the latencies of all seven BSER waves recorded at three different stimulus intensity and rate combinations. Clicks were presented at 10 and 30 per second, at a level of presentation of 60 dB above the click threshold of five normal hearing adults. A third trial was run at 30 dB nHL, at a click rate of 30 per second. Subjects tested were a group of 25 young (17-33 years) and 25 older (51-74 years).

The absolute latencies of all waves of the younger subjects increased slightly from 10 per second to 30 per second, with less of an increase apparent for the earlier waves. The older subjects demonstrated no increase in latency for waves I and II with increased click rate. All other waves increased slightly with increased rate of presentation.

Though the rates and intensity of click presentation employed by Fujikawa and Weber [1977] were slightly different than those used by Rowe [1978], it is worthwhile to compare the two studies. The Fujikawa and Weber [1977] study showed an increase in wave V latency of .26 msec. for the young adults and an increase of .19 msec. for the older group as rates were increased from 13 per second to 33 per second. The Rowe [1978] study showed a change of .25 msec. for the young adult and .26 msec. for the older group when increasing the rate of presentation from 10 per second to 30 per second. The latency shift scores for the two studies were very similar for the young adult but differed greatly for the older group. Perhaps the difference could be partially explained by the differences in the ages of the two older groups. Rowe's older subjects ranged from 51 to 74 years of age, whereas Fujikawa and Weber's older group ranged from 69 to 81 years of age.

Rowe also looked at the interpeak intervals of his subjects at the different rates and intensities. The I-III IPL increased with increased repetition rate and with increased age. There is a difference of .22 msec. between the I-III interval of the young and elderly at 60 dB when tested at 10 per second and 30 per second.

The Rowe study has several major shortcomings. First, the groups were not matched for sex. Since absolute latencies and IPLs are known to be longer for males than for females, it is essential that the groups be controlled for sex in normative studies of this type [Stockard and Sharbrough, 1978; Seitz et al., 1980]. Secondly, subjects chosen were not given hearing tests and were selected if they had no history of hearing deficit. Older subjects with gradual hearing losses are often not accurate judges of their hearing ability. As mentioned previously, subject hearing has been found to affect interpeak transmission time [Coats and Martin, 1977].

Patterson et al. [1981] compared the absolute latencies and IPLs of three groups: an older group (60 to 79 years), a middle aged group (40 to 59 years) and a young group (20 to 39 years). BSERs were recorded at 60, 70 and 80 dB (SL) for stimulus rates of 5, 10 and 15 clicks per second. The most prominent age differences in the results centered on wave III. Older adults had significantly longer wave III latencies than both middle aged and young adults. The young and middle aged groups were not different from each other. Latencies in the older groups were longer than those for the young group by approximately .19 msec. Patterson et al. [1981] found that wave III latencies of older males were less affected by increases in stimulus rate than were any of the other groups. Older individuals had longer I-III IPLs than both middle aged and young adults. Increased latencies with advanced age were also found for waves I, II and IV, but were restricted to the lowest intensity and were more evident in males than in females.

The prolonged wave III latencies which were found in this study support findings reported by Rowe [1978]. Both Rowe [1978] and Patterson et al. [1981] found significantly longer I-III interpeak intervals in the older group than in the younger group. Patterson suggested that the results imply changes in neural propagation within the brainstem of the elderly.

Maurizi et al. [1982] studied the effects of age on the BSER in a total of 86 male subjects between 60 and 80 years of age. All subjects underwent pure tone audiometry, impedance testing and the BSER. The BSER portion of the study was limited to two intensity levels: 70 and 80 dB nHL. Some 1600 rarefaction clicks of .1 msec. duration at a repetition rate of of 20 clicks per second were delivered monaurally through a TDH 39 headphone for each run. Subjects were classified into four groups on the basis of their age. The four age groups were: 60-65 years (34 subjects), 66-70 years (22 subjects) 71-75 years (22 subjects) and 76-86 years (8 subjects).

Statistically significant correlations were found between age and wave V latency with wave V latency increasing with age. Significant prolongations of the I-V IPL interval was also found in the older groups. The authors suggest that the prolongation of the I-V interval indicated a more or less marked age-related effect on the brainstem structures in the aged. The findings of increased IPLs as a function of aging support those of Rowe [1978] and Patterson et al. [1981].

Allison et al. [1983] tested 130 males and 156 females ranging from four to 95 years of age for visual and somatosensory as well as auditory evoked potentials. Auditory stimuli were only presented at 75 dB SL at a rate of 10 per second. Waves I through V showed a significant increase in latency with increasing age. Most latencies showed a steeper increase with age in males than in females. The authors also reported that most interpeak latencies increased with age, but it was not clear which interpeaks latencies they measured.

von Wedel [1979] examined the brainstem response in 142 subjects (74 females, 68 males) from 50 years to over 80 years of age. Peak occurrence, amplitude and the latency of the first five waves were measured using the ipsilateral recording montage at three intensity levels (3Ø, 5Ø and 7Ø dB nHL). He found an increasing latency with age for the first wave, although amplitudes showed no significant age dependency. The likelihood of missing waves I, III and V was also found to increase with age. von Wedel sugested that the age dependency of both the latency of wave I and the increase in missing waves reflected a reduction of excited nerve fibers and reduced transport processes in all regions of the auditory pathways up to the nucleus of the lateral lemniscus.

Jerger and Hall [198Ø] examined the latency and amplitude of wave V in the BSER as a function of chronological age in 182 male and 137 female subjects. Subjects were tested at 9Ø and 1ØØ dB HL. Some 98 of the subjects (aged 22 to 55) had hearing sensitivity within normal limits, but the remainder had sensori-neural hearing loss. In the normal hearing group, the latency of wave V increased .2 msec. over the age range from 22 to 55. Wave V amplitude decreased about 1Ø percent. In the sensori-neural loss group, wave V latency showed little change as a function of age. For males, the average latency in the oldest group was only .1 msec. longer than the average latency in the youngest group. For female subjects, there was no consistent change in latency with age. Jerger and

Hall conclude their study with the observation that the age effect on BSER was not unexpected considering the changes that have long been associated with aging.

The Jerger and Hall [1980] study has two major shortcomings. First, it is perhaps meaningless to attempt to discuss the effect of aging on auditory BSER based on a population ranging only to 55 years of age. Secondly, the issue of the lack of increase in latency of wave V with sensori-neural hearing loss might be the more important finding for a study of aging. In an aging population, most subjects would have some sensori-neural hearing loss in the high frequencies, so the absence of an increase in latency with this sensori-neural hearing loss group might be more representative of what would occur in an older population. It is unfortunate that Jerger and Hall did not report the degree of hearing loss in their subjects.

Jerger and Hall also failed to consider the effects of aging on any of the brainstem response other than wave V. Since peripheral hearing loss has been reported to influence the latency of wave I [Otto and McCandless, 1982], this wave might reflect cochlear presbycusis. Accordingly, the elderly may show changes in amplitude, latency or the percentage of occurrence of wave I. Since the click used in BSER stimulates the area of the cochlea primarily responsive to high frequencies (1-6 kHz), one might expect to see many morphological changes in the wave form of the elderly individual (with high frequency hearing loss) as compared to the younger subjects.

Beagley and Sheldrake [1978] examined the absolute latencies of waves I through V in a study of ten subjects (five males and five females) for each of the decades from the second to the eighth. All subjects had hearing within normal limits for their age. Each subject was tested three times: at 80 dB SL and 60 dB SL (at 20 clicks per second) and at 70 dB SL (at 10 clicks per second).

The test results showed no appreciable prolongation of the latency of any of the waves with increased age. The results of this study differed from those of the studies discussed previously [Jerger and Hall, 1980; Rowe, 1978; Patterson et al., 1981 and Maurizi, 1982]. Beagley and Sheldrake [1978] saw a tendency for the amplitude of wave V to decrease with increasing age. von Wedel [1979] found that wave amplitude had no significant age dependency.

Otto and McCandless [1982] studied the absolute and interpeak latencies of three groups: 30 elderly (60-80 years), 30 young (17-45 years) normal hearing subjects and 30 young subjects with sensori-neural hearing loss comparable with the elderly group. The addition of the group of young hearing impaired subjects permitted an analysis of the interaction of advanced age and high frequency hearing loss. The authors did not report the number of males and females in the study.

BSERs were elicited by clicks presented via earphones at the rate of 10 clicks per second. Clicks were presented at 80 and 50 dB nHL to each ear. The 80 dB nHL was selected for comparison of latencies because high frequency hearing losses were expected in a presbycusic population and so the higher presentation level would yield optimum waveforms.

Analysis of the results revealed no significant difference in either latency or IPL between the young hearing impaired and the presbycusic group, suggesting that latency or IPL differences observed with age, found in other studies, reflect high frequency hearing loss rather than some central aspect of the aging phemonenon. The study did, however, reveal a general trend toward degradation of wave form related to aging, with the earlier waves of the elderly subjects tending to lack clarity and be less identifiable. This finding is in agreement with those of von Wedel [1979], Maurizi et al. [1982] and others.

Harkins [1981] studied BSER in young (mean age 25 years) and very elderly women (mean age 71.2 years) to evaluate the effects of age on transmission time over the brainstem auditory afferent pathway. Stimulus intensity was

70 dB nHL determined from ten normal ears. Measurements of peak latencies and IPLs were determined at four interstimulus intervals: 100, 50, 20 and 10 msec. The elderly group showed delayed peak latencies for all waves, although there were no differences in IPLs. Both peak and interpeak latencies increased with decreasing ISI, but there was no age-ISI interaction. The absence of an age-ISI interaction is in contrast with Fujikawa and Weber [1977] and Rowe [1978].

The peak latency differences found by Harkins [1981] were attributed to peripheral processes (mild presbycusis), whereas the lack of an age effect for IPL and of an age-ISI interaction indicated no slowing of central transmission time in the afferent auditory system up to at least the region of the superior olivary complex and inferior colliculi. They also found no age differences in gross morphology, and no increase in response variability with age between runs. Response amplitude tended to be lower in the elderly compared to the young. The finding is consistent with Beagley and Sheldrake [1978], but contrasts with that of von Wedel [1979].

Rosenhamer et al. [1980] recorded BSERs to clicks presented at 22.5 per second at three sensation levels: 80, 60 and 40 dB. Sixty normal hearing subjects were grouped according to age and sex: young females (20 -37 years), elderly females (50-63 years), young males (23-40 years) and elderly males (50-65 years). All subjects were healthy and had normal pure tone audiograms (125-4000 Hz) with regard to age. The latencies of waves I, III and V, and the peak intervals of I-III, III-V and I-V were measured at 80 and 60 dB SL. At 40 dB SL only the latency of wave V was considered. The study found significant peak latency differences between elderly and young females, but not between elderly and young males. The difference for females was found to be in the order of .15 msec. for wave I, .2-.25 msec. for wave III and .3 msec. for wave V, a successive increase in the absolute latency difference from wave I to V. Significant differences in interpeak intervals were not found in the young and elderly males. Young females had significantly shorter I-V IPLs than older females at 60 dB SL, but not at 80 dB SL. There was no significant difference for young and older females for the III-V interval, but there was for the I-III interval with younger females having significantly shorter IPLs than older females. The differences in interpeak intervals between groups were not found for young and elderly males or young and elderly females. Thus the majority of the IPL data from this study support the data from Harkins [1981] and Beagley and Sheldrake [1978], but contrast with data from von Wedel [1979], Rowe [1978], Maurizi et al. [1982] and Allison et al. [1983].

GENERAL DISCUSSION

In summary, there seems to be some agreement that older subjects exhibit longer absolute peak latencies than younger ones. There is disagreement, however, as to whether the differences exist for all waves [Allison et al., 1983] or only for some waves: in particular wave III [Patterson et al., 1981] and wave I [von Wedel, 1979]. The conflicting finding was that of Beagley and Sheldrake [1978] who found no significant increase in absolute wave latency with an increase in age.

A major question is whether the changes in latency that are seen in the older individuals's BSER are the result of aging or simply the result of high frequency sensori- neural hearing losses. Harkins [1981] and Otto and McCandless [1982] suggest that the changes seen are due merely to the effects of the hearing loss of the elderly rather than more central changes in the auditory nervous systems.

Of the studies that analyzed IPL and age, Rosenhamer et al. [1980], Otto and McCandless [1982] and Harkins [1981] found no increase in IPL with age; whereas Rowe [1978], Allison et al. [1983] and Maurizi et al. [1982] found such increases. Clearly the issue of the relation of IPL to age needs further exploration. Clear understanding of the effects of aging on IPLs is essential if BSER techniques are to be effectively employed for the diagnosis of retrocochlear pathology in elderly patients.

There is disagreement as to whether waves decrease in amplitude with an increase in age. von Wedel [1979] found no significant age dependency of amplitudes, whereas Beagley and Sheldrake [1978] and Harkins [1981] found reduced amplitudes with older subjects.

Differences in the results of these studies can be explained, at least in part, by the lack of standardization in recording and stimulus parameters. It is difficult to compare studies that use different filters, phase stimulus, and intensity levels of click presentation and mode of presentation. Other factors that can play a major role in the differences among studies are the criteria for subject selection, particularly those concerning health status, sex and audiologic screening.

II. Sex Differences

Differences in BSER amplitude, latencies and IPLs have been reported between male and female populations in young and older age groups. If these differences exist, separate normative data must be derived for males and females to improve the accuracy of clinical diagnoses in elderly populations.

ABSOLUTE LATENCIES

Although there is general agreement that females have shorter latencies than males, these differences have not been established for all waves, at all intensities, in all age groups. Many studies have found a significant difference between the sexes for the later brainstem waves [Jerger and Hall, 1980; Patterson et al., 1981; Kjaer, 1979; Seitz et al., 1980; McClelland and McCrea, 1979; and Beagley and Sheldrake, 1978]. Wave III is often pivotal. Prior waves show a general trend for shorter latencies for females, but it is not until wave III that the difference becomes statistically significant.

Disagreement exists as to whether these differences exist at birth [Seitz et al., 1980] or first occur in adolescence [McClelland and McCrea, 1979]. Some studies report early age differences that persist into old age

[Beagley and Sheldrake, 1978]; whereas others find sex differences only to middle age [Rosenhamer et al., 1980].

INTERPEAK LATENCIES

There is also some evidence that females have shorter interpeak latencies, or transmission times, than males. Kjaer [1979] found significant differences in transmission time between waves I-III, I-IV, I-V and I-VII. Stockard and Stockard [1979] found significant differences in the I-V intervals. Rosenhamer et al., [1980] did not find the differences in interpeak interval significant at the .01 level.

AMPLITUDE

Females tend to have waves of greater amplitude than males. Jerger and Hall [1980] found that wave V was of greater amplitude for females than for males. Michalewski et al., [1980] found no significant sex differences for the amplitudes of waves I, II and III, but found a difference in waves IV through VIII. Kjaer [1979] found that females had significantly greater amplitudes of all waves.

ETIOLOGY

Although older females may generally be expected to have better high frequency hearing than males, thus partially explaining why the latency differences might occur in older groups, it does not provide an explanation for the differences occurring in young groups with no difference in hearing thresholds between the sexes.

Several explanations of these differences have been offered. Jerger and Hall [1980] attribute the differences to the relatively small dimension of the female central nervous system. Stockard and Stockard [1979] similarly suggest that the differences are related to head and brainstem size and related factors, such as the length of the external auditory canal and auditory nerve diameter. Patterson et al. [1981] notes, however, that if the observed differences were due to anatomical differences between the various segments of the auditory pathway, the differences would not be restricted to certain waves (as appears to be the case) but would transfer sequentially to all peaks along the brainstem pathway. Kjaer [1979] found no difference in latencies between groups of tall and short subjects of the same sex, causing doubt as to whether the differences observed between the sexes are the result of differences in the distances along the auditory pathway. Another possible explanation may be the differences in skull and soft tissue density [Michalewski et al., 1980]. Suffice to say, there is no single documentable reason for sex differences found in BSERs and there is some question about the existence of sex differences in the BSERs of older patients. Obviously, possible sex differences in older patients needs further investigation.

Chapter 4

ISSUES, DATA AND RESEARCH METHOD

I. Issues

The effects of biological aging on the absolute latencies, IPLs and amplitude of the BSER have not been thoroughly determined. Previous studies have reported results that are diverse. All of the studies reported have used the ipsilateral recording montage, while clinics have begun to routinely record using several different montages simultaneously. The present study was conceived to examine the effects of biological aging in men and women on the latencies and IPLs of waves I^{+} through V^{-} at four different intensity levels. Three recording montages were used: ipsilateral, contralateral and horizontal.

The present study was designed to investigate the following two issues:

1. The changes in absolute and interpeak latencies of the BSER and in amplitude ratios of waves V:I as a function of biological aging.

2. Differences, across age, between males and females in absolute and interpeak latencies and in wave amplitude.

The more general issue of wave morphology of the BSER of the individual is also considered. The effect of age, intensity, montage and sex on the number of waves absent in a particular run was examined. The patterns, if any, of the disappearance of the different waves was investigated to determine any observable changes of total wave morphology as a function of aging.

II. Data and Research Methods

SUBJECTS

Source of Subjects

Subjects for the study were, for the most part, friends and relatives of the researcher. The remaining subjects were obtained from the population of patients, employees and volunteers at the New York Veterans Administration Medical Center. From this population, subjects were chosen whose age, audiometric and health status met specific criteria discussed below.

Age and Sex Criteria

The eighty subjects who participated in this study divide into four age groupings, as shown in Table 1.

Table 1. Age and sex distribution of subjects.

Group	n*	Age Range	Mean Age Male	Mean Age Female
A	20	18-34	29.9	27.7
B	20	55-64	57.6	59.4
C	20	65-74	68.6	68.3
D	20	75-82	76.5	77.4

*10 males and 10 females in each group

Age 55 was selected as the lower limit for the older subjects for several reasons. In the decade from 50-60 there is a successive decrease in the number of persons with normal hearing and an increase in the degree of hearing impairment. Data on the increase in hearing impairment with age are shown in Appendix A (Table A.1). Subjects in this age range also experience a precipitous decline in visual acuity, with little change occurring before age 50 [Schow, 1978]. The upper cutoff for the younger group--34 years of age--was selected because, beyond this age, the median hearing levels are consistently worse at all frequencies for men.

Audiometric Criteria

Each potential subject was screened for normal hearing, using a Grason-Stadler 10 audiometer. Audiograms were obtained for each individual, including pure tone air and bone conduction, speech reception and discrimination. Pure tone air conduction was tested at 250, 500, 1000, 2000, 3000, 4000 and 6000 Hz (ANSI-69); bone conduction testing was done at 250, 500, 1000, 2000, 3000 and 4000 Hz; and discrimination testing was done at 40 dB SL using CID W-22 word lists. Some 95 subjects were tested to find the 80 subjects that met the audiometric criteria for the study.

Hearing norms used in this research are from the Health

Examination survey conducted in 1960-62 by the U.S. Department of Health, Education and Welfare (DHEW) [1965]. The data are shown in Appendix B (Figures B.1-4). A stratified sample of 7,710 persons was selected to represent 111 million adults in the U.S. civilian, non-institutionalized population aged 18 to 79, of whom 6,610 were examined. These norms were used because of the large sample size, and because testing was done under relatively controlled conditions with respect to equipment and acoustical environment.

Another survey was done by the U.S. DHEW in 1971-75 [U.S. Department of Health, Education and Welfare, 1980]. The results of that study are broadly consistent with those of the earlier study. Since the latter study excluded frequencies above 4000 Hz and ages below 25 years, it is considered less useful as a basis for establishing audiometric norms for the present study.

Subjects were considered to have normal hearing if pure tones at all frequencies were not more than 10 dB worse than the 1960 U.S. DHEW survey medians for their age decade. The ranges of pure tone thresholds for each of the age groups, by sex, are shown in Figures B.5-8. The loss of sensitivity in the older individuals is apparent and typical for a group of healthy aging adults. Older females also have better hearing, as compared with males in the same age group.

Impedance testing on a Grason-Stadler 1723 impedance audiometer was also performed. Tympanograms were considered normal if they fell within plus or minus 100 mm H_2O. This is the range accepted as normal in the New York Veterans Administration Medical Center.

Because of the time required for the testing procedure, only the better ear (based on the pure tone threshold averaged at 2, 4 and 6 kHz) was chosen for BSER testing. If a subject's hearing in both ears was equivalent (within 5 dB) the ear with the lower click threshold during BSER testing was selected. Each subject was tested for approximately 1-1/2 hours. Test periods much longer than that would have been difficult for the older individuals, and were not justified by the data requirements of the study.

In addition to the normal hearing criteria, all subjects in the study were examined by an ENT physician to ensure that they met the following general and auditory health criteria:

- The subjects had to have normal external auditory canal anatomy, including absence of tympanic membrane perforations; and had to be free of active infection of the external and middle ear, and of cerumen in the external auditory canal.

- The subjects had to be in generally good health at the time of testing, with no history of stroke or psychiatric or neurological problems.

- All subjects also had to be free of a history of drug or alcohol abuse[1].

TESTING PROCEDURES

Brainstem responses were recorded for all subjects using a Nicolet Pathfinder II Evoked Potential System. Subjects were seated comfortably in an adjustable recliner to facilitate the recording of the EEG and to minimize muscle artifact. The room was dimly lit and subjects were tested with their eyes closed.

Individual click thresholds were ascertained through earphones monaurally prior to BSER testing. These thresholds were obtained in 2 dB steps using an ascending method.

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[1] Acute ethanol intoxication has been reported to prolong interpeak latencies although, when the temperature of the subject is controlled for, these effects disappear. There are, however, residual IPL changes seen in the non-intoxicated state following chronic ethanol intoxication [Squires et al., 1978]. Drugs affecting specific neurotransmitters involved in the generation and modulation of BSER (e.g., Serotinen, Acetylcholin) alter relative amplitudes and affect IPLs as well [Stockard et al., 1980].

Stimuli

Auditory stimulation consisted of rarefaction clicks of .1 msec. duration, presented at a rate of 11.1 clicks per second through TDH 39 headsets with circumaural cushions. Rarefactions clicks were used because, in most cases, they produce a larger wave I than either condensation or alternating clicks [Stockard and Stockard, 1979]. Clicks presented at a slow rate of 11.1 per second provide clear wave patterns in a reasonable amount of test time. Clicks were presented monaurally with contralateral broadband masking at 40 dB HL. Contralateral masking was used to prevent cross-hearing of the click stimulus at higher click presentation levels.

The click stimulus was presented at four sensation levels whenever possible. These levels were 80, 60, 40 and 20 dB above the subject's click threshold. Presenting stimuli a fixed number of decibels above the individual's click threshold is referred to as dB sensation level (dB SL), since it is referenced to an individual threshold, rather than dB HL, which is referenced to the click threshold of a normal hearing group. The use of SL will permit, as best as possible, comparisons among subjects with different hearing capacities since the effective level of stimulation will be approximately the same. Actually, however, the effective level of stimulation depends on the rapidity of loudness growth as well as the amount of threshold elevation. At times in the older group, the runs at 80 dB SL were not possible because of the raised click thresholds of subjects in that group. The raised click thresholds prevented testing at 80 dB SL because of the 120 dB output limitation of the stimulus generator.

Recording Methods

Final BSER wave forms were based on the summed responses to 2000 clicks. Each run was repeated once. Computer artifact rejection was used to prevent trials contaminated by movement or muscle activity from being added to the BSER.

The wave forms were based on summed responses covering a sweep of 13 msec. from click onset. This time base was selected to best see the later waves of the older groups when testing at low sensation levels.

Standard gold electrodes were attached to the vertex and the medial surface of each earlobe, with a ground lead on the forehead. Electrode impedances were less than 3000 ohms. Scalp signals were amplified with a wideband amplifier using a bandpass of 100-3000 Hz. A low bandpass filter setting above 3000 Hz can also be used, but the typical bandpass recordings for BSER are 100/150-3000 Hz. The bandpass filter setting used in the recording of BSER should ideally include the spectra of the BSER.

The responses were recorded horizontally, ipsilaterally, and contralaterally. Ipsilateral recording is the standard montage, with the vertex Cz referred to the stimulated earlobe. Contralateral recording has Cz referred to the earlobe contralateral to stimulation, whereas horizontal has the active electrode on the contralateral earlobe and the reference on the stimulated earlobe. There are predictable morphological changes which are related to these three recording montages and which often help in identifying BSER components in clinical applications. Recording vertex to earlobe, rather than vertex to mastoid, helps improve wave I resolution.

MEASUREMENTS

The following measurements were taken for each subject at each sensation level creating a total of 204 data points for most subjects:

1. Absolute peak latencies for all waves (I^+, I^-, II, III, IV, V^+ and V^-) measured contralaterally, ipsilaterally and horizontally. Measurements of I^- and V^- were included in this study because of their presence at lower sensation levels when many waves are missing.

2. Interpeak latencies between waves $I^{+\&-}$ to III, $I^{+\&-}$ to $V^{+\&-}$ and III to $V^{+\&-}$.

3. Amplitude measurements (peak to trough) were made for waves I and V.

Chapter 5

RESULTS

I. Effects of Aging on BSER

INTRODUCTION

Means and standard deviations were calculated for males and females separately for the latencies and IPLs of each of the following waves: I^+, I^-, II, III, IV, V^+, V^-, I^+-III, I^--III, I^+-V^+, I^+-V^-, I^--V^+, I^--V^-, III-V^+ and III-V^-. The results for each recording montage, the four sensation levels and the four age groups, for males and females separately, are given in Appendix Tables A.2-7. Missing data in the tables indicate waves which are not identifiable at specific sensation levels. When testing at the low sensation level of 2Ø dB SL, only waves I^-, III, V^+ and V^- are typically identifiable.

A two-way analysis of variance (age by sex) was performed for absolute and interpeak latencies of each wave at each sensation level and recording montage. Results of these analyses are shown in Tables A.8-9. The significance of the main effects of age and sex, and the two way interactions between the two are reported, with asterisks (*) identifying significant effects at p< .Ø5.

Post hoc comparisons were carried out using the Least Significant Difference (LSD) test [Kim and Kohout, 1975]. Differences between age groups that are significant at at least $p < .05$ confidence limits are reported.

In the following discussion, the youngest group (18-34 years) is labeled group A, the 55-64 year olds group B, the 65-74 year olds group C and the 75-82 year olds group D. Each group usually includes ten male and ten female subjects. At times, however, because of the raised click threshold, older subjects were not tested at 80 dB SL, reducing the number of subjects at that intensity for groups C and D. These subjects could not be tested due to their audiogram configuration and the output limitations of the experimental equipment.

ISSUE I: AGE EFFECTS ON THE BSER

The first issue investigated in the present study was that of the changes in absolute and interpeak (IPL) latencies of the BSER as a function of age. Since a great number of data were generated by this study results for absolute and interpeak latencies are reported separately for each of the recording montages.

Effects on Absolute Latencies

Mean absolute latency values and numbers of subjects tested for each of the waves at all four intensity levels and three recording montages are reported in Table A.1Ø. Waves significantly affected by aging are marked with asterisks. A single asterisk(*) indicates a significant effect at $p < .05$, a double asterisk (**) $p < .01$ and a triple asterisk (***) $p < .001$.

Overall the data indicated increases in absolute latency with an increase in age, although the latency increases are not always significant. Of the 75 mean absolute latencies generated by this study, 3Ø (4Ø percent) have significant effects at $p < .05$ (Table A.8).

At 8Ø dB SL ipsilateral, five of the seven waves (I^+, I^-, II, III and V^+) show a significant increase in latency, across subjects, with increasing age, at $p < .05$ (Table A.1Ø). In the post hoc tests waves I^+, I^-, II and III all show significant latency increases between age groups A and B (Figure 4). Wave V^+ increased only .Ø3 msec. between groups A and B, which is not statistically significant. The mean absolute latencies of each of the five waves for groups C and D are significantly ($p < .05$) later than the mean absolute latencies of each wave for group A.

Five waves (I^+, I^-, II, III and IV) out of the seven contralaterally recorded at 8Ø dB SL show significant age effects at $p < .05$ (Table A.1Ø). All five waves show

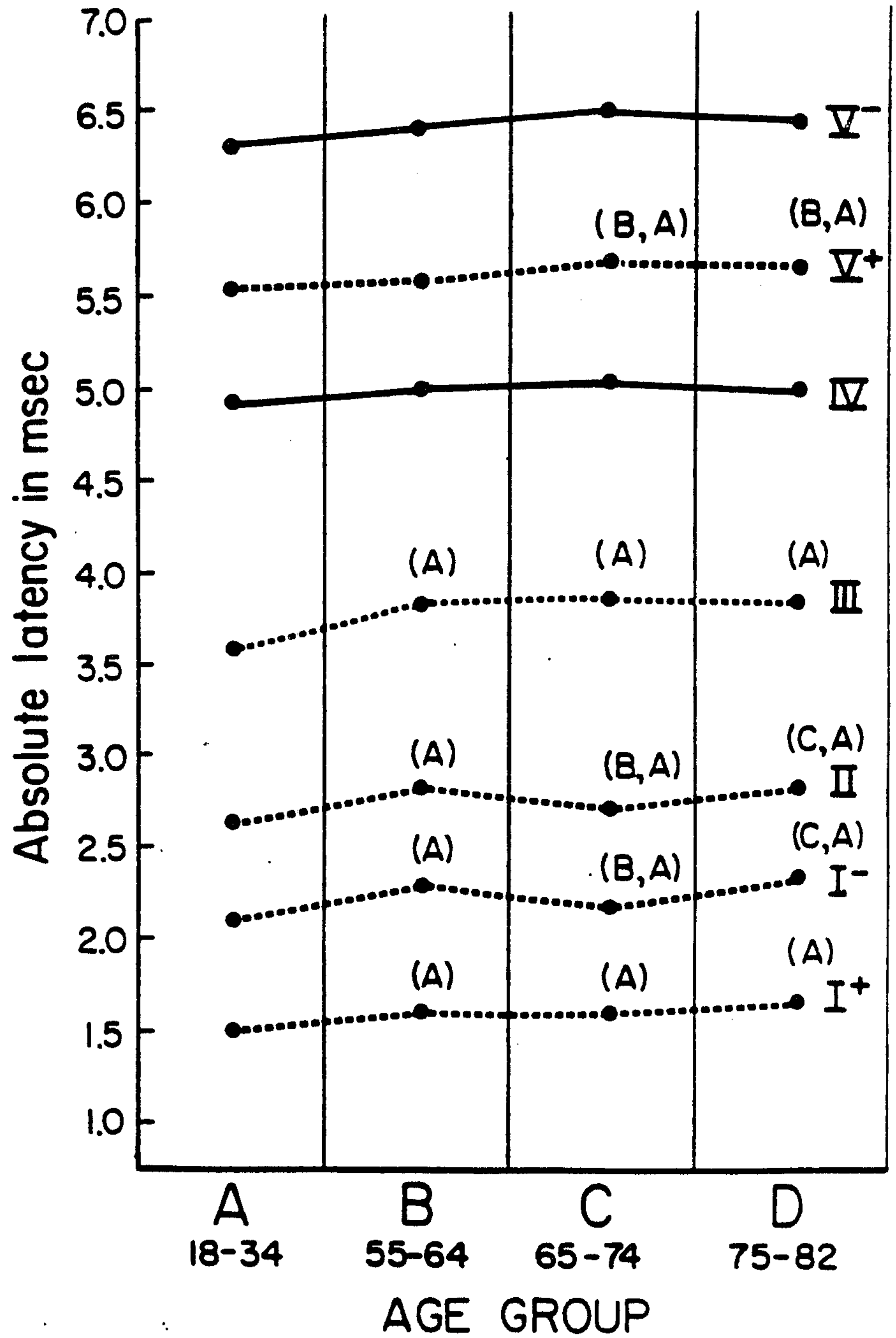

Figure 4. Change in mean absolute latencies by age group. Response recorded ipsilaterally at 80 dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

significant ($p < .05$) increase between groups A and B (Figure 5). The mean latencies generally increase again between B and C and between C and D. The mean absolute latencies of all waves for age groups C and D are significantly more delayed than those of group A.

In the horizontal montage all waves except wave IV show significant age effects at $p < .05$ (Table A.10). All six waves show a significant increase in latency between groups A and B (Figure 6). Although the absolute latency of wave II decreases significantly between age groups B and C the mean absolute latencies of age group C for that and other waves are greater than that of group A. Only wave V^- shows a significant decrease in mean absolute latency between age groups C and D, although the mean absolute latency of group D for this wave, as well as all other waves, is significantly greater than that of group A.

At 60 dB SL two out of the seven ipsilaterally recorded, two out of seven contralaterally recorded and four out of seven horizontally recorded waves show significant age effects (Table A.10). In the ipsilateral montage waves III and IV show significant ($p < .01$) age effects. Both waves show increases in latency through the first three age groups although they are not always significant. (Figure 7). Wave IV shows a decrease between age groups C and D, although the mean latency of age group D is significantly

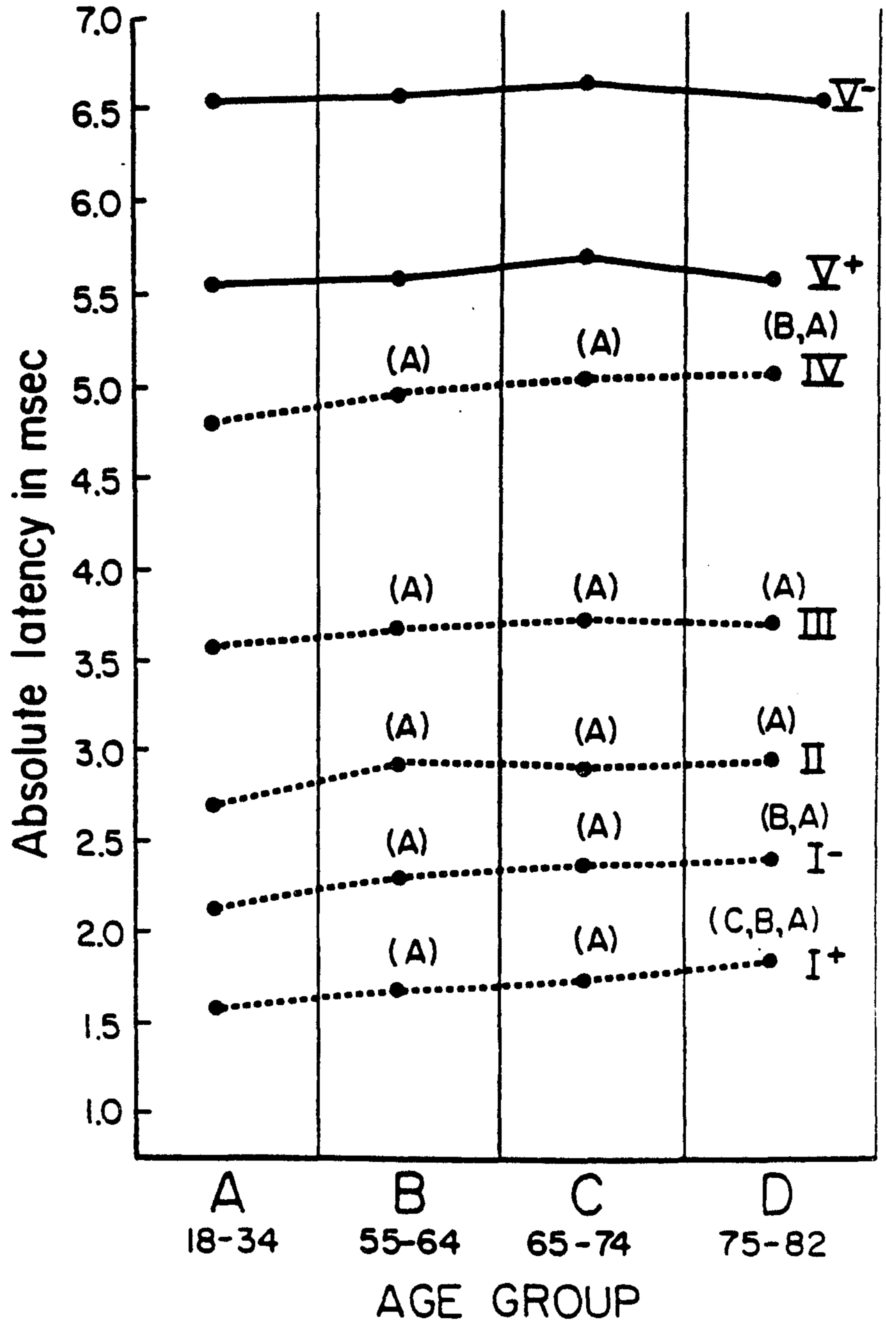

Figure 5. Change in mean absolute latencies by age group. Response recorded contralaterally at 80 dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

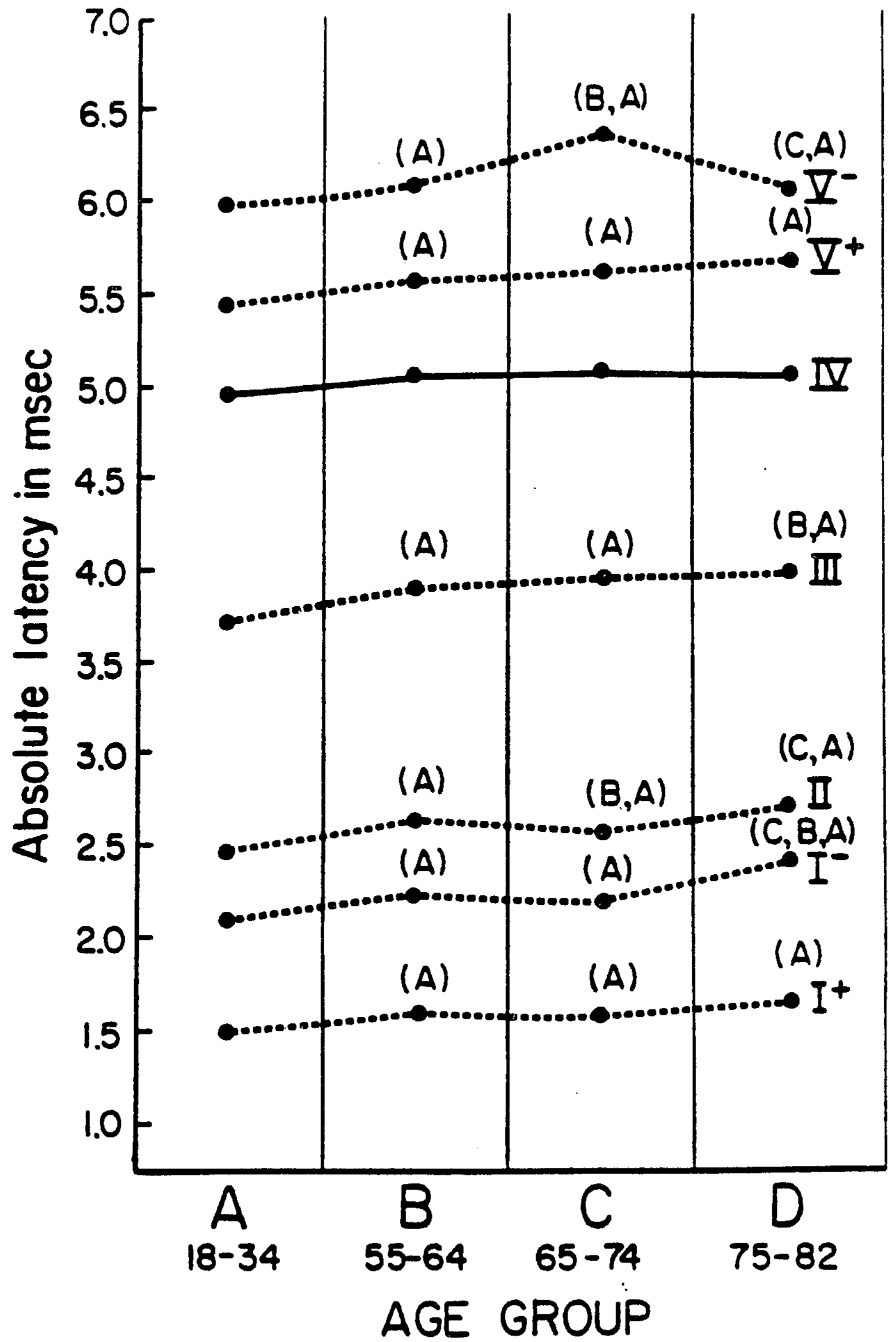

Figure 6. Change in mean absolute latencies by age group. Response recorded horizontally at 80 dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

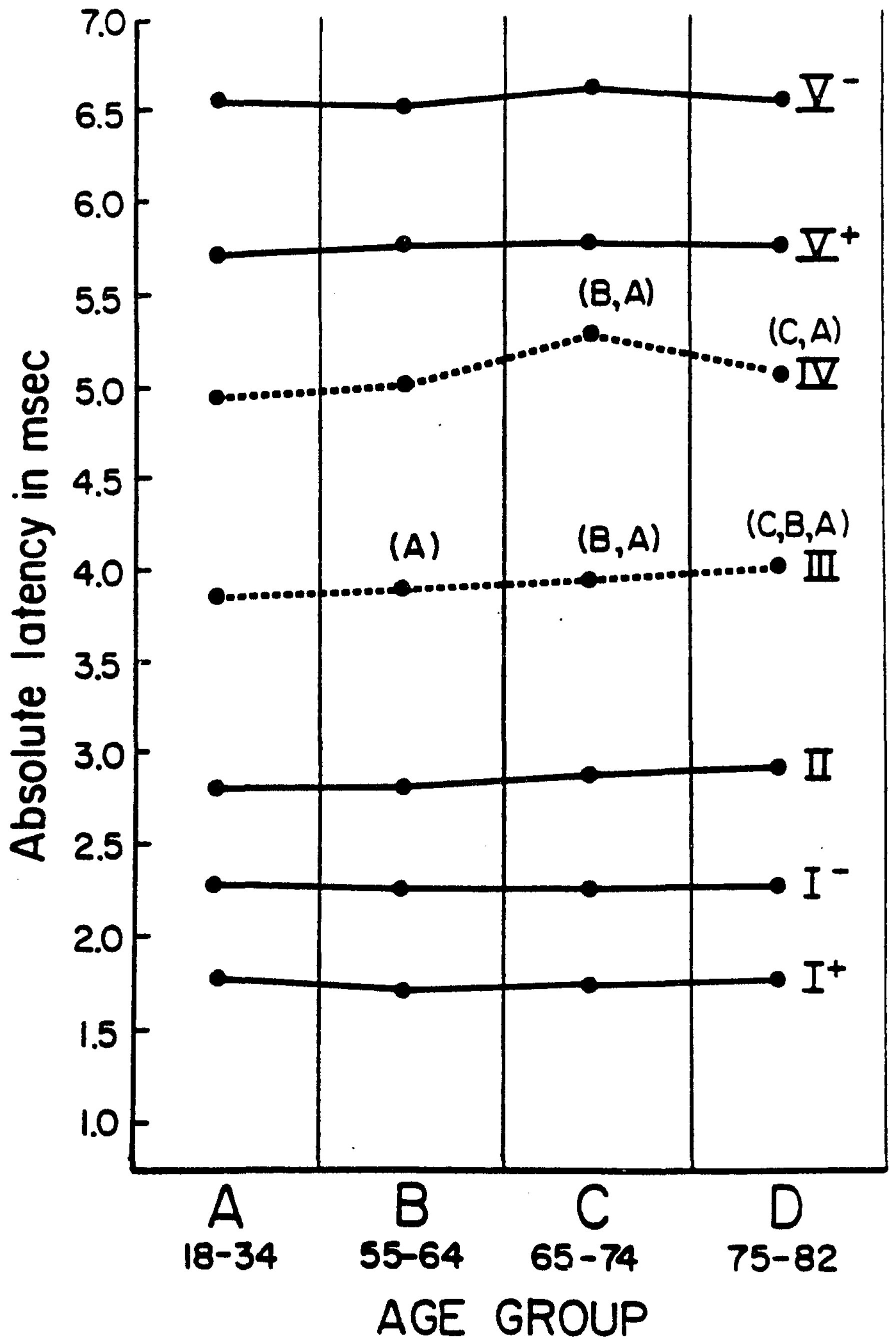

Figure 7. Change in mean absolute latencies by age group. Response recorded ipsilaterally at 60 dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

later than that of group A. Wave III shows significant increases in latency between each of the successive age groups.

The increases in absolute latencies of waves I^+ and IV recorded contralaterally are shown in Figure 8. For wave IV the mean latencies of groups C and D are significantly later than those of group A. Groups C and D of wave I^+ are significantly later than group B, but not significantly later than group A.

All four waves (III, IV, V^+ and V^-) that show a significant age effect in the horizontal montage are shown in Figure 9. The mean absolute latencies show an increase through the first three age groups and then decrease significantly between groups C and D. Despite the decrease, the mean absolute latencies of all waves except wave IV are significantly later for group D than for group A.

At 40 dB SL fewer waves are identifiable and so fewer waves showed significant increases with age. Waves I^+ and I^- ipsilaterally recorded and waves I^- and III contralaterally recorded showed significant age effects (Table A.10). All four waves increase in latency through the first three age groups (Figures 10-11) and decrease between groups C and D. Despite the decrease in mean absolute latency between the two oldest age groups, all

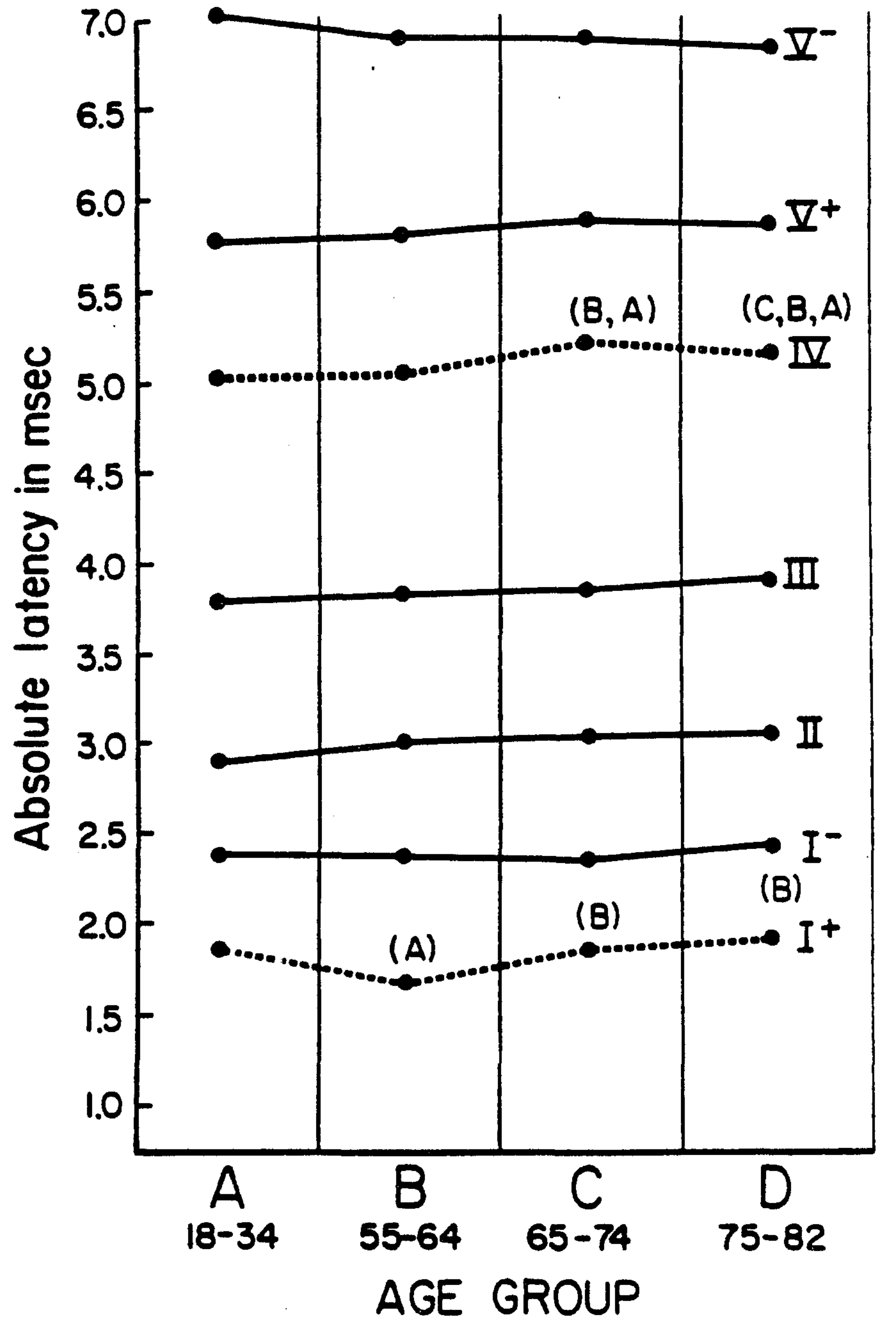

Figure 8. Change in mean absolute latencies by age group. Response recorded contralaterally at 60 dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

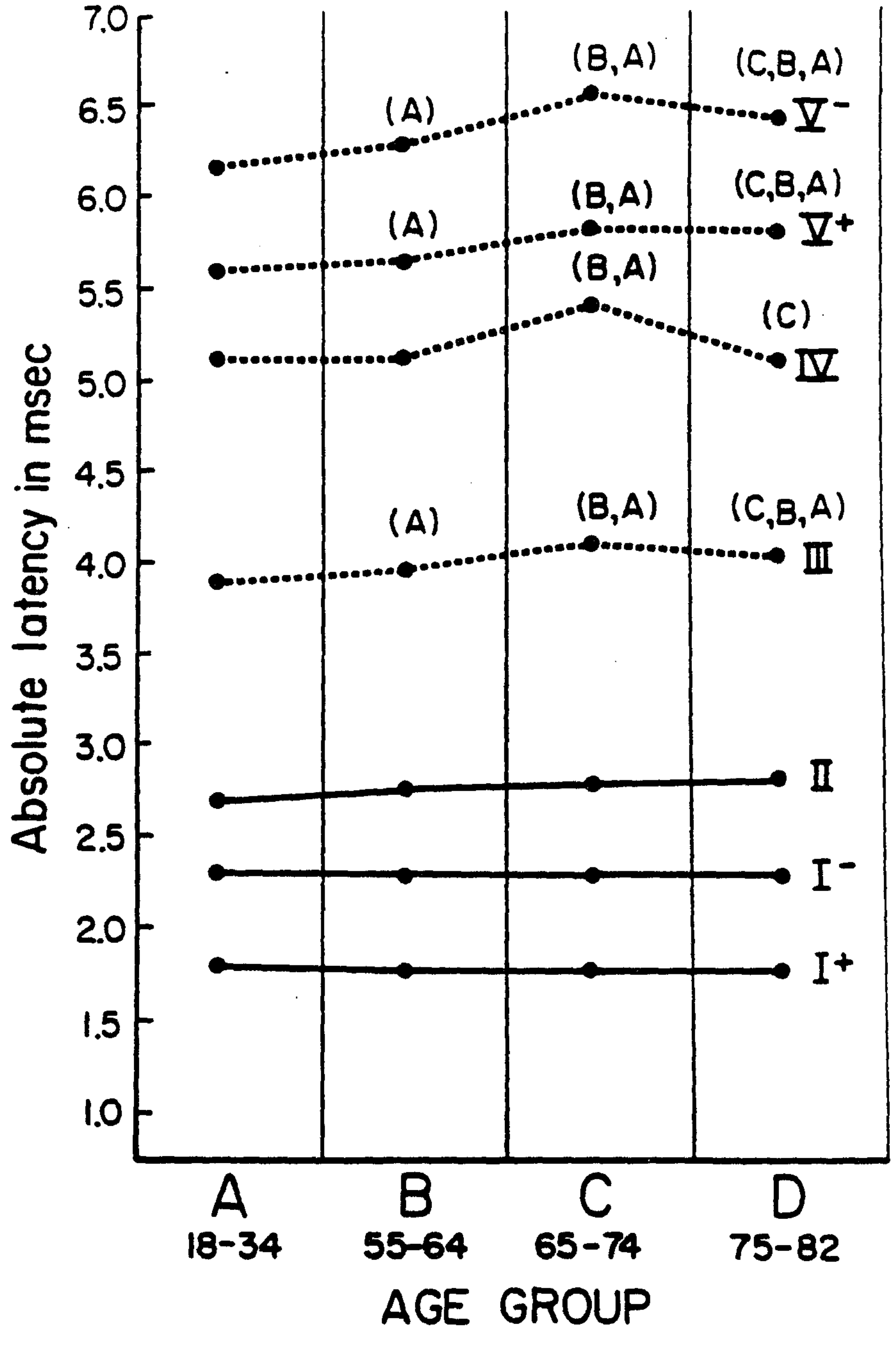

Figure 9. Change in mean absolute latencies by age group. Response recorded horizontally at 60 dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

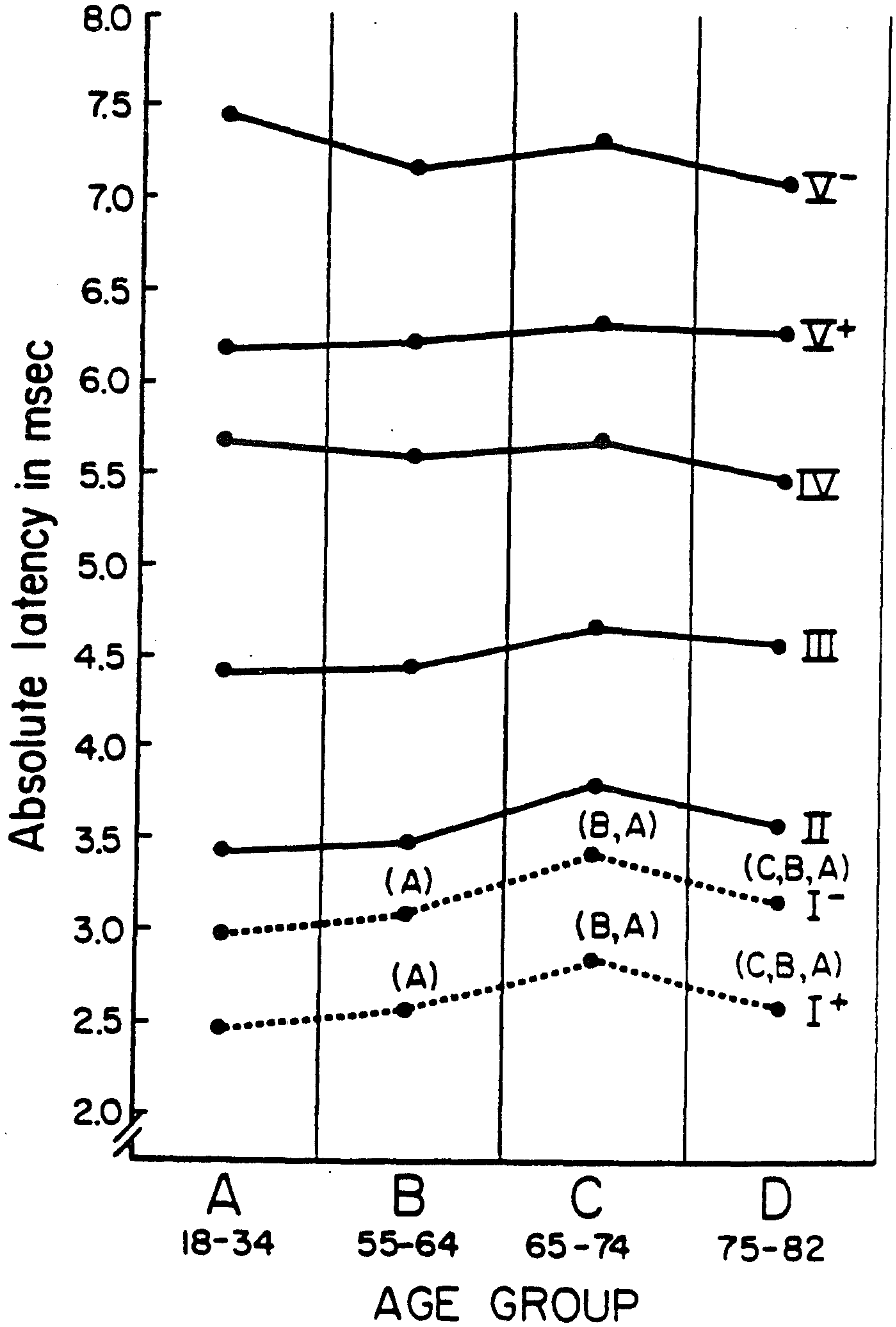

Figure 1Ø. Change in mean absolute latencies by age group. Response recorded ipsilaterally at 4Ø dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

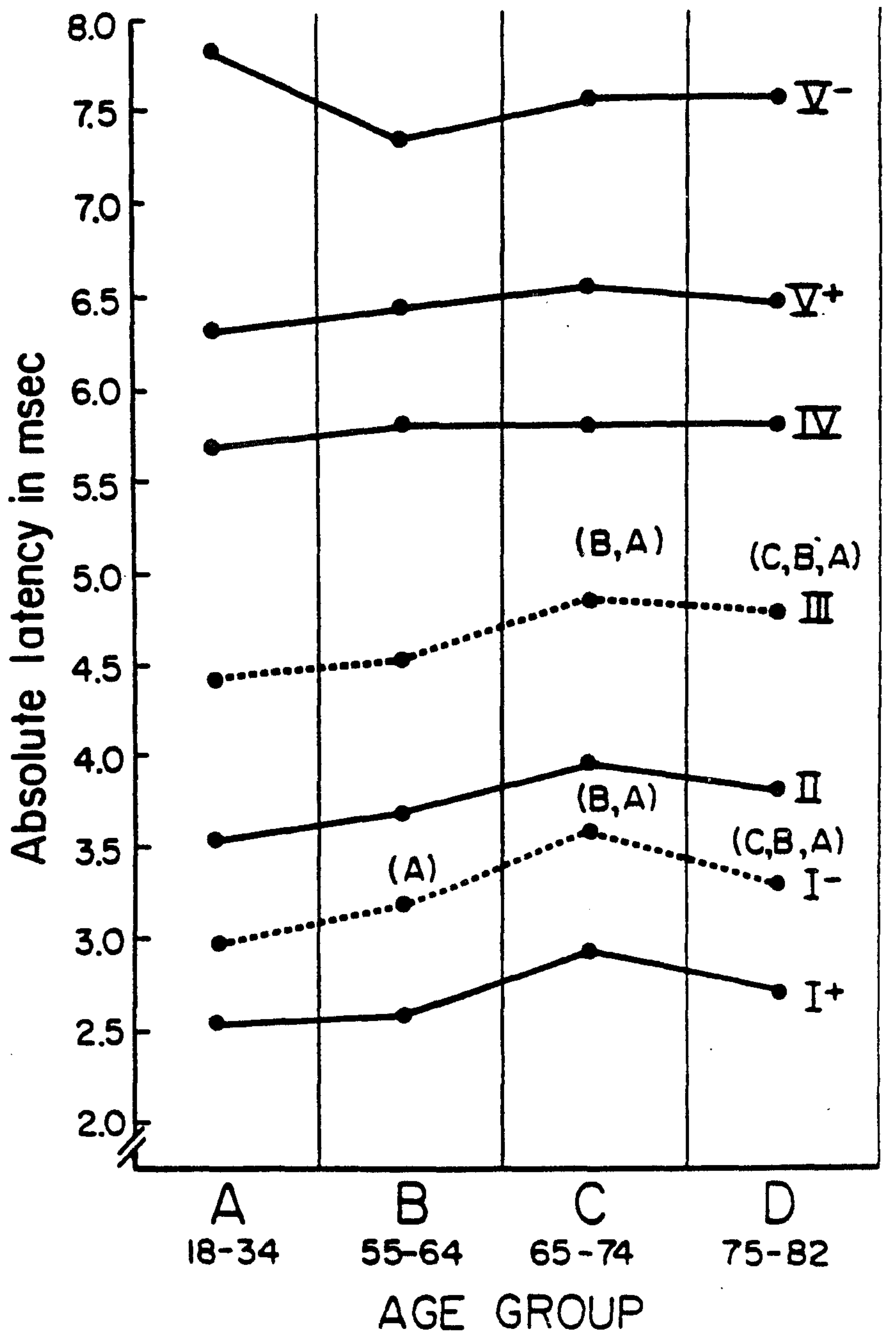

Figure 11. Change in mean absolute latencies by age group. Response recorded contralaterally at 40 dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

waves show significant increase in latency between age groups A and D. In the horizontal montage at 40 dB SL no waves showed significant age effects (Figure 12).

At 20 dB SL only wave III recorded ipsilaterally and contralaterally shows a significant age effect (Table A.10). Wave III in both ipsilateral and contralateral recording montages shows significant increases in latency between groups A and B and between groups B and C, and no further significant changes (Figures 13 and 14). No waves in the horizontal montage showed significant age effects (Figure 15).

In summary, many waves show a significant increase in absolute latency as a function of age. There is a significant increase between groups A and B; an increase between B and C is likely to occur at 20, 40 and 60 dB SL, but rarely occurs at 80 dB SL. An increase between groups C and D occurs less frequently. At 40 and 60 dB SL several waves show significant decreases between groups C and D, although the mean latency of group D is usually significantly greater than that of groups A and B.

Of the 30 mean absolute latencies significantly affected by age, 24 (80 percent) show significant increases in latencies between groups A and B. Some 29 mean absolute latencies are significantly later for groups C than group A,

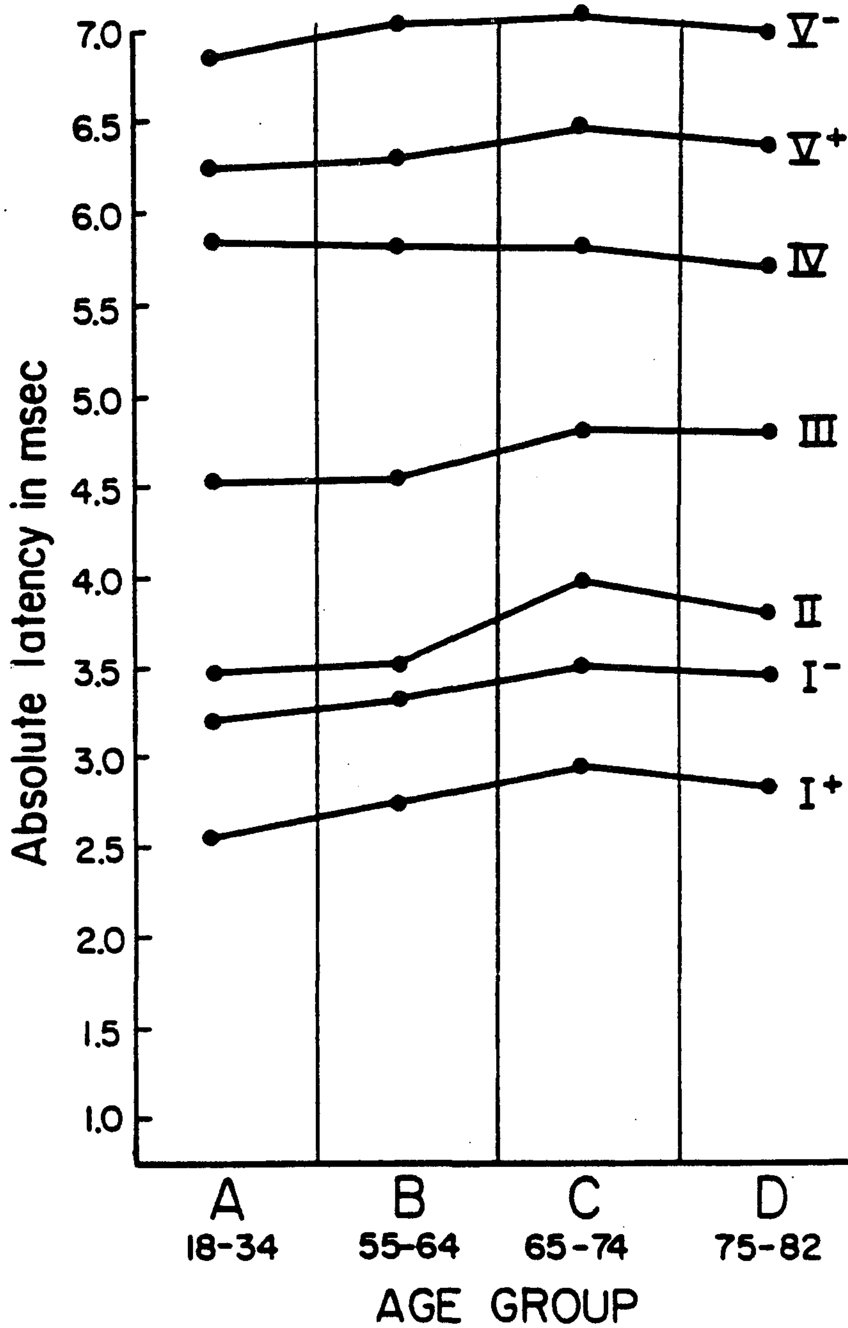

Figure 12. Change in mean absolute latencies by age group. Response recorded horizontally at 40 dB SL.

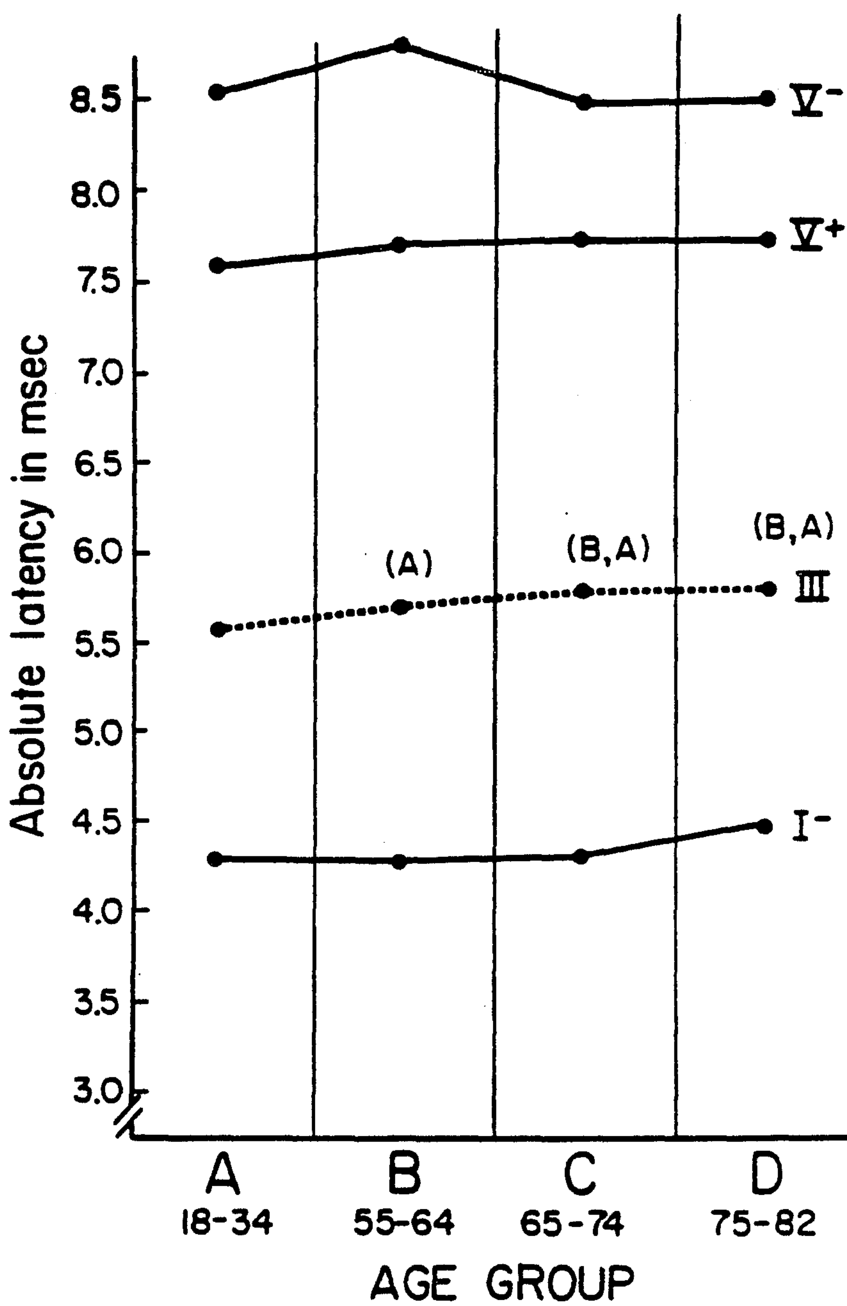

Figure 13. Change in mean absolute latencies by age group. Response recorded ipsilaterally at 2Ø dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

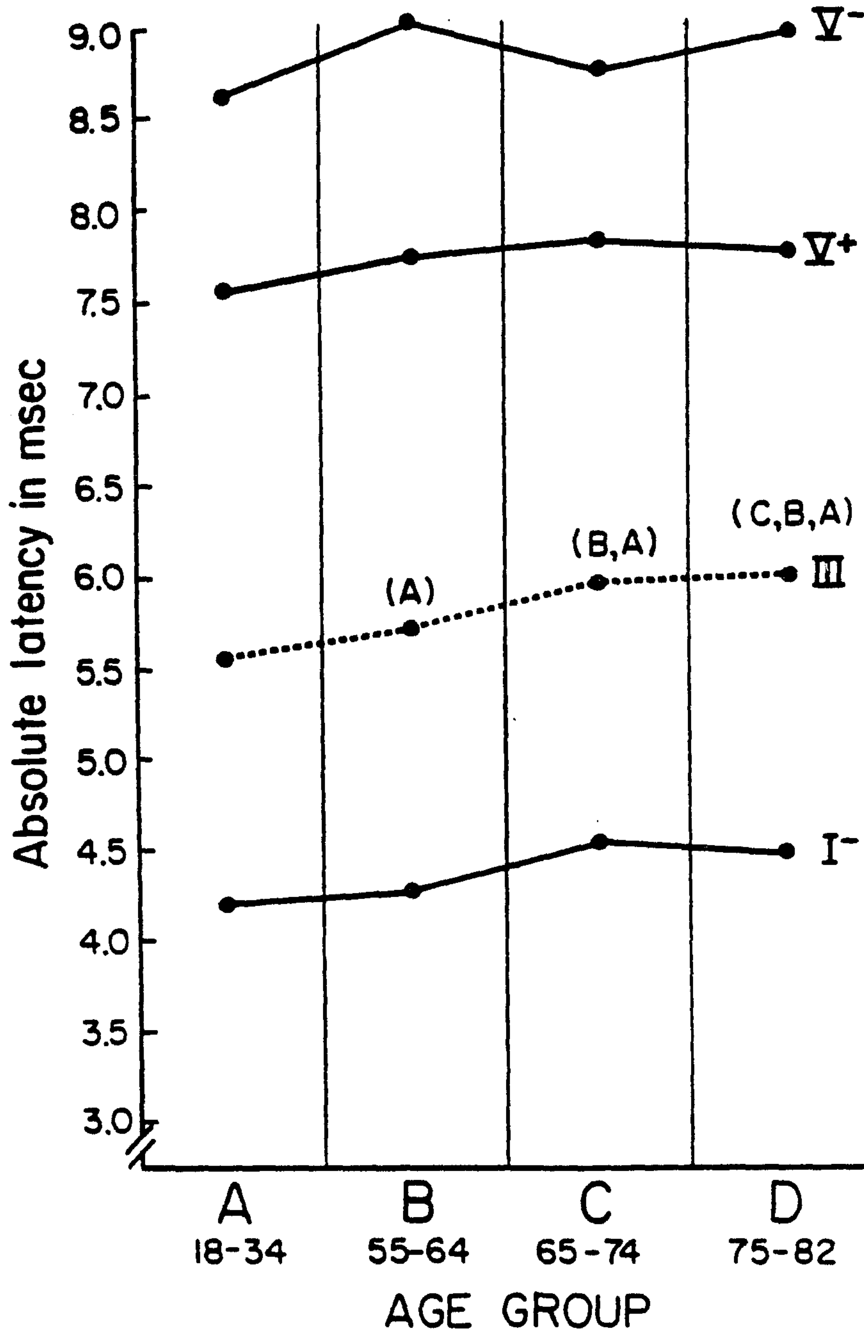

Figure 14. Change in mean absolute latencies by age group. Response recorded contralaterally at 20 dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

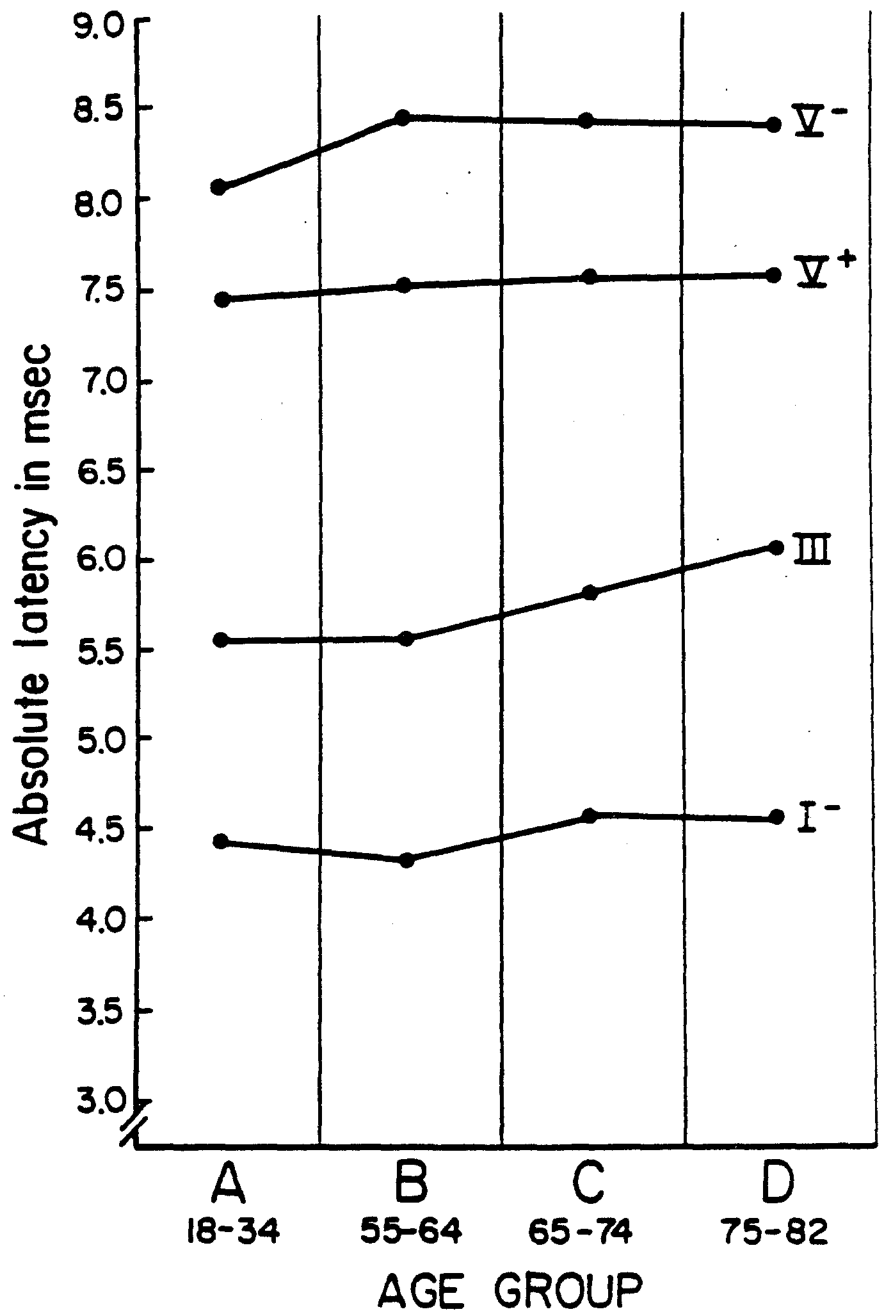

Figure 15. Change in mean absolute latencies by age group. Response recorded horizontally at 20 dB SL.

and group D than group A. Waves I^+ and III are significantly affected by age at every intensity level, but not in every recording montage.

Those waves indicating a significant sex by age effect are listed in Table A.8. When males and females differ in the effect of age on absolute latency, females most often show fewer significant increases in latency with aging than their male counterparts. Either females show fewer significant increases for a particular wave or show an increase in latency at a later age than do males. None of the waves showed significant increases at an earlier age for females than for males, although for waves V^+ horizontally recorded at 60 and 80 dB SL, and I^+ recorded horizontally at 80 dB SL the number of significant increases between age groups were the same.

Effects on Interpeak Latencies (IPLs)

Results of the analysis of the relation of age and IPLs using the two way analysis of variance (age by sex) are reported in Table A.9. IPLs that are significantly affected by age ($p < .05$) are identified by a single asterisk.

Mean IPL values and numbers of subjects for all IPLs at each intensity level and recording montage are shown in Tables A.11-13. IPLs that change significantly with aging are marked with an asterisk. A single asterisk indicates a significant effect at p< .05, a double asterisk p< .01 and a triple asterisk p< .001. Of the 87 IPLs generated by the study, 24 (28 percent) showed significant age effects. An effect is evident at all sensation levels and recording montages, although the relation seems to be a complex one with sensation level playing an important role. Mean IPLs for each age group were considered significantly different if they differed at p< .05 using the LSD post hoc test.

At 80 dB SL IPLs I^{-}-III, I^{-}-V^{+} ipsilaterally recorded and I^{+}-V^{-}, I^{-}-V^{-} and III-V^{-} horizontally recorded show significant age effects (Table A.11). Four of the five IPLs are fairly stable between age groups A and B (Figures 16 and 18). Only IPL I^{-}-V^{+} ipsilaterally recorded showed a significant decrease in mean IPL between the first two age groups (Figure 16). All five IPLs increase significantly between groups B and C, but the pattern reverses between groups C and D, with the IPLs showing a significant decrease. In the contralateral montage no IPLs showed significant age effects (Figure 17).

At 60 dB SL in the ipsilateral montage IPL I^{+}-III and I^{-}-III were significantly affected by age at p< .01 (Table A.11). In the horizontal montage I^{+}-III, I^{-}-III, I^{+}-V^{+}, and I^{+}-V^{-} all showed significant age effects at p< .001, while I^{-}-V^{-} and I^{-}-V^{+} showed significant effects at p< .01 (Table A.13). IPL I^{+}-III showed a significant age effect (p< .05)

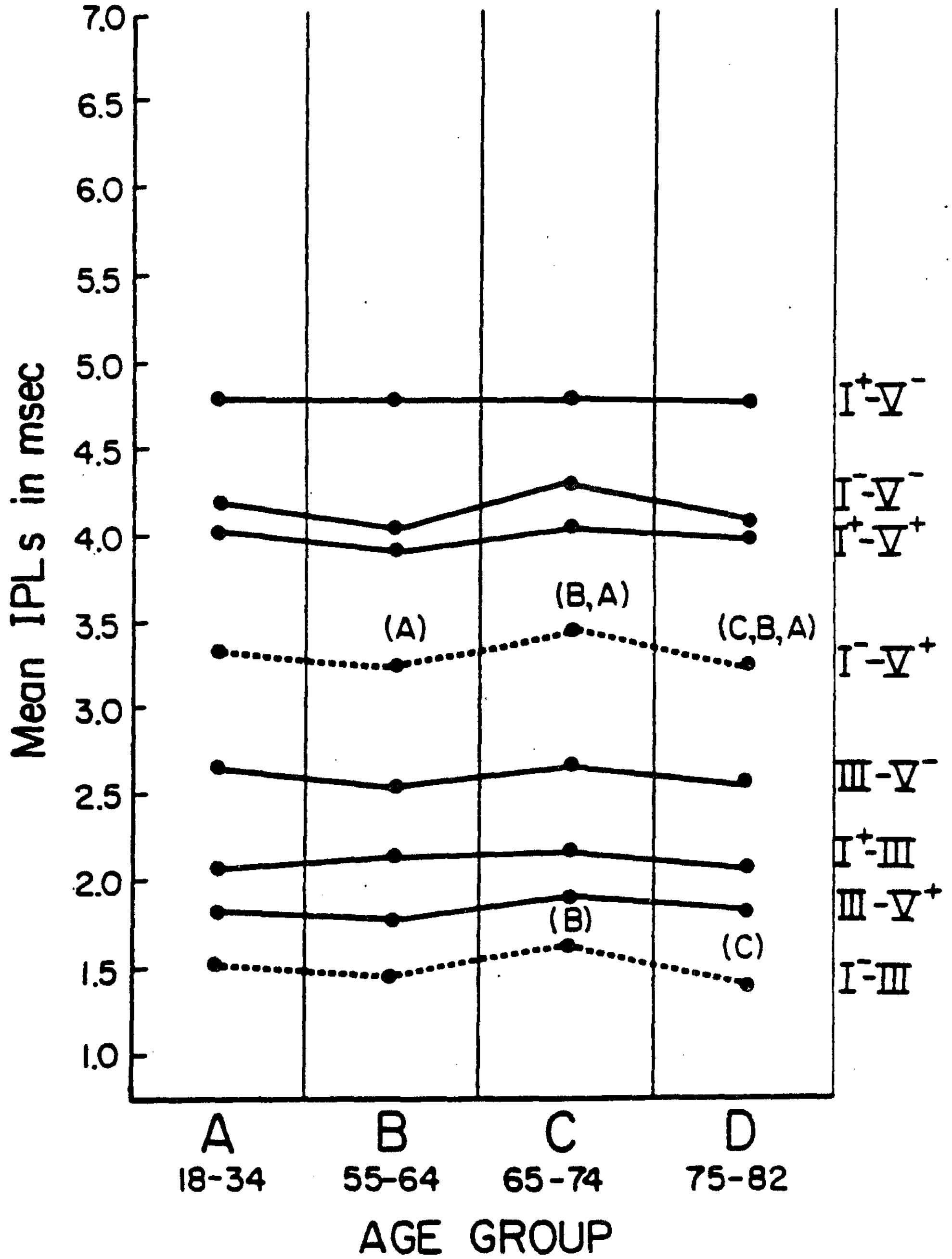

Figure 16. Change in mean interpeak latencies by age group. Response recorded ipsilaterally at 8Ø dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

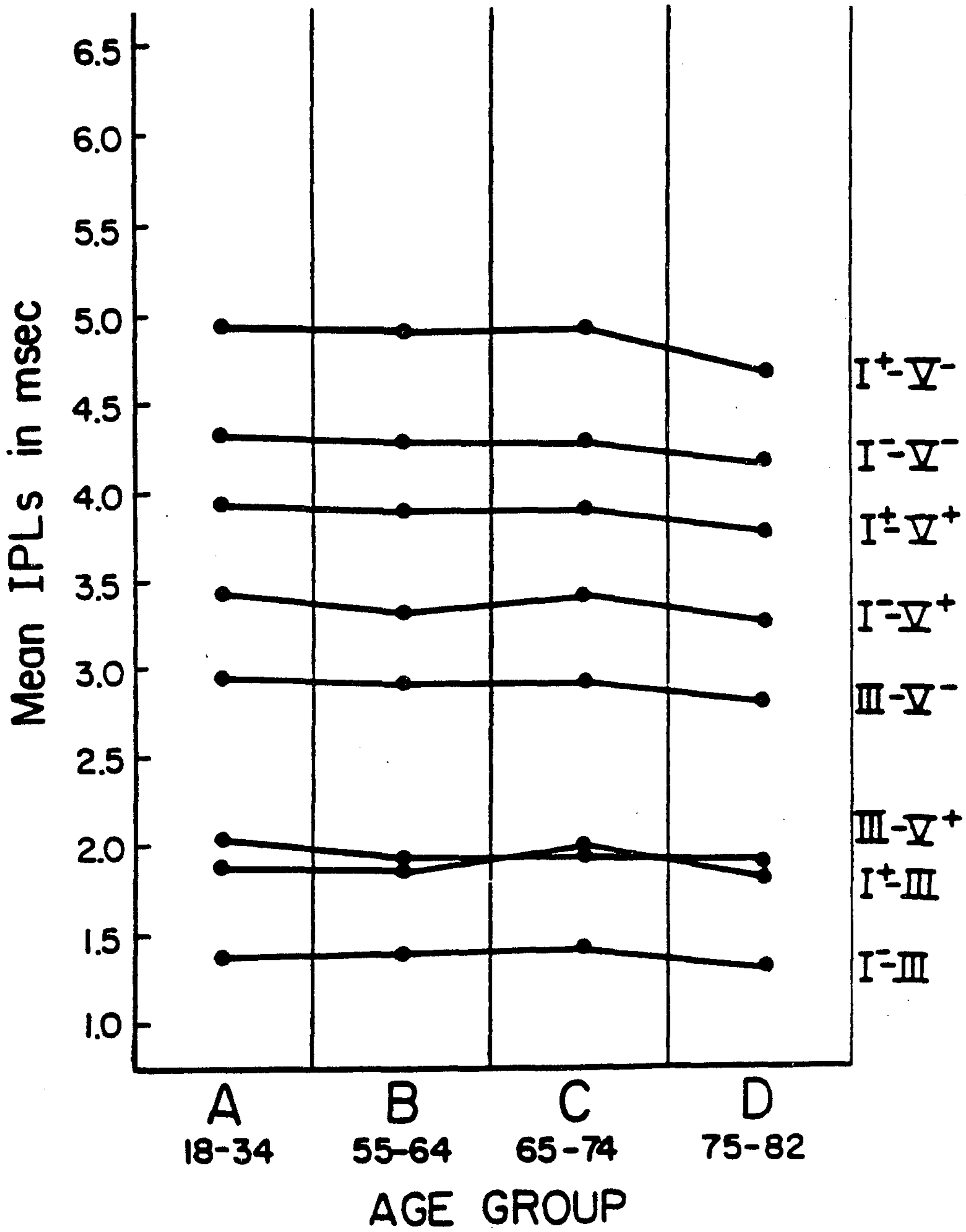

Figure 17. Change in mean interpeak latencies by age group. Response recorded contralaterally at 8Ø dB SL.

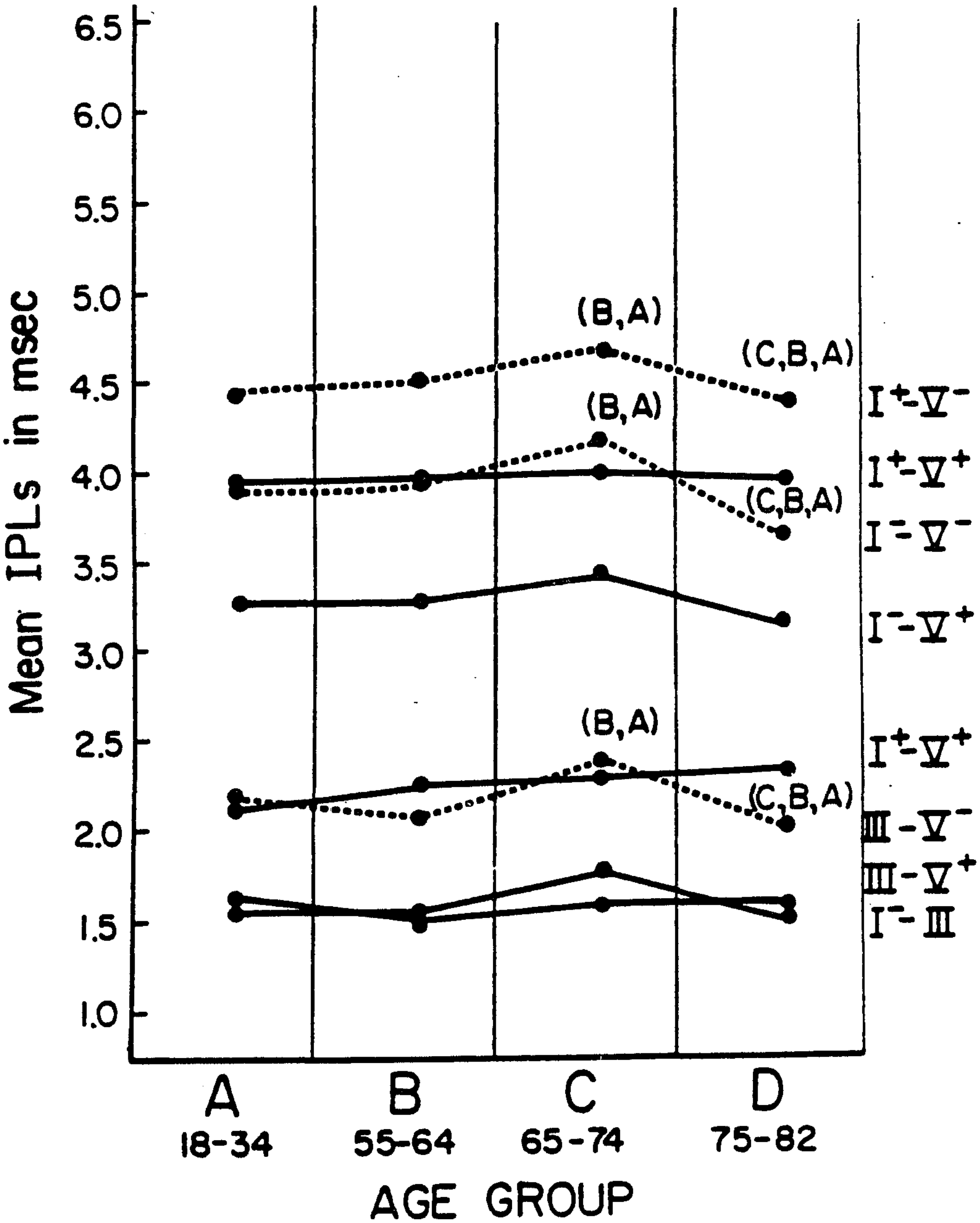

Figure 18. Change in mean interpeak latencies by age group. Response recorded horizontally at 8Ø dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

contralaterally recorded (Table A.12). At this sensation level IPLs showed continued increase through the first three age groups (Figures 19-21). All three IPLs increase between groups A and B and continue to increase between groups B and C. Only IPL I^{+}-III contralaterally recorded increases between groups A and B, decreases between B and C and then remains fairly stable (Figure 20). Most IPLs horizontally recorded at 60 dB SL show significant decrease between groups C and D (Figure 21), while the IPLs recorded contralaterally and ipsilaterally remain unchanged. For all montages mean IPLs of age groups C and D are significantly longer than those of group A and B.

IPLs at 20 and 40 dB SL

AT 40 dB SL, in the ipsilateral montage, IPLs I^{+}-V^{-}, I^{-}-V^{-} and III-V^{-} showed significant age effects at $p < .01$ (Table A.11). In the contralateral montage IPLs I^{+}-III, I^{+}-V^{-}, I^{-}-V^{+} and III-V^{+} all showed significant age effects at $p < .05$, whereas IPLs I^{-}-V^{-} and III-V^{-} showed significant age effects at $p < .001$ (Table A.12).

The age effect on IPLs at 40 dB SL was quite different from that at 60 and 80 dB SL. A significant decrease in mean IPLs occurred between groups A and B (Figures 22 and 23). Rarely did the mean IPLs remain stable. The only stable IPLs were III-V^{+} and I^{+}-III recorded contralaterally.

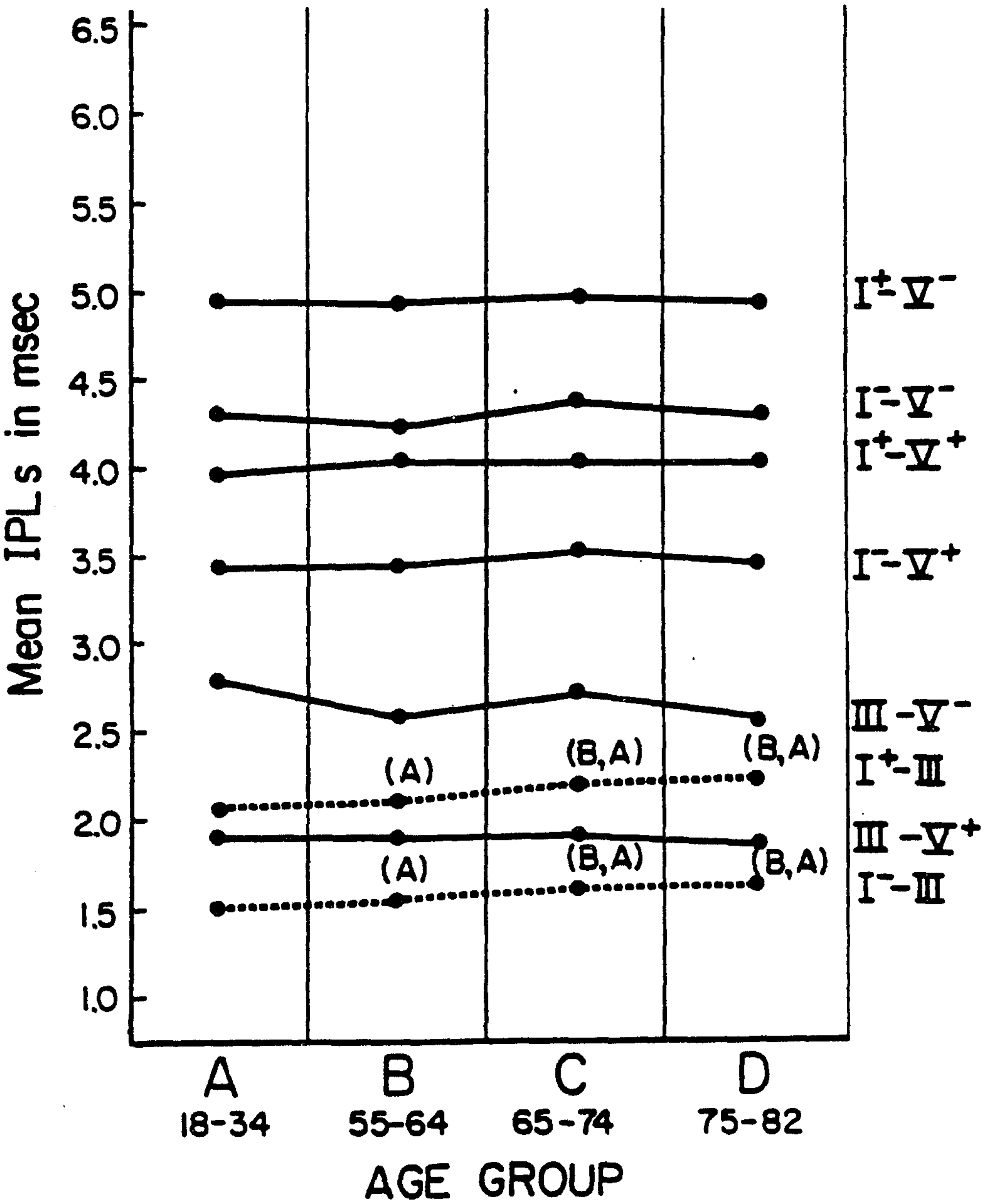

Figure 19. Change in mean interpeak latencies by age group. Response recorded ipsilaterally at 60 dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

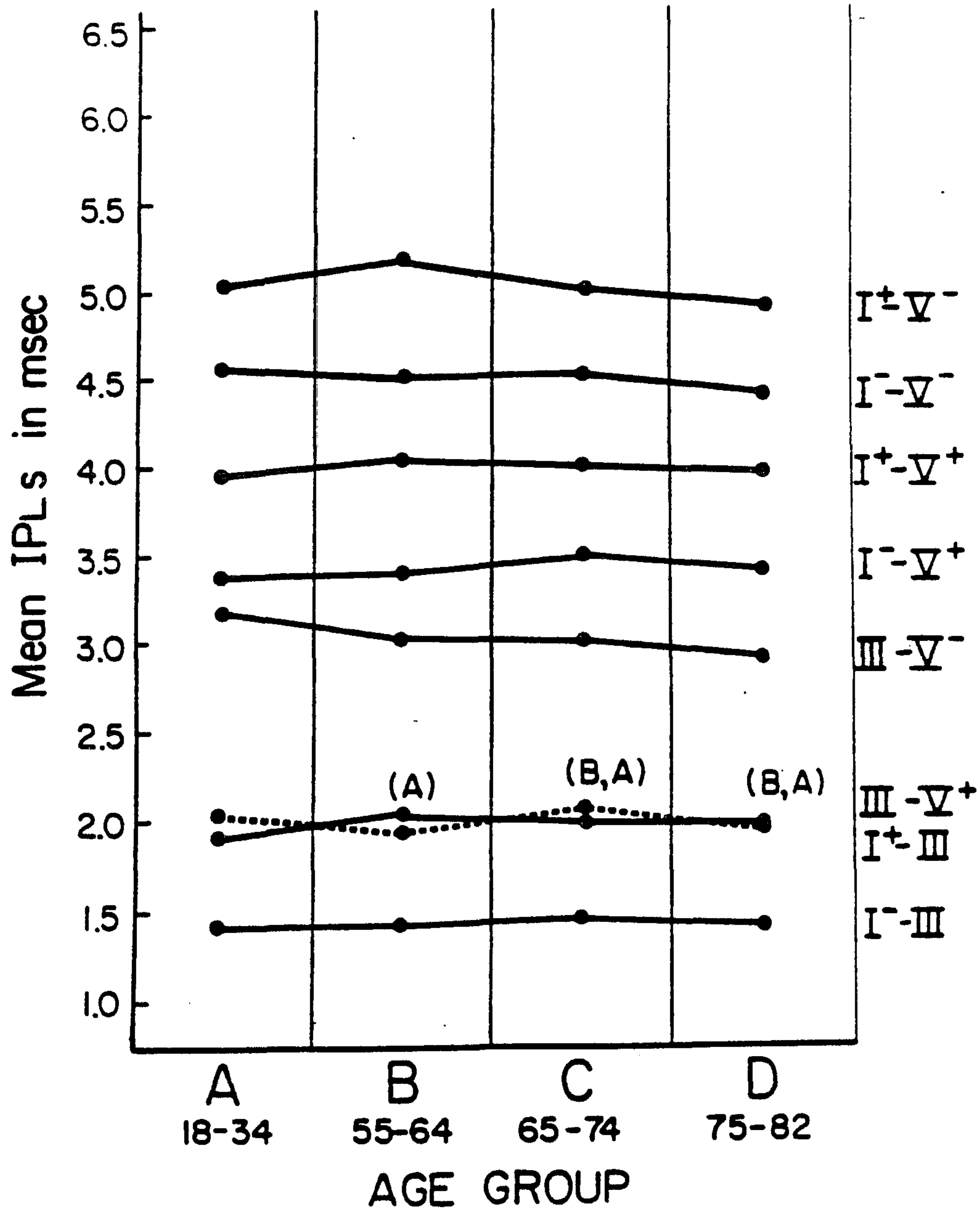

Figure 2Ø. Change in mean interpeak latencies by age group. Response recorded contralaterally at 6Ø dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

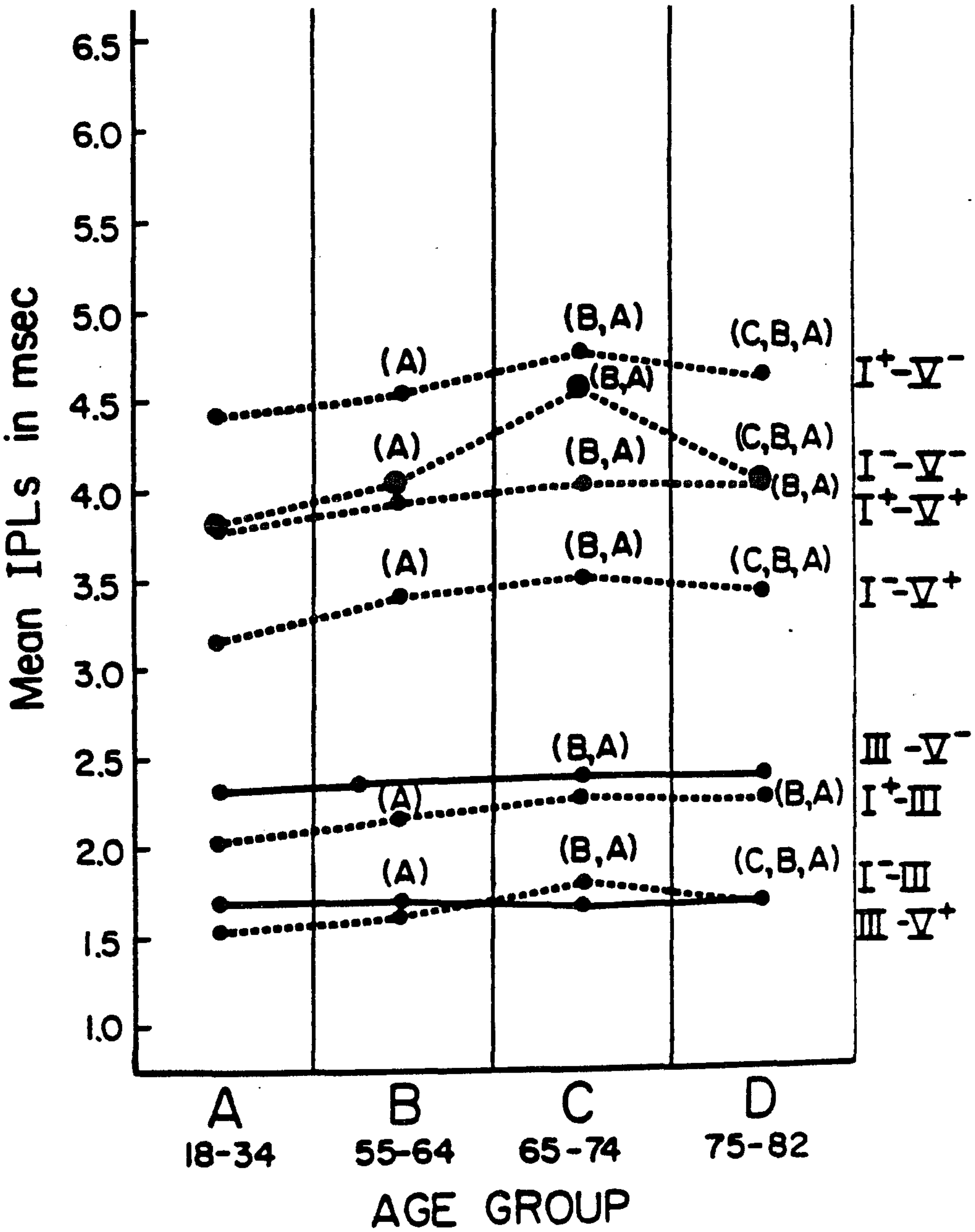

Figure 21. Change in mean interpeak latencies by age group. Response recorded horizontally at 6Ø dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

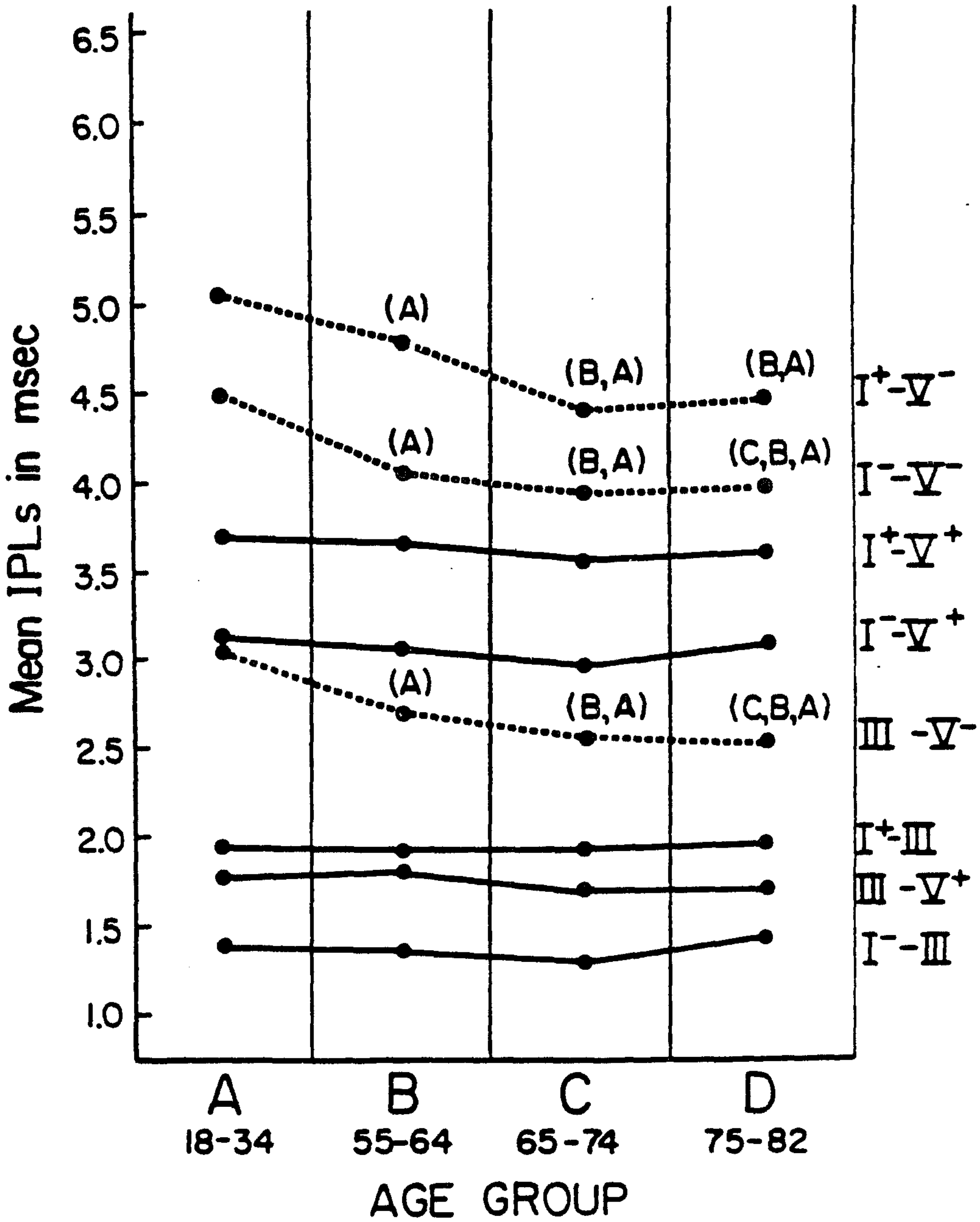

Figure 22. Change in mean interpeak latencies by age group. Response recorded ipsilaterally at 40 dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

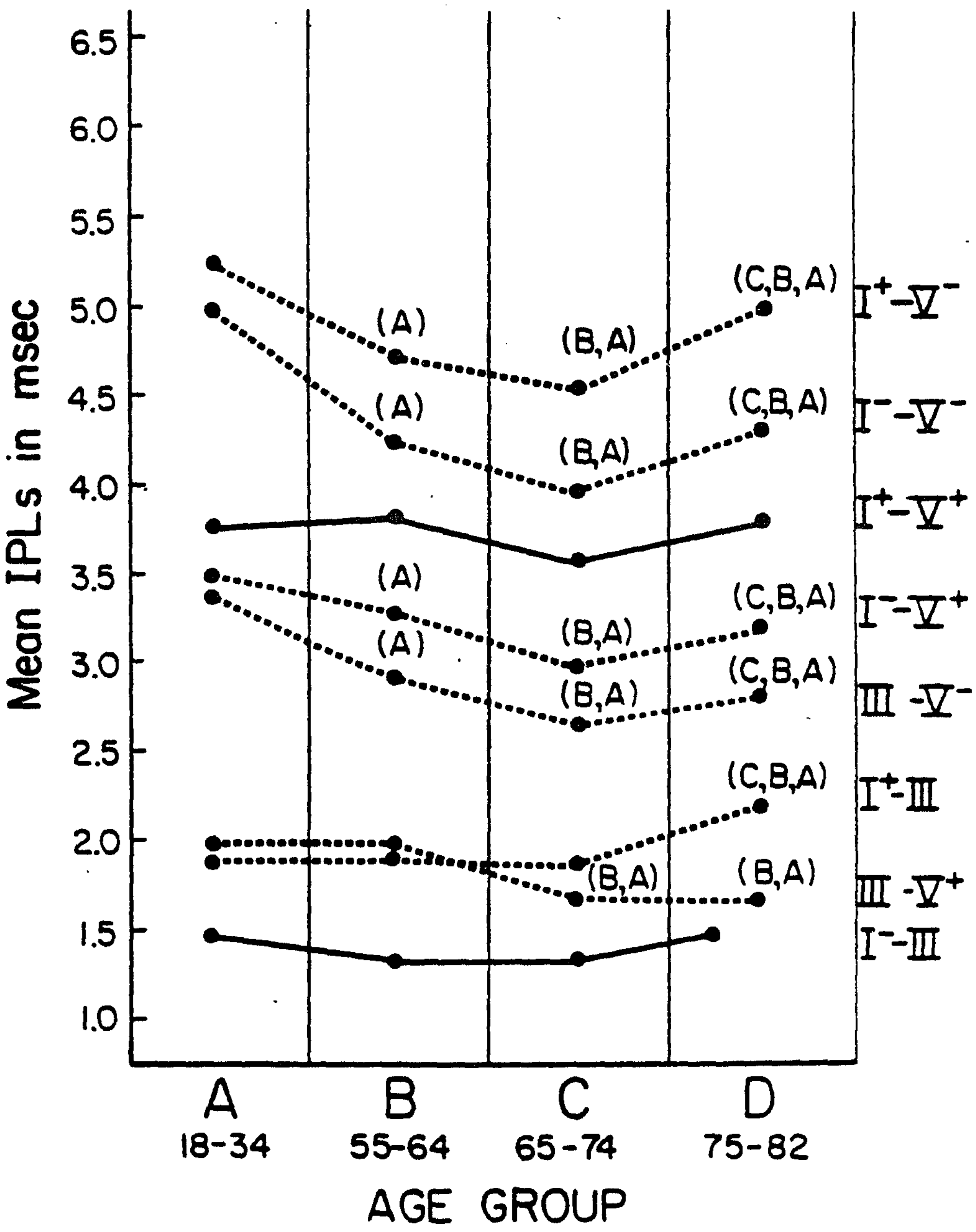

Figure 23. Change in mean interpeak latencies by age group. Response recorded contralaterally at 40 dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

All IPLs continued to significantly decrease between groups B and C, with the single exception that I^+-III contralaterally recorded at 40 dB SL decreased .01 msec., which was not significant. The majority of IPLs then showed a significant increase between groups C and D. All mean IPLs of age groups C and D were significantly earlier than age group A, the only exception being I^+-III. No IPL in the horizontal montage had significant age effects (Figure 24).

The single IPL that showed a significant effect of age ($p < .05$) at 20 dB SL was III-V^- recorded ipsilaterally (Table A.11). This IPL showed a significant increase of .12 msec. between groups A and B. A significant decrease of .50 msec occurred between groups B and C, with no further significant change taking place with further increase of age (Figure 25). No IPLs in the contralateral or horizontal montage had significant age effects (Figures 26 and 27).

SUMMARY

Of the 87 mean IPLs generated by this study 24 (28 percent) changed significance with increased age. At the higher sensation levels of 80 and 60 dB SL, IPLs generally increased through the first three age groups, although the increase was not always significant. At 80 dB SL most IPLs showed no significant change between groups A and B, whereas at 60 dB SL a significant increase occurred between these

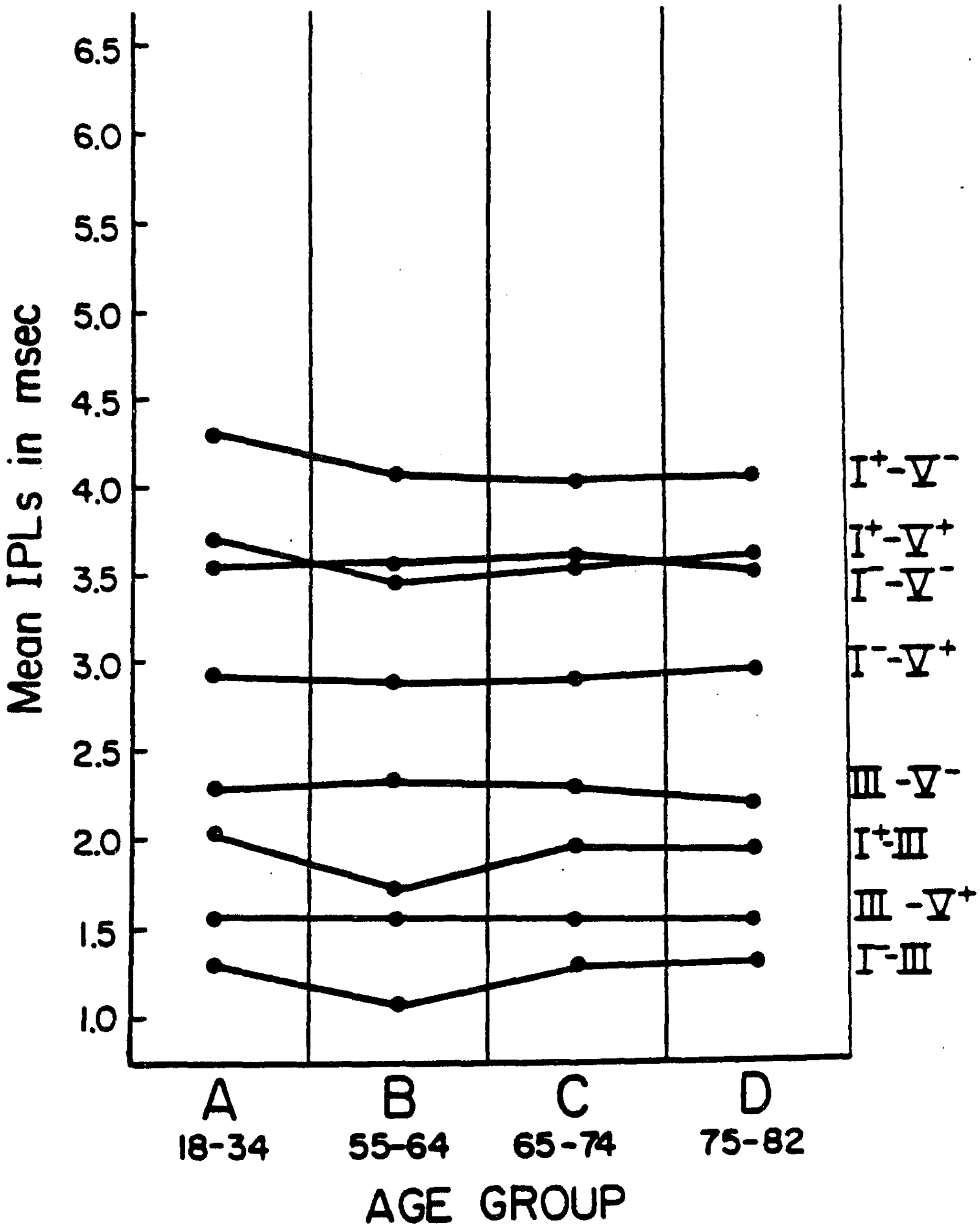

Figure 24. Change in mean interpeak latencies by age group. Response recorded horizontally at 40 dB SL.

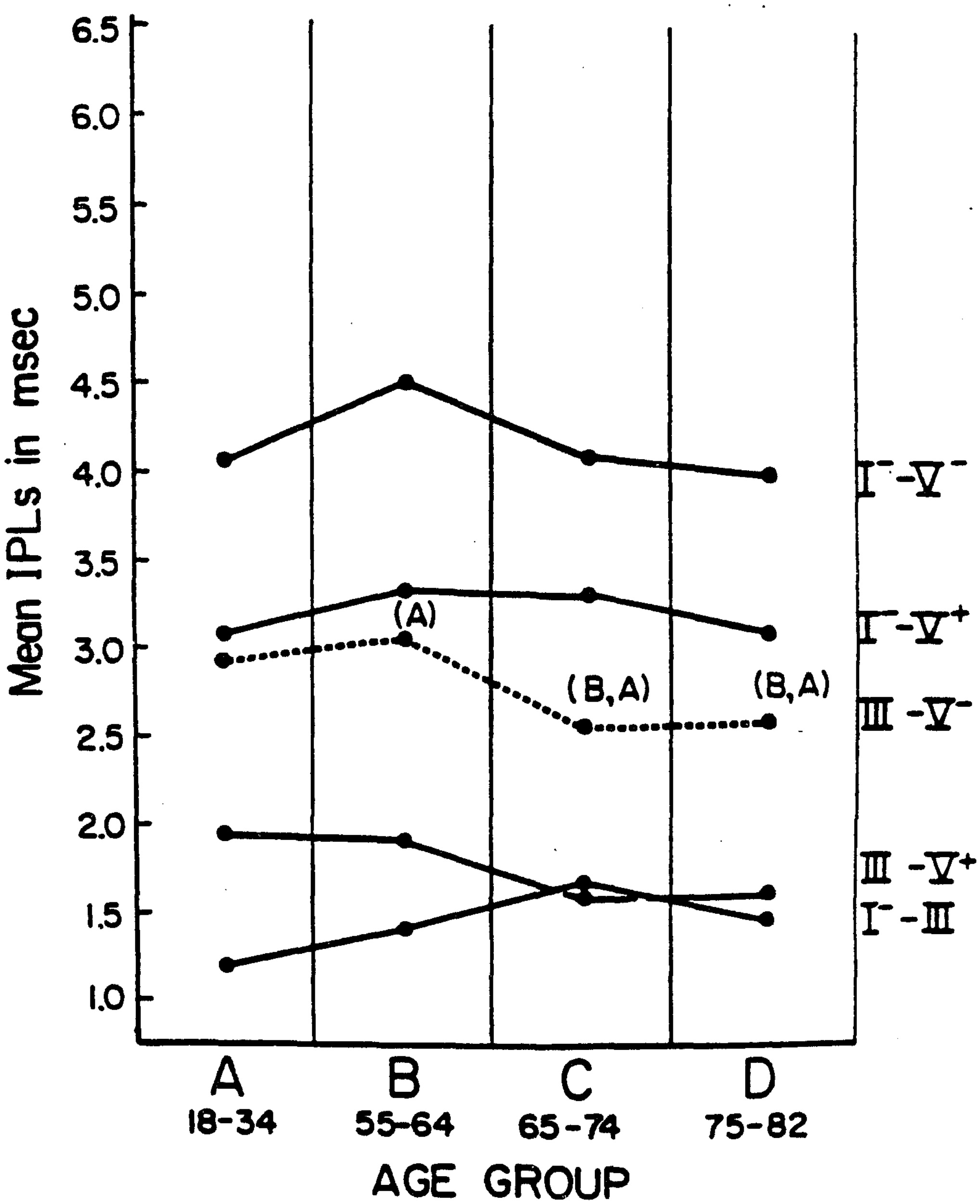

Figure 25. Change in mean interpeak latencies by age group. Response recorded ipsilaterally at 20 dB SL. Dotted lines indicate significant age effect. Letters in parentheses indicate significant difference from prior age groups.

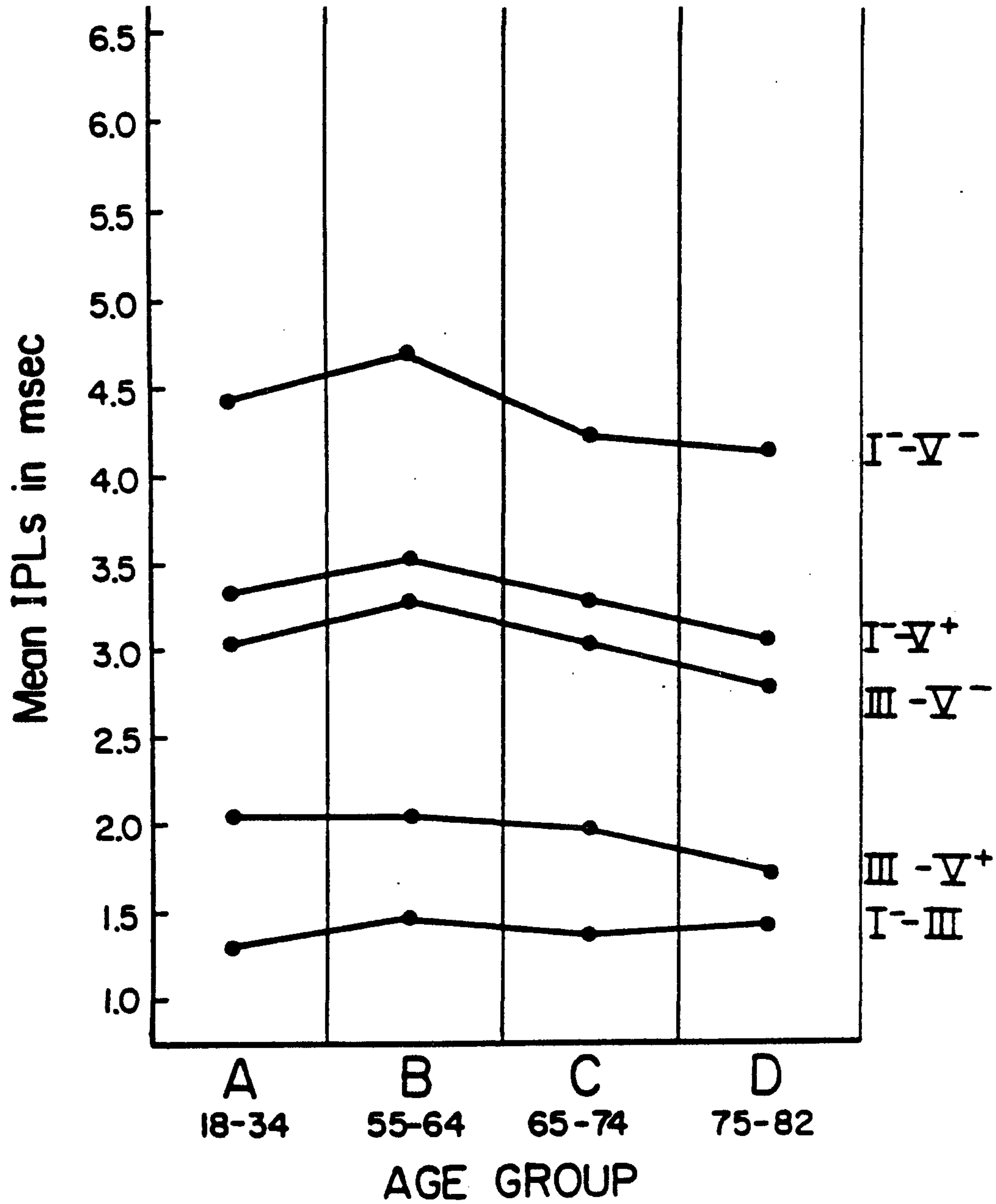

Figure 26. Change in mean interpeak latencies by age group. Response recorded contralaterally at 2Ø dB SL.

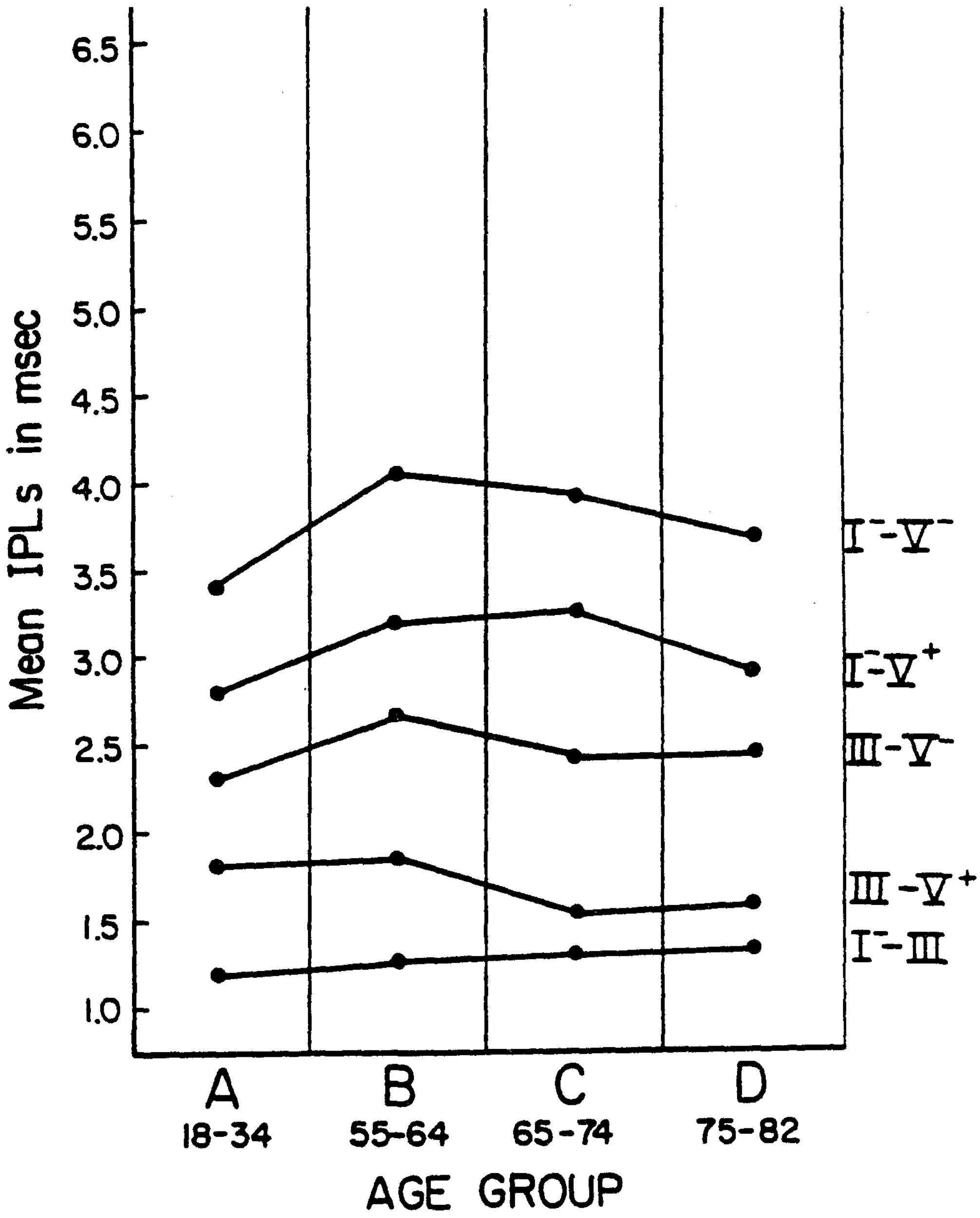

Figure 27. Change in mean interpeak latencies by age group. Response recorded horizontally at 20 dB SL.

two groups. A significant increase in mean IPL between groups B and C occurred at both 80 and 60 dB SL. Most IPLs recorded at 80 and 60 dB SL showed a significant decrease between groups C and D, although they remain significantly later than age group A.

The IPLs' relation to age differed when recorded at 40 dB SL. At this level IPLs showed a decrease between groups A and B, and between B and C, but a significant increase often occurred between groups C and D. In addition IPLs of age groups C and D were most often significantly shorter than age group A.

II. Sex Effects on Absolute and Interpeak Latencies

INTRODUCTION

Results of the two way analysis of variance are shown in Tables A.8-9. An Asterisk identifies the absolute and interpeak latencies that reveal a significant sex effect.

ISSUE 2: SEX EFFECTS ON BSER

The present study was designed to address a second major issue: do males and females have different absolute and interpeak latencies irrespective of age?

Absolute Latencies

Mean absolute latency values in msec., across age, for each of the recording montages and sensation levels are shown in Table A.14. A single asterisk identifies female latencies that are significantly different than their male counterpart at $p < .05$, a double asterisk $p < .01$, and a triple asterisk $p < .001$. When male and female latencies differ significantly, female latencies are always earlier than male. The later waves (III, IV, V^+ and V^-) are most often significantly earlier for females, regardless of the sensation level. Wave V^+ is earlier at every level and all recording montages except horizontally at 80 and 40 dB SL. The horizontal montage produces poorer wave Vs and has a higher probability for waves to be missing than do the other montages. The probability that differences between males and females is statistically significant is less for the earlier waves than for the later ones. Waves III, IV, V^+ and V^- are significantly earlier for females at most sensation levels and recording montages, while waves I^+, I^- and II rarely show significantly different latencies between males and females.

Wave V^+ is an average of .07 msec. shorter for females than males when recording at 80 dB SL and averaging all three montages. At 60 dB SL the average difference is .12 msec., at 40 dB SL it is .19 msec. and at 20 dB SL it is .25 msec.

The mean absolute latencies and standard deviations of waves for males and females separately for each age group and each recording montage are shown in Tables A.2-4. An overview of the results indicate that the mean absolute latencies of most waves are shorter for females of all ages than for males in corresponding age groups. A total of 144 mean latencies were generated for waves IV, V^+ and V^- for all ages and montages and at each sensation level. Male latencies were earlier eleven times (seven times in the horizontal montage), but the differences were never significant. Thus female absolute latencies are shorter than males for the later waves (III, IV, V^+ and V^-) for all age groups in the study.

Interpeak Latencies

Results from the analyses of variance showing the effect of sex on the IPL are given in Table A.9. Of the 87 mean IPLs generated by this study, 2Ø (23 percent) show significant sex effects. The mean interpeak latencies for males and females that showed a significant sex effect are reported in Table A.15. Asterisks indicate the level of significance. When significant differences in mean IPLs occurred between males and females, females have the shorter transmission time. The IPL of I^{+}-V^{-} is significantly shorter for females than males at every sensation level, although not in every recording montage.

SUMMARY

In general, female subjects tended to have shorter absolute latencies and IPLs than males, as was expected, although the differences were not always significant even at the $p< .Ø5$ level. The mean absolute latencies of waves III, IV, V^{+} and V^{-} were usually significantly earlier for females than males. The IPL of I^{+}-V^{-} is significantly shorter for females than for males at every sensation level.

III. Amplitude

INTRODUCTION

The amplitude of waves I and V, peak to trough, were measured for all subjects. The relation of the amplitude ratio of waves V:I and aging was investigated, as well as the relation of amplitude of both waves and the variables of intensity, age and sex.

AGING EFFECTS ON AMPLITUDE RATIOS

A ratio of the amplitude (peak to trough) of waves V:I was calculated for each individual at 80, 60 and 40 dB SL. This amplitude ratio was also included in the two way analysis of variance (age by sex). Results of the analyses of variance are given in Table A.16. No significant effect was found for age on this amplitude ratio at any sensation level.

AMPLITUDE OF WAVES I AND V

A three way repeated measures analysis of variance design (sensation level by sex by age) was performed on the amplitude of waves I and V at two sensation levels and (60 and 40 dB SL) and the ipsilateral recording montage. The ipsilateral montage was selected because waves I and V are present most often in this montage. Wave I was missing quite often in the contralateral montage, whereas wave V is often missing in the horizontal montage. The 8Ø dB SL was omitted since, as previously noted, many of th older subjects could not be tested at that level. The 2Ø dB SL was also omitted because wave I is usually not present at that level. Results of the analyses are shown in Table A.17.

<u>Amplitudes of Waves V and I</u>

The amplitude of wave V was significantly greater ($p < .001$) than wave I. This was true for both males and females and at both 6Ø and 4Ø dB SL.

<u>Effect of Age</u>

The amplitude of waves I and V were significantly affected ($p < .02$) by increased age. The amplitudes of both waves decreased through the first three age groups and then increased significantly for the oldest group (75-82).

<u>Effect of Sex</u>

Although the amplitudes of waves I and V are usually greater for females than for males, the main effect of sex was never significant. In the three way interaction among intensity, wave and sex, the amplitude of wave I at 6Ø dB SL and V at 4Ø dB SL were significantly greater for females than for males.

Effect of Intensity

Highly significant ($p < .001$) effects for intensity were found on the amplitude of both waves I and V. As intensity decreased, the amplitude of both waves decreased significantly. Wave I appeared to be more affected by intensity than was wave V. The mean amplitude of wave I at 40 dB SL was less than one half of the mean amplitude of the wave recorded at 60 dB SL. The amplitude of wave V at 40 dB SL was 80 percent of the amplitude recorded at 60 dB SL.

Summary

No effect was found on the amplitude ratios of waves V:I for increasing age, although the amplitude of each of the waves decreased significantly with the age of subjects through the first three age groups. The amplitude of both waves also decreased as intensity decreased, with wave I being more affected than wave V.

IV. Repeated Measures Analysis of Variance

INTRODUCTION

A four way repeated measures analysis of variance design (sensation level, montage, sex and age) was done on a subset of waves and IPLs at two sensation levels (6Ø and 4Ø dB SL) and two recording montages (ipsilateral and contralateral). This analysis was performed to identify interactions than could not be identified in the previous ANOVAs. Interaction between intensity and montage on sex and age, and on each other, would be apparent from this analysis. These interactions would not be seen in the previous two way (age and sex) analysis of variance.

The waves included in the repeated measures design were I^-, III, V^+ and V^-. The sensation levels included were 6Ø and 4Ø dB SL and the recording montages were ipsilateral and contralateral. These waves are particularly robust when recorded at the selected intensity levels and montages. The horizontal montage was not included because absent waves at 6Ø and 4Ø dB SL are primarily a horizontal phenomenon occurring at V^+ and V^-. If a wave was missing with a particular recording montage, it was replaced with the mean absolute latency of the other montage. This replacement occurred only five times in a total of 1,28Ø data points. For the 8Ø subjects, wave I^- contralateral at 4Ø dB SL had to be replaced with the ipsilateral response three times. Wave III contralateral at 40 dB SL was replaced with the ipsilateral montage once. The only other data replacement that was necessary was the single replacement of wave V^+ contralaterally recorded at 40 dB SL. The IPLs measured were I^--III, I^--V^-, III-V^+ and III-V^-. Main effect results of the four way repeated measures analysis are given in Table A.18. Only the main effects of sex, age, intensity and montage are shown. Post hoc tests were performed using the LSD test. The results reported are significant at $p < .05$.

Effects of Intensity

Highly significant effects ($p < .001$) were found for intensity on all absolute latencies (Table A.18). As intensity decreased, all absolute latencies increased significantly, with wave I^- being the most affected.

A sample response from a 64 year old female recorded ipsilaterally at 80, 60, 40 and 20 dB SL is shown in Figure 28. The increase in latency of waves as intensity decreases is apparent.

Effects of Age

Significant age effects were found for the absolute latencies of waves I^- and III but not for the later waves V^+

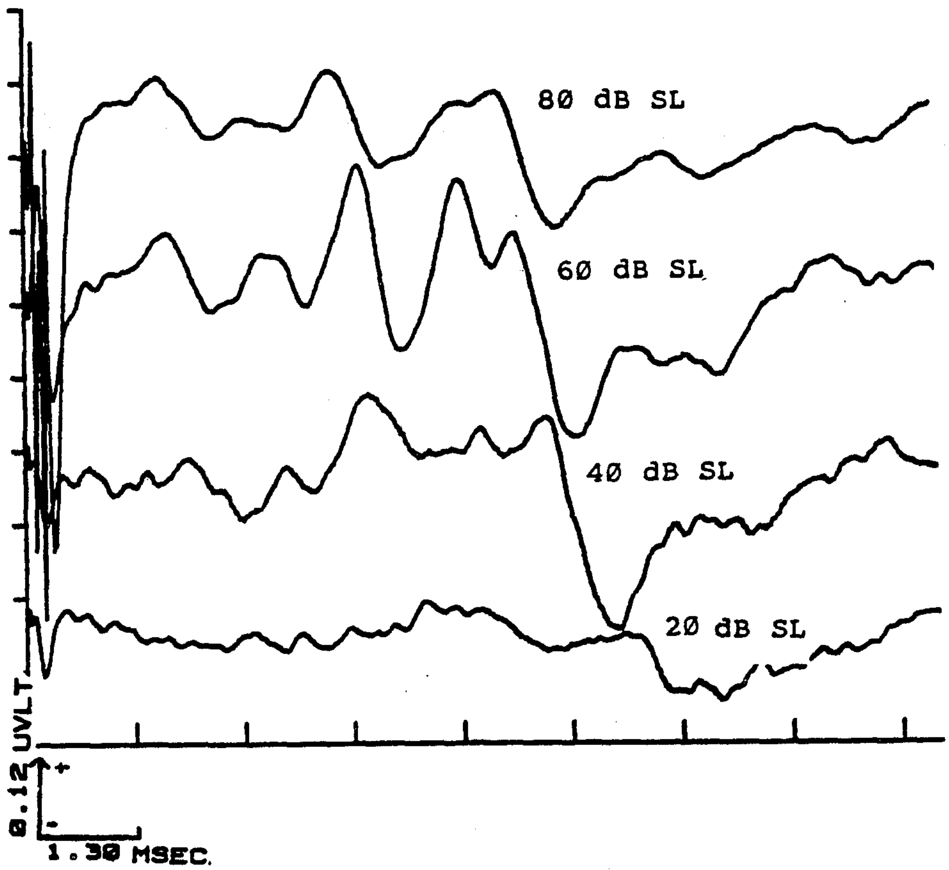

Figure 28. BSER of a 64 year old female subject: four intensity levels, ipsilateral montage, summed response to 4ØØØ rarefaction clicks.

and V^- (Table A.18). The effects of age on waves I^- and III across intensity and montage are shown in Figure 29. The mean latencies of waves I^- amd III (across intensity and montage) show significant increase between groups A and B and between groups B and C. Wave III stabilizes, while wave I^- decreases significantly, between groups C and D.

Age had a significant effect on the IPL of I^--V^- (p= .004) and III-V^- (p= .001) (Table A.18). Across age the IPLs of I^--V^- and III-V^- decreased with a decrease in the intensity, but there was an interesting two way interaction between age and intensity. For both IPLs the transmission times increased between 60 and 40 dB SL for group A, but decreased for all other age groups.

Effects of Sex

Females had significantly shorter absolute latencies of waves III (p= .033), V^+ (p= .002) and V^- (p= .004), but not I^- (Table A.18). This was usually true for all age groups. Of the 48 pairs of mean latencies for waves III, V^- and V^+ generated by the study male latencies were earlier than female six times. The means of these waves for all age groups (males and females separately) are shown in Table A.19. The overall difference between male and female latencies, averaged over sensation levels and montage, was .13 msec. for wave III, .19 msec. for wave V^+ and .24 msec.

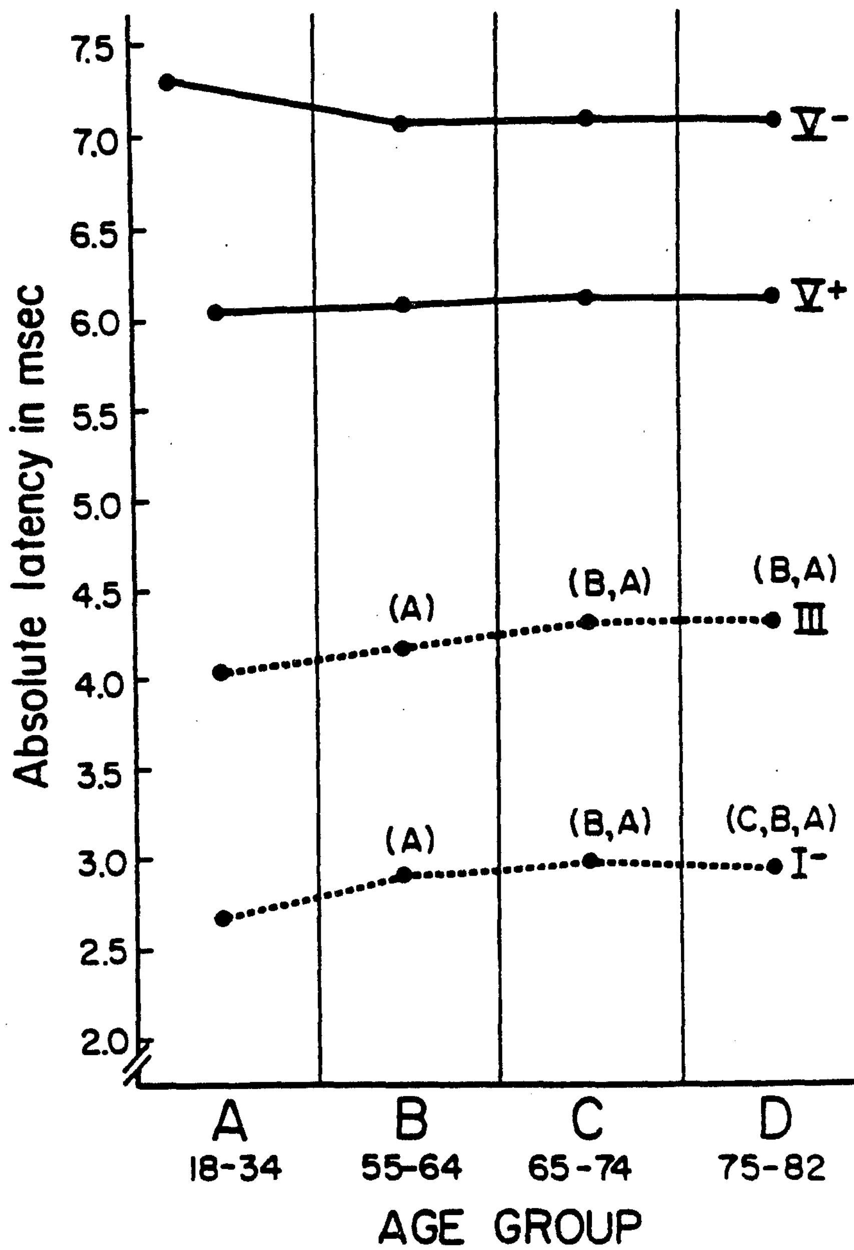

Figure 29. Change in mean absolute latencies by age group, across intensity, sex and montage; repeated measures design. Dotted lines indicate significant age effects. Letters in parentheses indicate significant difference from prior age groups.

for wave V^-, with the difference increasing for the later waves.

Sex had a significant (p= .Ø39) effect on the IPL of I^--V^+ (Table A.18). The mean IPL for males across age, sensation level and montage was 3.35 msec. and for females was 3.26 msec. The mean I^--V^+ IPLs were earlier for females than males at both senation levels and montages.

Effects of Montage

The recording montage had a highly significant effect on waves III, V^+ and V^- (p= .ØØ1) and on the IPLs of III-V^-, I^--V^- (p= .ØØ1) and I^--III (p= .ØØ2) (Table A.18). The contralateral recording of wave III produces significantly earlier waves than does the ipsilateral recording. This was true at both 6Ø and 4Ø dB SL. The mean latency of wave III (across intensity) recorded ipsilaterally was 4.29 msec. and recorded contralaterally it was 4.25 msec. Females show earlier latencies contralaterally than ipsilaterally at both 6Ø and 4Ø dB SL, while males show this pattern at 6Ø dB SL and then show a reverse at 4Ø dB SL.

The mean latencies for the contralateral recording of waves V^+ and V^- were significantly later than the ipsilateral recording at both 6Ø and 4Ø dB SL. The ipsilateral mean (across intensity) of V^+ was 6.1Ø msec. and the contralateral mean latency was 6.17 msec. For wave

V^- the ipsilateral mean (across intensity) was 7.01 msec. and the contralateral 7.26 msec. The contralateral latencies for both V^+ and V^- were significantly later than the ipsilateral for all age groups and sensation levels.

Four IPLs, I^--III, I^--V^-, III-V^- and III-V^+ showed highly significant effects of montage (p= .002, Table A.18). I^--III shows shorter IPLs when recorded contralaterally than ipsilaterally. The three remaining IPLs I^--V^-, III-V^- and III-V^+ are significantly longer in the contralateral montage than the ipsilateral. The differences between the montages for these IPLs are greater at 60 dB SL than at 40 dB SL.

Effects of Hearing

All older subjects tested in this study had some degree of high frequency sensori-neural hearing loss, although their hearing was within normal limits for their age. In an attempt to separate the effects of hearing loss from the more central effects of biological aging, a second repeated measures analysis of variance was performed which included an adjustment for hearing. Pure tone thresholds for 1, 2, 3, 4, 6 and 8 kHz were averaged for each individual included in the repeated measure design. The four way analysis of variance (intensity by age by sex by montage) was repeated with the pure tone average for each individual included as a covariate. This was done to examine whether the hearing of the subjects was the cause of the absolute and interpeak latency changes observed with increased age.

Results showed that, once the data were adjusted for the pure tone average, the effects of age on the absolute an interpeak latencies disappeared. Apparently, the significant age effects reflect the peripheral hearing loss of the older population rather than the more central changes that the aging individual undergoes.

Women generally have better high frequency hearing than do men (Figures B.6-8). When the repeated measures analysis was adjusted for hearing, the effect of sex was lost for wave III but remained significant for waves V^+ and V^-. The pure tone adjustment had no effect on other sources of variation. Effects for sensation level and montage remained unchanged.

Summary

The results of the repeated measures analysis of variance of this subgroup agrees in most respects with the analysis reported earlier in this study. The effects of sex, with females having shorter latencies than males is most evident in the later waves: III, V^+ and V^-. Women also have significantly shorter IPLs than men for this reason.

Mean latencies of waves tend to increase through the first three age groups and either decrease or stabilize between the last two groups. The effect of aging on IPLs is affected by sensation level, a finding reported in the earlier analysis in this study. IPLs tend to increase with increasing age at higher sensation levels and decrease at lower levels.

An important result of the repeated measures analysis incorporating the pure tone average as a covariate was the disappearance of the age effects on absolute and interpeak latencies. Accordingly, the significant age effects reflect the peripheral hearing loss of the older population rather than the more extensive central aging effects.

Sensation levels and montage both had strong effects on absolute latencies and IPLs. Absolute latencies increase with decreases in sensation level. IPLs were generally longer when recorded contralaterally than ipsilaterally, with the effect greater at 60 dB SL than at 40 dB SL. The effect of montage on waves differed for each wave. Wave III is earlier when contralaterally recorded, while waves V^+ and V^- are significantly later than with ipsilateral recording.

V. Wave Morphology

INTRODUCTION

Wave morphology is one of the most subjective measures of basic evaluation and the last major issue addressed in this study. There are individual differences in the morphology of the response that are not easily explained, creating difficulty distinguishing the normal variation in response from the pathological. An example of a normal response recorded ipsilaterally at 60 dB SL from each of the four age groups is shown in Figure 30. The difference in normal responses, especially from the two oldest age groups is immediately apparent, although the absolute and interpeak latencies of all waves are within normal limits.

WAVES MISSING

Often particular waves may be missing although the response is normal. Waves may be missing due to factors such as intensity of presentation, subject hearing, recording montage or unidentifiable factors which contribute to the normal variation in the response. In an attempt to identify factors that contribute to the probability of a wave being missing in a particular run, a four way analysis of variance (age by sex by montage by intensity) was performed for each wave. If a wave was missing for a particular run, it was

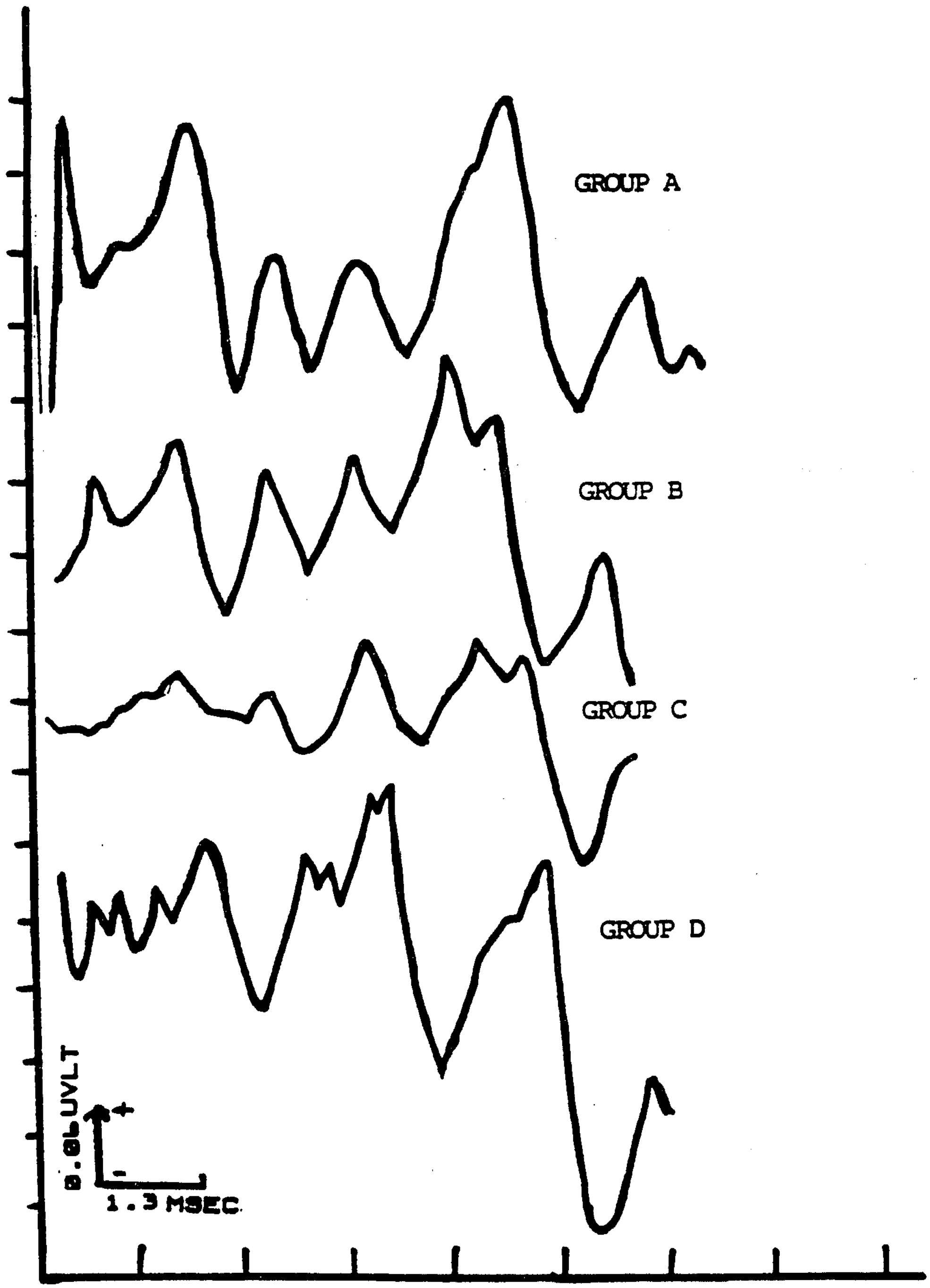

Figure 30. Normal BSERs, four age groups. Summed responses to 4000 rarefaction clicks recorded ipsilaterally at 60 dB SL.

labeled 1, if it was present it was labeled Ø. Since the number of possibilities for a wave appearing in any given run was known, this procedure permitted determination of the relative frequency, and hence probability, of a wave being missing.

The analysis excluded the runs recorded at 8Ø dB SL since many of the older subjects could not be tested at that level. The raised click thresholds of subjects in that group prevented testing at 8Ø dB SL because of the 12Ø dB output limit of the stimulus generator. Wave V^- was also excluded from the analysis since it always appeared with wave V^+, which was included. Thus the analysis included the 2Ø, 4Ø and 6Ø dB SL intensity levels; three recording montages; and the sex variable. The waves included in the analysis were I^+ through V^+. The results of this analysis are shown in Table A.18. Post hoc tests were performed when indicated, using the LSD test. Differences between the reported groups are significant at $p < .05$.

EFFECT OF INTENSITY

As would be expected, highly significant effects ($p < .001$) were found for intensity for all waves (Table A.2Ø). As intensity decreased, the probability of a particular wave being missing increased significantly. All waves except wave V^+ showed significant increases in the probability of being missing at all stimulus levels from 60, 40 and 20 dB SL. The probability of wave V^+ being missing did not change significantly between 60 and 40 dB SL, although it was present significantly less often as the intensity of presentation decreased from 40 to 20 dB SL. As is well known, wave V^+ is less affected by intensity of presentation than are other waves. At 20 db SL only waves I^-, III, V^+ and V^- were most often present. This was the same for both older and younger subjects.

EFFECT OF MONTAGE

The effect of recording montage was largely as expected. Waves II, III, IV and V^+ showed a higher probability of being missing in the horizontal montage than in either the ipsilateral or contralateral. The effect of the horizontal montage on wave II was unexpected. Wave V^+ for females was affected significantly more by the horizontal montage than was the case for males, and was missing more often.

As anticipated the number of I^+s and I^-s missing occurred more often in the contralateral recording montage than in either of the others. Unexpectedly, the horizontal montage produced significantly more I^+ missing than did the ipsilateral. On only six out of 543 occasions was a wave I^+ absent ipsilaterally and contralaterally but present in the horizontal montage. This occurred at 40 dB SL five of the six times. Often the horizontal montage contributed to the identification of wave I^+, providing reinforcement when there was doubt in either or both of the other montages. The ultimate usefulness of the horizontal montage for wave I identification is questionable, however, when one includes the extra time it takes to evaluate the horizontal montage and the added expense of multi-channel instrumentation in clinical settings.

EFFECT OF AGE

The probability of a particular wave being missing increased steadily as a function of increasing age. (Table A.20). Nonetheless it is not until age group C (65-74 years) that the probability of a wave being missing is significantly greater than for the youngest group (18-34 years). Aging also has more of an effect on the probability of wave I^+ being missing than any other wave. Only this wave had a significantly higher probability of being missing in group B than in group A.

All waves showed a significant sex by age interaction. The number of waves missing increased through the four age groups for males although for females it increased for the first three age groups and decreased between groups C and D.

Chapter 6

DISCUSSION AND CLINICAL IMPLICATIONS

I. Age effects on BSER

The objective of this study was to determine the changes and variations in BSER wave morphology which may be the result of aging and of differences between the sexes. In particular, the study was undertaken to determine the effects of the normal aging processes of males and females on the BSER; absolute and interpeak latencies, amplitude ratios of waves V to I, and general morphological patterns. Accordingly, 80 healthy men and women (40 of each) with normal hearing for their ages, were divided into four age groups: 18-34 years, 55-64 years, 65-74 years and 75-84 years. All subjects were tested at four intensity levels, using three different electrode montages as previously described.

LATENCY EFFECTS AS A FUNCTION OF AGE

Absolute Latency

The results of this study are generally supportive of the first issue of this research: the absolute latencies of the BSER increase with age, although the increases are not always significant (Table A.2). Of the 75 mean absolute latencies generated by this study, 30 (40 percent) showed significant age effects at $p < .05$, and 23 (31 percent) showed significant effects at $p < .01$.

The increase in mean absolute latency with increased age was usually apparent through age group C (65-74), and affected the earlier waves (I^+, I^-, II and III) more often than the later ones (IV, V^+ and V^-). At 80 and 60 dB SL, latencies increased through the first three age groups and tended to stabilize between groups C and D. At 40 dB SL, an increase in mean absolute latencies also occurred through the first three age groups. At this sensation level, a decrease in mean absolute latency often occurred between groups C and D (that is, group D had shorter peak latencies than group C), although the mean absolute latency of age group D was still later than the mean absolute latency of group A. A possible explanation for this decrease in mean absolute latency between groups C and D will be discussed later in this chapter.

A comparison of the results of this study with others is confounded by differences in recording variables, such as filter settings and montage; in stimulus variables, such as rate, sensation level and click phase; and in subject variables, such as age groups and sex. Means and standard deviations of the absolute latencies of waves may therefore be expected to differ among studies, although effects of increased age should be apparent on the absolute latencies of all studies.

The results of the present study are consistent with Harkins [1981], testing at 70 dB HL, who found increases in latency for all positive waves I^+ through V^+, as a function of aging. Differences were significant at the $p < .05$ level for only waves I and III. The present study also found significant increases in absolute mean latencies to be present most often for the earlier waves (I^+, I^-, II and III).

The increase in latency with increased age that occurred in the present study was generally less than in other studies. This might have been due to stricter subject selection criteria employed in this study than in others. Rowe [1978] reported a significant ($p < .01$) increase in the mean absolute latency of wave III of .52 msec. between his young subjects (mean age 25.1 years) and older subjects (mean age 61.7 years) when testing at 60 dB nHL. Patterson et al. [1981] testing at 60, 70 and 80 dB SL reported significant ($p < .009$) increases in mean absolute latencies for wave III of .19 msec. between the older group (60-79) and the younger group (20-39). A significant ($p < .001$) increase in mean latency of wave III occurred in the present study, with an increase of .14 msec. occurring between age groups A and C in the ipsilateral montage at 80 dB SL.

Jerger and Hall [1980] reported a significant increase in the mean absolute latency of wave V of .2 msec. over the age range from 25 to 55, testing at an average of 83-85 dB nHL. The present study showed a significant ($p < .001$) increase of .13 msec. for wave V between age groups A and B when testing ipsilaterally at 60 dB SL. In contrast, Beagley and Sheldrake [1978] found essentially (sic) no significant increase in the absolute latency of wave V with increasing age.

Increase in absolute latency with increasing age generally occurred for both men and women in the present study, although several waves showed a significant interaction between age and sex at particular recording montages and sensation levels (Table A.8). When males and females differed, females showed fewer significant increases in latency with aging than their male counterparts. Either females showed fewer significant increases for a particular wave, or showed an increase in latency at a more advanced age than did their male counterparts. (See, for example, wave III recorded horizontally at 60 dB SL, Table A.3.) These results are consistent with those of Allison et al. [1983] and Patterson et al. [1981], but differ from those of Rosenhamer et al. [1980]. Allison et al. [1983] reported that males showed a "steeper" increase as function of increased age than did females. Patterson et al. [1981]

found that increases in absolute latency of waves I, II and IV with increased age were more evident in males than in females. The results of Rosenhamer et al. [1980] differed from the present study and from Patterson et al. [1981] and Allison et al. [1983], finding significant peak latency differences between elderly and young females, but not between elderly and young males.

Interpeak Latencies

Of the 87 mean IPLs generated by this study, 24 (28 percent) showed significant age effects ($p < .05$), while 17 (20 percent) showed significant effects at ($p < .01$) level. Since 40 percent of the mean absolute latencies showed significant effects ($p < .05$) with increased age, there appears to be a greater effect of age on the mean absolute latencies than on interpeak latencies or transmission time. This reflects more peripheral rather than central changes occurring with age.

Interpeak latencies that showed significant age effects generally increased through the first three age groups when recorded at 80 and 60 dB SL. Interpeak latencies often decreased insignificantly between groups C and D, although at 80 and 60 dB SL, the IPLs of group D remained significantly longer than group A.

Studies in the literature have generally examined IPLs at high intensity levels. Rowe [1978] testing at 60 dB nHL found a significant increase ($p < .01$) in the I^+-III IPL of .22 msec between his young (17-33) and older (51-74) subjects. Patterson et al. [1981] also found a significant increase in the I^+-III IPL (the amount of increase was not reported) when testing at 60, 70, and 80 dB SL between the younger (20-39) and older (60-79) subjects. The difference score was reported to be reduced at 60 dB SL for males. The present study reported less of an increase in the I^+-III IPL with increased age than did Rowe [1978]. The I^+-III IPL increased (insignificantly) .07 msec. at 80 dB SL and .15 msec. at 60 dB SL ($p < .001$) between age groups A and C recorded ipsilaterally.

Maurizi et al. [1982], testing at 70 dB nHL, found a significant increase ($p < .001$) of .09 msec. in the I^+-V^+ IPL between his younger subjects (28-42 years) and older subjects (60-65 years), and .14 msec. increase between the younger subjects and the 66-70 year olds. The present study found insignificant increases of .07 msec. between age groups A and B, and .08 msec. between groups A and C when recording at 60 dB SL.

The relation between increased age and IPL is a complex one, with sensation level playing an important role. As mentioned previously, when testing at 80 and 60 dB SL, the present study showed IPLs increasing through the first three age groups. Conversely, when testing at 40 dB SL those IPLs that show significant effects for increased age show decreases in IPLs between groups A and B, and further decreases between groups B and C. The mean IPLs of groups C and D, when testing at 40 dB SL, are significantly shorter than of group A.

Other studies on IPLs and aging have only tested at higher intensity levels and so no comparisons can be made. Possible explanations for the decrease in transmission time with age found in the present study at lower sensation levels can be found in research on the relation of high frequency hearing loss and IPLs, since an increasing occurrance of high frequency hearing loss is a function of increasing age. This high frequency hearing loss causes the shift in wave I to be greater than the shift in waves III or V. Thus the interpeak latencies decrease as a result of the peripheral high frequency hearing loss. This issue will be considered later in this chapter.

Regardless of the explanation, the present study, as well as others [Coats and Martin, 1977; Coats, 1978; Selters and Brackman, 1977; and Stockard and Stockard, 1979], show shortening of IPLs when testing subjects with high frequency hearing loss at low sensation levels. It is clinically important to recognize this shortening of transmission time since the IPL time required to determine an abnormal response necessarily shortens when testing subjects with high frequency hearing loss at low sensation levels.

AGING AND HIGH FREQUENCY HEARING LOSS

Effects of High Frequency Hearing Loss on Absolute and Interpeak Latencies

It is almost impossible to separate the effects of aging on absolute latency from those of high frequency hearing loss. Results of this study show that absolute latency increases as a person ages. It is well documented that, in patients with high frequency sloping audiograms, absolute latencies will also be prolonged [Jerger and Mauldin, 1978; Selters and Brackman, 1977; Coats and Martin, 1977; and Coats, 1978]. It is difficult to determimne whether the increase in latencies evidenced in this study are the result of the more pervasive changes in the auditory system that accompanies aging, or simply the result of a peripheral hearing loss.

As previously mentioned, the literature is replete with evidence suggesting that subjects with high frequency hearing loss have shortened IPLs [Coats and Martin, 1977; Stockard et al.,1979]. The present study shows shortening of IPLs with increasing age when testing at 40 dB SL.

In general, researchers have found that as intensity decreases from 50 to 40 dB SL, a large shift in latency usually occurs for the earlier waves (I^+ and I^-) which is not paralleled by an equal shift in the later waves, such as wave V [Stockard and Stockard, 1980; Coats and Martin, 1977]. Results of the present study concur with the previous ones, indicating that wave I^- showed more of an increase in latency with decrease in intensity than do waves III, V^+ and V^-. Thus at lower sensation levels, IPLs such as I^--V^- would necessarily be shorter than at higher levels. Only waves I^-, III, V^+ and V^- were included in this analysis, thus the lack of commentary on wave I^+.

Coats [1978] found, as did the present study, that the decrease in transmission time with decreasing click intensity becomes more pronounced with subjects with high frequency hearing loss. The decrease in IPL transmission time is more precipitous as the high frequency hearing loss increases. The present study found this precipitous decrease in transmission time with decrease in intensity as a person ages for the IPLs of I^+-III, I^+-V^-, I^--V^-, I^--V^+, III-V^- and III-V^+ although it did not always occur in every montage.

Etiology

In an attempt to explain the decrease in IPL that occurs with decreases in intensity, Stockard et al. [1979] suggested that it is largely the result of greater changes in the latency of wave I, which is the surface reflection of the eighth nerve action potential (AP), than of wave V. They suggest that the AP is composed of two peaks, which are usually fused in the surface recording of wave I, and probably reflect activity in neuronal populations with high and low thresholds. The thresholds for activation of these two neuronal populations usually overlap at stimulus intensities between 40 and 60 dB SL, the transition zone. Between click stimulation of 50 and 40 dB SL, AP amplitude dominance shifts from one peak to the other, causing a sudden shift in the latency of wave I. This transition is also seen in the surface recorded wave I in BSER.

Stockard and Stockard [1979] also suggests that wave I is dominated by activation of the basal portion of the cochlea at moderate to high intensities. As intensity decreases, however, it is triggered in progressively more apical regions of the cochlea. Increasing travel time along the cochlea partition with decreases in stimulus intensity result in an increase in the absolute wave I latency. Wave V is dominated by a more extensive length of the cochlear partition and is less affected by high frequency hearing loss and decreases in intensity than wave I, causing the large decreases in IPL as intensity decreases with increasing age.

The decreases in transmission time at lower sensation levels is more pronounced in subjects with high frequency hearing loss. Perhaps subjects with high frequency hearing loss and damage to the hair cells in the basal end of the cochlea suffer from more increased travel time along the cochlear partition as stimulus intensity is decreased than do normal hearing subjects, resulting in more of an increase in the latency of wave I. Since wave V is dominated by a contribution of a more extensive length of the cochlear partition, it is less affected by high frequency hearing loss. Thus the increase in wave I is not mirrored by an increase in wave V, causing shortened IPLs in subjects with high frequency hearing loss at low intensities.

An interesting question arises as to why the IPLs do not continue to decrease between age groups C and D although the high frequency hearing loss of group D is greater than group C. It is possible that group D had more retrocochlear changes due to increased age than group C, thus increasing transmission time despite the normal shortening of IPLs with cochlear pathology. If that is the case, it is not until the oldest age group that changes in transmission time resulting from changes within the central auditory system due to aging are extensive enough to increase the IPL despite the effect of high frequency hearing loss.

IPLs at High Intensities.

In the present study, when testing at high sensation levels of 80 and 60 dB SL, mean IPLs increased with increasing age. This occurred despite the fact that subjects in the present study suffered from increased hearing loss as a function of age. It is possible that the increased IPLs with increased age of subjects seen in the present study may be the result of changes within the more central auditory system of the aging individual offsetting the more peripheral effects of cochlear hearing loss. Thus changes within the central auditory system of the aging individual may have delayed transmission time resulting from changes in the neural propagation within the brainstem and thus increasing the IPL time. The changes within the central nervous system of the aging are extensive making it probable that there would be an effect on transmission time.

A Statistical Attempt to Separate Hearing Loss from Aging

An attempt was made in the present study to statistically separate the effects of advancing age from hearing loss on the absolute and interpeak latencies of the BSER, as described in the previous chapter. The results indicate that the significant age effects on absolute latencies and IPLs are primarily the result of the loss of peripheral hearing in aging, rather than central changes in the auditory nervous system which result in increased latencies and IPLs in the BSER of the older subjects.

There are some major problems with the statistical approach in attempting to separate hearing loss from aging. As has been discussed, presbycusis includes changes in the entire auditory system, beginning at the external ear and extending to the brain. Thus partialling out the high frequency hearing loss of the elderly would also exclude all the changes in the auditory nervous system as a person ages biologically. A control group of young hearing impaired subject would permit comparisons between the effect of a peripheral cochlear hearing loss and combined peripheral and central presbycusic losses on the absolute and interpeak latencies.

An Experimental Test of Hearing Loss and Aging

In an experimental effort to separate the effects of hearing loss from the effects of aging on the BSER, Otto and McCandless [1982] matched a younger group of hearing impaired subjects with an older group with comparable losses. The addition of this group of younger hearing impaired subjects permitted an analysis of the interaction of advanced age and high frequency hearing loss. No significant differences in either absolute or interpeak latencies between the young hearing impaired and the presbycusic group were found. Otto and McCandless [1982] conclude that absolute latency or IPL differences observed with increased age are the result of high frequency hearing loss rather than some more central aspect of the aging process.

The results of the repeated measure analysis employed in the present study, including the pure tone hearing loss, offer additional support for Otto and McCandless [1982] since the hearing loss of subjects in the present study accounted for much of the variation in absolute and interpeak latencies.

CLINICAL IMPLICATIONS

The credibility of the BSER in identifying neurotologic abnormalities such as brain stem lesions and acoustic tumors is affected by the ratio of true to false positives as well as the number of false negatives, and is a function of both the true incidence of the disease and the decision criterion used for determining an abnormal response [Hyde and Blair, 1981]. Criteria for BSER abnormality usually include prolongation of absolute latencies, interpeak latencies and, to a lesser extent, reduction in the amplitude ratio of wave V to wave I. The present study was concerned with the effect of aging on these variables: absolute latencies, IPLs and amplitude ratio. Does aging affect the decision criterion that should be used for determining an abnormal response?

Absolute Latencies

Results of the present study indicate a clear statistical relation between increasing age and an increase in absolute latencies. As noted previously, it is generally accepted that patients with high frequency sloping audiograms have prolonged absolute latencies [Jerger and Mauldin, 1978; Coats and Martin, 1977; and Coats, 1978]. Thus, severe high frequency hearing loss can mimic neurotologic pathology [Hyde annd Blair, 1981].

In an effort to decrease the number of false positive test results, clinics have begun to use adjusted criteria for determining normal absolute latencies when testing patients with severe high frequency hearing loss. Correction for sensory hearing loss is a complex matter, dependent upon both the slope and severity of the loss [Jerger and Mauldin, 1978]. One of the most common correction procedures currently used in clinics was introduced by Selters and Brackman [1977]. They suggested a correction factor based on the pure tone threshold at 4 kHz. When the pure tone threshold of the subject at 4 kHz exceeded 50 dB, 0.1 msec. is subtracted from the observed wave V latency for every additional 10 dB of loss. Using this correction factor, Selters and Brackman [1977] reported a false negative rate of 4 percent and a false positive rate of 8 percent. Comparing the absolute latencies of wave V interaurally, the difference between the wave V latencies of the two ears should not be more than .2 msec.

Hyde and Blair [1981] suggested a modification of the Selters and Brackman [1977] correction factor which would decrease the number of false positives. This modification would subtract Ø.1 for every 5 dB of loss above 55 dB.

The increased absolute latencies observed in older subjects in the present study were analyzed to determine if they fell within the absolute latency limits established for group A using the Selters and Brackman [1977] criterion. If this were the case, there would be no need for separate normative data based on the age of the subjects.

Mean values and range for wave V^+ for males and females in the present study, recorded ipsilaterally at 8Ø dB SL are reported in Table 2. Range is +/- two standard deviations about the mean. The mean latency of the wave showed a significant (p= .Ø24) aging effect.

The mean latencies for males and females increase through age group C (although less of an increase occurred for females than for males). No subject within group B had

Table 2. Mean values and range in msec. for wave V^+ for males and females in the study. Range is +/- two standard deviations about the mean.

	Males		Females	
Age Group	Mean	Range	Mean	Range
A	5.49	5.17-5.81	5.52	5.22-5.82
B	5.56	5.40-5.72	5.52	5.12-5.92
C	5.81	5.57-6.05	5.56	5.22-5.90
D	5.72	5.34-6.10	5.40	5.14-5.56

hearing at 4 kHz that was worse than 50 dB. One male subject in group C had hearing at 4 kHz that was beyond 50 dB. Despite the excellent hearing of subjects in groups B and C, the mean absolute latencies increased with increasing age. In fact, using the normative values for group A when testing group C would increase the number of false positives for males and for females. Older subjects (needing no adjustment for hearing levels at 4 kHz) whose wave V latency fell within the normal latency range of group C, would be incorrectly labeled as abnormal if the range established for group A were used. Obviously, for this wave as well as others that increased significantly with aging, the increase reflects more than just hearing loss. The data suggest that increased age, in addition to increased sensori-neural hearing loss, increases absolute latencies. Thus it would seem that separate norms are needed, at least through age 74, for the absolute latencies of waves.

Interpeak Latencies

The effect of aging on IPLs is a complex one. Despite the tendency for IPLs to decrease with increased sensorineural hearing loss, IPLs tend to increase with increasing age when using high click intensity levels. For example, the means and standard deviations for males and females for the I^--III IPL recorded ipsilaterally at 60 dB SL are given in Table 3. It appears from the data that increasing age prolongs IPLs when recording at high intensity levels. If subjects in groups B, C or D were tested using ranges established for age group A, the number of false positive readings would increase, diminishing the credibility of the test.

Table 3. Mean values and range in msec. for I^--III IPL for males and females in the study. Range is +/- two standard deviations about the mean.

	Males		Females	
Age Group	Mean	Range	Mean	Range
A	1.51	1.35-1.67	1.49	1.27-1.71
B	1.60	1.44-1.76	1.53	1.29-1.77
C	1.69	1.19-2.19	1.61	1.37-1.85
D	1.72	1.24-2.20	1.63	1.31-1.95

IPLs tend to decrease with increasing age when testing at low sensation levels. The results from the present study are reported in Table 4 for the I^--V^- IPL recorded

Table 4. Mean values and range in msec. for I^--V^- IPL for males and females in the study. Range is +/- two standard deviations about the mean.

	Males		Females	
Age Group	Mean	Range	Mean	Range
A	4.86	3.66-6.06	5.01	3.27-6.75
B	4.21	3.41-5.01	4.20	3.32-5.08
C	4.06	2.86-5.26	3.81	2.27-5.35
D	4.21	3.35-5.07	4.39	3.05-5.73

contralaterally at 40 dB SL. Using IPL norms established for group A, when testing groups B, C or D, would increase the number of false negative results from the test procedure.

Summary

The results of this study strongly indicate the need for clinical norms for absolute and interpeak latencies to be generated for different aged patients, at least through age 75. It is evident that changes in absolute and interpeak latencies that are apparent with older subjects reflect more than just sensori-neural hearing loss, and are probably the result of changes occurring within the auditory nervous system of the aging individual.

THE OLDEST AGE GROUP

It has been noted that the increase in absolute latency with increased age reported in this study occurred for only the first three age groups, that is, up to the age of 74. This was true for both men and women. At high sensation levels, IPLs increased through the first three age groups and then showed a significant decrease between groups C and D. At 40 dB SL, IPLs decreased through the first three age groups and then often showed a significant increase between groups C and D. The decrease in amplitude of waves I and V, decreased with increased age for the first three age groups, but then increased between groups C and D.

The uniqueness of the older group was again apparent in the increased probability of a wave being missing with increasing age, in all four age groups for males, but through only the first three age groups for females. A decrease in the number of waves missing between groups C and D occurred for female subjects. The uniqueness of the oldest group is apparent in practically all the measurements of the present study, absolute latencies, IPLs, amplitude and number of waves missing. This uniqueness may be attributable to the strict criteria used for the inclusion of subjects in this study which were likely to produce subjects for the study who were more robust and healthier than the average of their age"XBThe oldest group in the present study may, therefore, have actually been healthier than the second oldest group, although similarly to age group B and C, they showed some increase in absolute and interpeak latencies.

II. Effect of Sex on the BSER

The second major issue addressed by the present study was whether significant differences in absolute and interpeak latencies occur between males and females across all ages. The data on sex were analyzed for all four age groups at each sensation level and recording montage.

LATENCIES AND THE EFFECT OF SEX

Absolute Latencies

As stated in the previous chapter, the results of the present study demonstrated that the absolute latencies of most waves of females in all four age groups were shorter than those of males in corresponding age groups, although the differences in mean absolute latencies for the earlier waves (i.e. I^+, I^- and II) were not usually significant. Females tended to have significantly shorter waves III, IV, V^+ and V^- than did their male counterparts. This occurred for all age groups and recording montages.

Kjaer [1979] found that females had significantly shorter waves III, IV and V^+ (he did not measure wave V^-) than did males and that this difference continued for waves VI and VII ($p < .0005$). In this study Kjaer reported a difference between males and females of .09 msec. for wave III, .14 for wave IV and .21 for wave V^+ when testing at 75 dB nHL. Results from the present study averaging the mean latencies for 60 and 80 dB SL in the ipsilateral montage show a difference between males and females of .08 msec. for wave III, .11 msec. for wave IV and .12 msec. for wave V.

In contrast to the present study and the Kjaer [1979] study, Michalewski et al. [1979] and McClelland and McCrae [1979] both found that the differences in latency between males and females did was not significant until wave V^+. Michalewski et al. [1980] tested 7 females and 13 males at 60, 70 and 80 dB SL although the differences between males and females in the earlier waves was not significant, wave III was an average of .15 msec. earlier for females than males, and wave IV .12 msec. earlier averaged across intensity. Wave V was .18 msec. shorter for females than males averaged across intensity and was significant at $p = .019$. McClelland and McCrea [1979], testing at 80 dB SL found no significant latency differences for wave I, a small difference for wave III and a difference at 80 dB SL for wave V, significant at the $p < .001$ level. Exact data for the differences between the earlier waves were not reported.

The difference in absolute latency between males and females for waves III to V^- occurred for all four age groups in the present study. In Beagley and Sheldrake [1978], too, sex differences in absolute latencies persisted through the eighth decade. In contrast, Rosenhamer et al. [1980]

reported differences in absolute latencies of waves I, III, and V between males and females occurring only through middle age.

Variations in method between the present study and Rosenhammer et al. [1980] may account for these differences. Rosenhamer tested at a faster click rate (22.5 per second) than did the present study (11.1 per second). Fujikawa and Weber [1977] reported the increased effect of a faster stimulus rate on older subjects. Rosenhamer et al. [1980] found that in only about one half of their older subjects (50-65) were they able to identify wave V when testing at 40 dB SL, making comparisons between the latencies of males and females in this oldest group very difficult.

Interpeak Latencies and Sex

Results of the present study indicated that females generally have shorter IPLs than males. These differences are present for all age groups, sensation levels and recording montages. For some age groups and IPLs the pattern is reversed, with males having shorter IPLs than females, although the differences were never significant. For example, IPL I^{+}-III recorded ipsilaterally at 80 dB SL was .02 msec. longer for females than males in age group A (Table A.2).

The shorter IPLs of females than males reported in the present study are consistent with Kjaer [1979] and Stockard et al. [1978]. Kjaer [1979] reported a difference score between males and females of .06 msec. for the IPL of I-III ($p < .05$) and .18 msec. for the IPL of I-V ($p < .0005$) recorded at 75 dB nHL. Stockard et al. [1978], testing at 60 dB SL found a difference score between males and females of .01 msec. (not significant) for the I-III IPL, of .13 msec. for the IPL of III-V ($p < .002$) and of .12 for I-V ($p < .05$). In the present study, the difference score between males and female for I^+-III IPL was .14 msec. at 80 dB SL in the contralateral montage ($p < .01$). The difference between male and female transmission time for the I^+-V^+ IPL was significant ($p < .05$) only at 40 dB SL ipsilaterally recorded, where the difference score was .17 msec (Table A.15). The difference between male and female I^+-V^- was significant at all levels and was an average of .29 msec. at 80 dB SL averaged for the ipsilateral and contralateral montage.

Clinical Implications

The results of the present study illustrate the importance of accounting for the sex of subjects when setting up clinical protocols. Obviously the data from this study strongly indicate the need for separate norms for males and females since females have been found to have significantly shorter absolute latencies (in waves III, IV, V^+ and V^-), and shorter IPLs than males. If norms for normal female subjects are used in testing males, the number of false positive readings (absolute latencies and IPL erroneously labelled beyond normal limits), would significantly increase regardless of the clinical criteria established for pathology. Conversely, if norms generated by male subjects are used when testing females, possible pathologies may be overlooked. An absolute latency or IPL that would be considered within normal limits for a male might be beyond normal limits for a female. Too many false positive or false negative results will reduce the clinical utility of the testing protocol.

III. Wave Morphology

The effect of aging and sex on wave morphology is another major issue addressed by this study. The subjective nature of evaluating the morphology of a BSER make differences due to aging and sex difficult to quantify. Three objective measures of waveform analyzed in the present study are: the amplitude of waves I and V, the amplitude ratio of waves V:I and the probability of waves being missing in a particular run.

EFFECT OF AGING ON AMPLITUDE

The amplitude (peak to trough) of waves I and V were measured in the present study at all levels where the waves could be identified. A ratio of the amplitude of waves V:I was calculated for each individual and was analyzed for the effect of aging. A second analysis of the relation of sex and aging on the amplitude of waves I and V ipsilaterally recorded at 60 and 40 dB SL was also performed, as previously described.

Amplitude Ratios of Waves V:I

No significant effect was found for age on the V:I amplitude ratio at any sensation level or montage. It appears that, although increasing age affects the amplitudes of waves (as will be discussed later), it has no affect on the amplitude ratio because it impacts both waves similarly. Clinically it would not be necessary to use different normative data for this amplitude ratio as subject age.

Age Effects on the Amplitude of Waves V and I

The amplitudes of both waves I and V decrease significantly (p= .02) with increasing age, through the first three age groups in the present study. The decrease in amplitude with increasing age, evident in this study, differs from the results of von Wedel [1979], who found no significant age dependencies for the amplitude of wave I and V in subjects ranging in age from 50 to >80. years. Jerger and Hall [1980] reported a slight decrease in wave V amplitude for young and older females, and a decrease that was twice as great for young and older males (age range 25-55 years). Maurizi et al. [1982] reported overall reduced peak amplitudes in comparing BSER tracings of the aged with those of the young, but tests for significance were not performed.

EFFECT OF SEX ON AMPLITUDE

Although in casual observation the amplitudes of waves V and I appear to be greater for females than males, the differences were not significant at $p< .05$. The mean amplitudes of only waves I at 60 dB SL and V at 40 dB SL were significantly greater ($p< .05$) for females than males.

The results of the present study were in general agreement with Jerger and Hall [1980] who found that the wave V amplitude was 25 percent larger in female subject than in male when recorded at 70 and 90 dB nHL. The results of the present study differed from those of Kjaer [1979] who found consistently significant differences in amplitude of waves I through V ($p < .005$) with females having higher amplitudes than males.

MISSING WAVES

Effect of Age

Results of the present study indicate that, with increasing age, the probability increases for all waves except wave IV being missing. Wave IV was often difficult to identify for all age groups. The increase in number of waves missing was not significant ($p = .05$) until age group C. Group C had consistently more waves missing in any given run than did groups A or B. Wave I^+ was more affected by increasing age than any of the other waves, showing a significant ($p < .05$) increase in the probability of being missing as early as age group B, and increasing consistently thereafter between each group. The results of the present study agree with those of von Wedel [1979] who reported an increase in probability of waves I, II, III and V being missing with increasing age.

The increased likelihood of a particular wave being missing for the older age groups occurred for both men and women through the first three age groups. The probability of a particular wave being missing also increased for men between age groups C and D, but it decreased for women.

Effect of Montage

Difficulties have often been reported in identifying wave I in ipsilateral recording. Hyde and Blair [1981], for example, reported that in 400 cases of cochlear hearing loss, the incidence of a reliable wave I is approximately 42 percent. Similarly, in the present study, for older subjects with increased hearing loss, wave I was found to be more affected by age ($p < .001$) than were the other waves. Wave I was missing significantly ($p < .05$) more often in age group B than in group A, and continued to be missing significantly more often for each subsequent age group. Other waves were not missing significantly ($p < .01$) more often until age group C.

Because of problems of identifying wave I in subjects with cochlear hearing losses, the present study included the recording of BSER using the horizontal montage. This montage is often recommended to help in identifying wave I. The results from the present study indicate the utility of the horizontal montage in helping to identify wave I were disappointing. Unexpectedly, the horizontal montage produced significantly more missing waves I than did the ipsilateral montage which is routinely used clinically. As previously reported, only on six occasions was a wave I missing ipsilaterally and contralaterally but present in the horizontal montage. That means out of a possible 543 times, the horizontal montage helped on six occasions to provide a wave I (.01 percent) when it was not present in either of the other montages. This occurred at 40 dB SL five out of the six times. It is true that the horizontal montage contributed to the identification of wave I by providing reinforcement and direction when there was doubt in either or both of the other montages. Yet the low productivity of the horizontal montage in identifying wave I that was found in the study would lead one to discontinue the routine use of the horizontal montage, except perhaps at lower recording levels such as 40 dB SL. Additional incentive to discontinue use of the horizontal montage was the unexpected finding of more waves II missing in the horizontal montage than in either the ipsilateral or contralateral. It was expected that the later waves (III, IV and V) would be missing more often in the horizontal montage than either of the other two, but the horizontal montage is usually expected to improve identification of the earlier waves I and II.

Hyde and Blair [1981] reported that in approximately 25 percent of 400 cases with hearing loss of cochlear etiology, waves IV and V are fused so as to produce a broadened complex of indeterminate latency. The authors suggest using a contralateral mastoid reference to help resolve the fusion of waves IV and V. They found that inspection of the contralateral recording resolved the fusion problem in about half the cases. In the present study, the contralateral montage helped to separate a IV/V complex twenty-one times out of a possible 543 runs (.04 percent). Wave V was significantly ($p < .001$) affected by montage, producing mean latencies which were significantly later in the contralateral montage than in the ipsilateral. The additional knowledge of the effect of montage on the latency of wave V contributed significantly to the identification of the wave. Thus, the contralateral montage appeared to be a useful addition to the recording procedure because of the combination of its ability to aid in identifying wave V when it is fused ipsilaterally and because the significant effect of montage producing waves V that are later contralaterally than ipsilaterally.

IV. The Statistical Design of the Study

The statistical techniques used in the present study were a two way ANOVA (age by sex) for the mean absolute latency of each wave and for each mean IPL, and a four way repeated measures analysis of variance (age by sex by intensity by montage) for a subset of waves. The use of the ANOVA, rather than just a repeated measures analysis of variance was necessary since a large number of waves was missing for each subject and a repeated measures analysis cannot be performed with missing data.

The use of multiple ANOVAs had many drawbacks. First, it did not permit an analysis of the interactions of variables such as on each other, as was discussed in Chapter 5. Secondly, with the use of multiple tests there is an increased likelihood of making a type I error and rejecting the null hypothesis when it is in effect true. With the 87 ANOVAs performed on the seven mean absolute latencies, using a significance level of $p < .05$, 4.4 mean absolute latencies could have been reported as significantly different purely by chance. Some 30 (40 percent) of the mean absolute latencies generated by the study showed significant age effects, a number far greater than would have been expected by chance. Thus, despite the inherent problems involved with using multiple ANOVAs, results of the study show effects other than what could have been expected purely by chance.

Using a significance criterion of $p < .01$ rather than $p < .05$ would, of course, reduced the chance of making a type I error (at the cost of increasing the chance of making a type II error). Thus the .05 level was chosen as the minimum significance level for the present study, but higher significance levels are also reported wherever relevant. Out of the 75 mean absolute latencies generated by the study, 23 (31%) were significant at $p<.01$.

V. Implications for Future Research

WAVES I^- AND V^- IN THE EVALUATION OF BSERS

A potentially important study suggested by the present research would be an evalution of the usefulness of wave I^- and V^- peaks in BSER testing. Many clinicians concentrate on the presence of the positive peaks of waves I, III and V and the IPLs between them. In the case of patients with sensori-neural hearing loss the identification of a I^+ is often difficult or impossible. Wave I^- is quite robust, however. In the present study, it was one of the waves least likely to be missing, often being identifiable at sensation levels as low as 20 dB SL. The time in msec. between wave I^- and wave III or V^+ or V^- was measured in this study and could be utilized to determine brainstem transmission time and help in neuro-otologic diagnosis in the absence of an identifiable wave I^+.

As reported by Hyde and Blair [1981] waves IV and V are often fused with cochlear hearing loss, thus indicating the potential for using wave V^- in place of V^+ when looking at absolute and interpeak latencies in patients with cochlear hearing loss.

Using norms established in this study for the absolute latency of waves I^- and V^- and the IPLs of I^--III, I^--V^+ and I^--V^-, it would be possible to analyze BSERs of patients with inconclusive results due to missing or unidentifiable waves I^+ and V^+.

ADDITIONAL AGE GROUPS

The present study, using cross-section data, found significant changes between the absolute latency and IPLs of the 18-34 year olds and the 55-64 year olds. Research is necessary to determine at what age the changes in latency and IPLs begin. Since a longitudinal study was not feasible for the present study, additional studies of the BSER of subjects in the age range between 35 and 54 would be clinically useful.

MATCHED SENSORI-NEURAL HEARING LOSS

The present study used only subjects with normal hearing for their age group. The inclusion of a control group of young subjects with sensori-neural hearing loss comparable to the loss of the older group of subjects would permit discrimination of changes in BSERs that result from peripheral changes from those that are the result of the more central effects of aging.

RELATION OF BSER TO PATTERNS OF PRESBYCUSIS

After extensive studies of human temporal bones, Schuknecht [1964, 1967] categorized presbycusis into four distinct types: sensory, neural, metabolic and mechanical.

These classifications are related to the relative contributions of central and peripheral atrophy to the hearing loss. Clinically, it is often difficult to distinguish among these presbycusic types based simply on audiometric data and subject history.

Hayes [1984] described a systematic way of differentiating presbycusis based on results of speech audiometry testing. She describes three distinct patterns of presbycusis:

1. Primarily peripheral presbycusis, with performance on speech recognition tasks proportional to the degree and configuration of pure tone sensitivity loss.

2. Mixed peripheral and central presbycusis, with speech recognition performance depressed for materials sensitive to central auditory effects, but consistent with the pure tone audiogram for material sensitive to peripheral effects.

3. Pronounced central presbycusis, with performance severely depressed for all speech materials.

An analysis of the relation between presbycusic types based on Hayes' classification system and the BSER would contribute information about the effect on BSER of the sites of atrophy or change within the auditory nervous system of the elderly.

USE OF CLICK PHASE TO SEPARATE CENTRAL FROM PERIPHERAL EFFECTS

Stockard and Stockard [1979] noted that phase differences in absolute latencies are often enhanced in patients with sensori-neural hearing loss. The presbycusic individual usually has central as well as peripheral auditory changes contributing to his sensori-neural nearing loss, while the young hearing impaired typically has solely peripheral changes. Click phase may be useful in differentiating between the two groups.

RECORDING MONTAGES

More definitive research is still required to determine potential benefits of the use of the contralateral and horizontal montages in the clinical use of BSER testing. In the acquisition of test equipment, clinics facing budget constraints require additional evidence of the benefits to be derived from equipment capable of simultaneously recording the responses from all three montages.

V. Conclusions

INTRODUCTION

The present study is unique in its size and scope, as compared with previous studies of the relation of the normal aging process to the BSER. The study included four groups: normal healthy young adults, 18-34 years; and three decades of older subjects, 55-64, 65-74 and 75-82. Each group included 10 males and 10 females carefully screened to meet the 1960-62 United States National Health Survey mean peripheral threshold requirements for normal hearing for his or her respective age group and sex. Each subject's better ear was tested at 80, 60, 40 and 20 dB SL, using a .1 msec. rarefaction click. BSERs were recorded using ipsilateral, contralateral and horizontal montages. Measurements were made whenever possible for absolute latencies of waves I^+ through V^-, including the negative peak of wave I.

No other study to date has examined such a large aging sample under carefully controlled conditions, using four intensities and three recording montages. Maurizi et al. [1982] studied the effects of age on the BSER of a total of 86 male and female subjects between 60 and 80 years of age at only 70 and 80 dB nHL intensity levels. Patterson et al. [1981] recorded BSERs at only 60, 70 and 80 dB SL, whereas Allison et al. [1983] tested only at 75 dB SL. Jerger and

Hall [1980], although testing a large group of subjects (182 males and 137 females), recorded BSERs at only 90 and 100 dB nHL and examined the effects of aging on wave V only. The present study is important since, not only did it test a large group of subjects covering a wide age range, but it did so at four intensity levels and three recording montages, providing data on the effects of aging on the BSER in a very extensive range of testing combinations.

RESULTS

As anticipated from previous data in the literature, the present study found aging to be statistically related to the absolute and interpeak latencies of the subjects. Of the 75 mean absolute latencies generated by this study, 30 (40 percent) showed significant effects of age at $p < .05$ and 23 (31 percent) showed significant effects at $p < .01$. Of the 87 mean IPLs generated by this study, 24 (28 percent) showed significant effects of age at $p < .05$, while 17 (20 percent) showed significant effects at $p < .01$. These results indicate a greater effect of age on the mean absolute latencies than on the interpeak latencies, or transmission time. The significant age effects appear to be more of a reflection of the peripheral hearing loss of the older population than of more central changes due to aging.

Aging and Absolute Latencies

Although increased absolute latencies were shown to be statistically related to increasing age for all waves (although not at every sensation level), the effect was more pronounced on the earlier waves (I^+, I^-, and III). Waves I^+ and III were significantly affected by age at every sensation level, although not in every recording montage. Wave III showed significant age effects in 8 out of 12 combinations of recording montage and sensation level. Waves I^+ and I^- showed significant age effects in 5 out of 12 combinations, with the number of significant age effects second only to that of wave III. These results indicate that the presbycusis of the older subjects had most extensive effects on waves I^+, I^- and III.

The increase in mean absolute latency with increased age that occurred in the present study was generally present only through age group C. This would lead clinicians to question whether additional normative data are necessary when testing normal aging patients over the age of 75. It remains uncertain whether this increase in absolute latency would continue in older subjects past age 75 in a clinical testing situation where these older patients are not screened to have normal hearing for their age and to meet the stringent health criteria used for selection of subjects for the present study. That issue is left unresolved by the present study.

Aging and IPLs

Previous studies have generally examined IPLs at high intensity levels (6Ø and 8Ø dB SL) and have concluded that IPLs increase with increased age at these levels. The present study found this increase to occur through the first three age groups.

The addition in this study of the 4Ø dB SL recording level was unique and important. Clinicians are often faced with testing older patients who have raised click thresholds, requiring testing to be done at low sensation levels due to the output limitations of the testing equipment. The present study showed that, when testing at 4Ø dB SL, those IPLs with significant age effects show a decrease in transmission time, or shorter IPLs, with increasing age rather than the expected increase that was apparent at higher testing levels. This decrease took place through the first three age groups and is perhaps one of the most important findings of the present study. To identify normal response, it is essential to be aware of the normal variation in transmission time that takes place in the older patient when testing at low levels. Unless the clinician adjusts normative values for the decrease in normal IPL when testing an older patient at low sensation levels, the number of false negatives would be excessive, reducing the credibility of the testing technique.

When testing at 40 db SL, the IPLs in this study decreased with increasing age only through age group C. This decrease in transmission time was primarily the result of testing subjects with high frequency hearing loss at low levels. It is possible that group D had more retrocochlear changes due to increased age than did group C, thus increasing transmission time, despite the normal shortening of IPLs with cochlear pathology. If that were the case, it is not until the oldest age group that changes in transmission time resulting from changes within the central auditory system associated with aging are extensive enough to increase the IPL despite the effect of high frequency hearing loss.

Aging and the Wave V:I Amplitude Ratio

Although increasing age affected the amplitude of waves, it had no effect on the amplitude ratio because it impacted both waves similarly. For the averge normal subject, the amplitude of wave V exceeds the amplitude of wave I, resulting in a V:I amplitude ratio >1.0. A substantially reduced amplitude ratio of .50 or less may have diagnostic significance [Hall, 1984]. The results of this study indicate that it would not be necessary to use different normative values for this amplitude ratio when testing an older population.

EFFECT OF SEX ON THE BSER

The results of the present study illustrate the importance of accounting for the sex of subjects when establishing clinical protocols. The results of the study indicate that females in all four age groups have shorter absolute latencies than do males in corresponding age groups. Although the differences were not always significant, females tended to have significantly shorter absolute latencies for waves III, IV, V^+ and V^- than did their male counterparts. Females also tended to have shorter IPLs than their male counterparts, although, again, the differences are not always significant. The difference between male and female IPLs of I^+-V^- was significantly shorter at all sensation levels where it was measurable.

The data from the study strongly indicate the need for separate norms for males and females. If norms for normal female subjects are used in testing males, the number of false positive readings (absolute latencies and IPLs apparently exceeding normal limits) would significantly increase regardless of the clinical criteria established for pathology.

EFFECT OF MONTAGE ON THE BSER

Another important finding of the present study was the limited usefulness of the horizontal montage in helping to identify wave I. Although the horizontal montage contrbuted to the identification of wave I by providing reinforcement and direction when there was doubt in either or both of the other montages, it still proved to be of limited use in testing a normal population. Unexpectedly, the horizontal montage produced significantly more missing waves I than did the ipsilateral montage, which is routinely used clinically. As reported previously, the horizontal montage helped on only six out of a possible 543 occasions to provide a wave I when it was not present in either of the other montages. The limited usefulness of the horizontal montage in identifying wave I that was found in the study would lead one to question the cost effectiveness of acquiring expensive test equipment capable of simultaneously recording the responses from all three montages.

Since the population tested in this study was a normal aging one, more definitive research is still required to determine the utility of the horizontal montage in testing a clinical population. Since, as previously discussed, the horizontal montage was more helpful when testing at lower sensation levels than higher, it may also prove to be more useful when testing a clinical population with possible pathologies than it was in the normal aging group.

SUMMARY

The results of the present study contribute extensively to the increase of knowledge of the systematic subject variables which affect the BSER. As noted in the introduction, it is essential that the clinician identify the normal variation in test results that are predictable from information about the population from which the patient comes. This study documented changes in absolute latencies, IPLs and amplitudes of waves associated with the normal aging process. Knowledge of these population differences permits interpretation of the test data to be as accurate as possible, increasing the utility of the BSER as a diagnostic technique.

APPENDICES

APPENDIX A--TABLES

Table A.1. Frequency of hearing impairment by age
United States National Health Survey,
July 1957 - June 1958
(Data refer to the civilian noninstitutionalized population, and include total deafness.)

Age (Years)	Number of Cases	Rate per 1,000 persons
All ages	5,822,000	34.6
Under 25	583,000	7.9
a5-44	941,000	20.6
45-64	1,801,000	52.2
65-74	1,244,000	129.2
75 and over	1,253,000	256.4

Table A.2. Means and standard deviations of absolute latencies in msec., ipsilaterally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Stand. Dev.		Number	
			Males	Females	M	F
I^+	80	18-34	1.49(.06)	1.51(.11)	10	10
		55-64	1.61(.10)	1.56(.08)	10	10
		65-74	1.65(.14)	1.54(.06)	5	8
		75-82	1.56(.07)	1.80(.18)	4	2
	60	18-34	1.79(.15)	1.78(.07)	10	10
		55-64	1.78(.16)	1.72(.10)	10	10
		65-74	1.86(.13)	1.69(.14)	10	9
		75-82	1.84(.19)	1.75(.21)	9	10
	40	18-34	2.62(.26)	2.46(.20)	10	9
		55-64	2.74(.36)	2.57(.52)	10	8
		65-74	3.07(.36)	2.83(.22)	9	10
		75-82	2.62(.20)	2.82(.33)	7	9
I^-	80	18-34	2.10(.08)	2.12(.11)	10	10
		55-64	2.27(.12)	2.28(.10)	10	10
		65-74	2.25(.12)	2.28(.10)	10	10
		75-82	2.36(.26)	2.25(.02)	5	2
	60	18-34	2.33(.12)	2.36(.08)	10	10
		55-64	2.37(.13)	2.31(.10)	10	10
		65-74	2.40(.19)	2.23(.10)	10	10
		75-82	2.31(.16)	2.39(.18)	10	10
	40	18-34	3.19(.31)	3.03(.23)	10	10
		55-64	3.33(.42)	3.04(.58)	10	9
		65-74	3.74(.50)	3.27(.39)	10	10
		75-82	3.13(.31)	3.40(.30)	10	10
	20	18-34	4.40(.34)	4.34(.39)	5	8
		55-64	4.25(.28)	4.26(.37)	8	7
		65-74	4.17(.36)	4.53(.27)	6	6
		75-82	4.49(.51)	4.50(.69)	7	10
II	80	18-34	2.64(.09)	2.63(.16)	10	10
		55-64	2.82(.16)	2.77(.19)	10	10
		65-74	2.79(.15)	2.66(.22)	6	8
		75-82	2.86(.27)	2.74(.02)	5	2
	60	18-34	2.85(.09)	2.86(.14)	10	10
		55-64	2.91(.08)	2.85(.14)	10	10
		65-74	3.01(.23)	2.81(.21)	10	10
		75-82	2.95(.12)	2.97(.16)	10	10
	40	18-34	3.62(.36)	3.42(.39)	9	8

Table A.2. Means and standard deviations of absolute latencies in msec., ipsilaterally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Stand. Dev.		Number	
			Males	Females	M	F
		55-64	3.84(.53)	3.39(.70)	8	6
		65-74	4.07(.51)	3.77(.40)	7	7
		75-82	3.63(.25)	3.79(.45)	6	8
III	80	18-34	3.62(.12)	3.63(.11)	10	10
		55-64	3.80(.14)	3.73(.17)	10	10
		65-74	3.84(.08)	3.73(.19)	6	8
		75-82	3.81(.08)	3.68(.00)	5	2
	60	18-34	3.84(.14)	3.85(.16)	10	10
		55-64	3.97(.18)	3.84(.18)	10	10
		65-74	4.09(.15)	3.84(.18)	10	10
		75-82	4.03(.12)	4.03(.14)	10	10
	40	18-34	4.56(.30)	4.44(.22)	10	10
		55-64	4.66(.52)	4.47(.59)	10	10
		56-74	4.89(.45)	4.67(.30)	10	10
		75-82	4.69(.22)	4.73(.42)	10	10
	20	18-34	5.72(.34)	5.51(.29)	9	9
		55-64	5.80(.43)	5.64(.28)	8	9
		65-74	5.96(.41)	6.08(.68)	6	7
		75-82	6.12(.45)	5.95(.52)	5	9
IV	80	18-34	4.92(.26)	4.89(.24)	10	10
		55-64	4.96(.22)	5.02(.20)	10	10
		65-74	5.06(.22)	4.98(.26)	6	8
		75-82	5.07(.16)	4.76(.32)	5	2
	60	18-34	5.15(.15)	5.04(.20)	10	10
		55-64	5.17(.20)	5.04(.21)	10	10
		65-74	5.50(.22)	5.09(.25)	10	10
		75-82	5.19(.16)	5.13(.21)	10	10
	40	18-34	5.83(.31)	5.63(.20)	10	5
		55-64	5.78(.40)	5.64(.61)	10	8
		65-74	5.95(.39)	5.68(.29)	9	8
		75-82	5.81(.34)	5.60(.24)	7	10
V+	80	18-34	5.49(.16)	5.52(.15)	10	10
		55-64	5.56(.08)	5.52(.20)	10	10
		65-74	5.81(.12)	5.56(.17)	6	8
		75-82	5.72(.19)	5.40(.13)	5	2
	60	18-34	5.74(.12)	5.74(.15)	10	10
		55-64	5.83(.20)	5.73(.23)	10	10
		65-74	6.05(.19)	5.69(.23)	10	10

Table A.2. Means and standard deviations of absolute latencies in msec., ipsilaterally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Stand. Dev.		Number	
			Males	Females	M	F
		75-82	5.89(.14)	5.78(.15)	10	10
	40	18-34	6.39(.15)	6.18(.23)	10	10
		55-64	6.43(.40)	6.31(.52)	10	10
		65-74	6.65(.45)	6.27(.26)	10	10
		75-82	6.60(.41)	6.30(.19)	10	10
	20	18-34	7.81(.43)	7.28(.35)	10	10
		55-64	7.75(.25)	7.53(.59)	10	10
		65-74	7.77(.62)	7.62(.42)	9	9
		75-82	7.83(.62)	7.54(.58)	10	10
V^-	80	18-34	6.41(.37)	6.23(.17)	10	10
		55-64	6.47(.20)	6.30(.27)	10	10
		65-74	6.70(.41)	6.34(.22)	6	8
		75-82	6.51(.21)	6.26(.36)	5	2
	60	18-34	6.71(.42)	6.62(.55)	10	10
		55-64	6.74(.54)	6.41(.28)	10	10
		65-74	7.00(.31)	6.43(.34)	10	10
		75-82	6.75(.34)	6.56(.25)	10	10
	40	18-34	7.83(.52)	7.40(.76)	10	10
		55-64	7.48(.61)	7.12(.53)	10	10
		65-74	7.65(.51)	7.13(.57)	10	10
		75-82	7.38(.33)	7.12(.30)	10	10
	20	18-34	8.79(.46)	8.26(.42)	10	10
		55-64	8.98(.54)	8.64(.73)	10	10
		65-74	8.56(.49)	8.44(.70)	9	9
		75-82	8.73(.89)	8.32(.63)	10	10

Table A.3. Means and standard deviations of absolute latencies in msec. contralaterally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
I^+	80	18-34	1.64(.15)	1.61(.10)	7	8
		55-64	1.69(.11)	1.79(.12)	6	3
		65-74	1.76(.13)	1.73(.12)	5	6
		75-82	1.78(.15)	1.92(.20)	4	2
	60	18-34	1.80(.14)	1.87(.11)	9	7
		55-64	1.76(.14)	1.67(.13)	5	9
		65-74	1.95(.07)	1.73(.10)	6	6
		75-82	1.90(.19)	1.87(.15)	5	7
	40	18-34	2.70(.15)	2.42(.08)	7	3
		55-64	2.65(.28)	2.62(.52)	4	4
		65-74	3.00(.32)	2.82(.20)	7	5
		75-82	2.63(.21)	2.80(.41)	5	5
I^-	80	18-34	2.18(.09)	2.17(.15)	10	10
		55-64	2.30(.17)	2.25(.12)	10	10
		65-74	2.39(.11)	2.23(.10)	6	8
		75-82	2.37(.09)	2.28(.12)	5	2
	60	18-34	2.41(.10)	2.38(.14)	10	10
		55-64	2.47(.22)	2.33(.17)	10	10
		65-74	2.46(.20)	2.31(.19)	10	10
		75-82	2.36(.18)	2.49(.25)	10	10
	40	18-34	3.01(.18)	2.91(.20)	9	9
		55-64	3.26(.28)	3.13(.56)	10	9
		65-74	3.67(.37)	3.43(.63)	10	9
		75-82	3.34(.44)	3.20(.36)	10	10
	20	18-34	4.29(.32)	4.15(.40)	8	7
		55-64	4.34(.41)	4.15(.30)	9	7
		65-74	4.27(.22)	4.73(.36)	4	6
		75-82	4.64(.46)	4.40(.52)	5	9
II	80	18-34	2.74(.06)	2.73(.17)	10	10
		55-64	2.94(.17)	2.85(.16)	10	10
		65-74	2.95(.13)	2.78(.22)	6	8
		75-82	2.96(.15)	2.76(.13)	5	2
	60	18-34	2.94(.09)	2.94(.16)	10	10
		55-64	3.07(.16)	2.93(.18)	10	10
		64-74	3.11(.29)	2.93(.18)	10	10
		75-82	3.00(.12)	3.07(.22)	10	10
	40	18-34	3.65(.35)	3.48(.31)	9	3

Table A.3. Means and standard deviations of absolute latencies in msec. contralaterally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
		55-64	3.94(.47)	3.50(.60)	7	7
		65-74	4.06(.46)	3.75(.44)	7	8
		75-82	3.76(.29)	3.81(.38)	6	10
III	80	18-34	3.60(.08)	3.53(.16)	10	10
		55-64	3.71(.14)	3.66(.17)	10	10
		65-74	3.84(.11)	3.65(.20)	6	8
		75-82	3.77(.10)	3.50(.19)	5	2
	60	18-34	3.80(.14)	3.82(.15)	10	10
		55-64	3.90(.14)	3.82(.20)	10	10
		65-74	3.98(.16)	3.79(.20)	10	10
		75-82	3.92(.05)	3.86(.13)	10	10
	40	18-34	4.57(.38)	4.27(.20)	10	10
		55-64	4.60(.47)	4.44(.61)	10	10
		65-74	5.00(.46)	4.65(.31)	10	8
		75-82	4.78(.35)	4.76(.52)	10	10
	20	18-34	5.70(.20)	5.41(.25)	8	8
		55-64	5.76(.28)	5.70(.39)	9	8
		65-74	5.96(.42)	5.94(.33)	6	4
		75-82	6.11(.77)	5.92(.50)	5	8
IV	80	18-34	4.82(.18)	4.77(.18)	10	10
		55-64	4.98(.14)	4.98(.21)	10	10
		65-74	5.01(.19)	5.00(.22)	6	8
		75-82	5.12(.13)	4.87(.11)	5	2
	60	18-34	5.09(.10)	4.94(.17)	10	10
		55-64	5.11(.21)	5.01(.23)	10	10
		65-74	5.45(.14)	5.01(.26)	10	10
		75-82	5.19(.23)	5.12(.17)	10	10
	40	18-34	5.82(.32)	5.60(.14)	10	8
		55-64	5.90(.49)	5.75(.61)	10	9
		65-74	5.93(.40)	5.69(.30)	9	8
		75-82	5.93(.37)	5.66(.34)	9	8
V^+	80	18-34	5.60(.15)	5.57(.15)	10	10
		55-64	5.62(.07)	5.60(.21)	10	10
		64-74	5.81(.19)	5.63(.21)	6	8
		75-82	5.71(.14)	5.41(.19)	5	2
	60	18-34	5.81(.26)	5.82(.14)	10	10
		55-64	5.89(.21)	5.80(.20)	10	10

Table A.3. Means and standard deviations of absolute latencies in msec. contralaterally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
		65-74	6.09(.22)	5.81(.18)	10	10
		75-84	5.95(.19)	5.87(.20)	10	10
	40	18-34	6.43(.12)	6.25(.22)	10	10
		55-64	6.47(.40)	6.40(.52)	10	10
		65-74	6.71(.42)	6.32(.25)	10	9
		75-82	6.61(.38)	6.35(.26)	10	10
	20	18-34	7.88(.38)	7.34(.24)	10	10
		55-64	7.88(.33)	7.63(.62)	9	10
		65-74	7.89(.55)	7.71(.44)	9	9
		75-84	7.93(.67)	7.56(.55)	9	9
V⁻	80	18-34	6.68(.40)	6.40(.34)	10	10
		55-64	6.64(.16)	6.54(.27)	10	10
		64-74	6.87(.49)	6.49(.25)	6	10
		75-82	6.66(.38)	6.27(.36)	5	10
	60	18-34	6.86(.35)	7.20(.81)	10	10
		55-64	6.94(.57)	6.91(.48)	10	10
		65-74	7.10(.33)	6.74(.28)	10	10
		75-82	7.10(.48)	6.67(.31)	10	10
	40	18-34	7.85(.61)	7.86(.76)	10	10
		55-64	7.47(.53)	7.31(.40)	10	10
		65-74	7.74(.54)	7.24(.41)	10	9
		75-82	7.55(.39)	7.59(.56)	10	10
	20	18-34	8.96(.38)	8.43(.51)	10	10
		55-64	8.94(.45)	9.06(.84)	9	10
		65-74	8.84(.74)	8.64(.59)	9	9
		75-82	9.23(1.11)	8.54(.83)	9	9

Table A.4. Means and standard deviations of absolute latencies in msec. horizontally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
I+	80	18-34	1.48(.07)	1.50(.10)	10	10
		55-64	1.60(.08)	1.58(.10)	10	10
		65-74	1.64(.09)	1.52(.09)	6	8
		75-82	1.51(.02)	1.68(.00)	3	2
	60	18-34	1.79(.16)	1.79(.09)	10	10
		55-64	1.80(.17)	1.72(.11)	10	10
		65-74	1.87(.12)	1.70(.16)	9	10
		75-82	1.77(.14)	1.75(.19)	8	10
	40	18-34	2.65(.24)	2.51(.24)	9	8
		55-64	2.78(.27)	2.70(.54)	9	7
		65-74	3.02(.42)	2.67(.16)	8	5
		75-82	2.75(.25)	2.81(.27)	5	9
I-	80	18-34	2.05(.10)	2.12(.15)	10	10
		55-64	2.23(.09)	2.20(.20)	10	10
		65-74	2.17(.05)	2.04(.10)	6	8
		75-82	2.44(.61)	2.15(.01)	5	2
	60	18-34	2.35(.23)	2.32(.09)	10	10
		55-64	2.30(.15)	2.31(.22)	10	10
		65-74	2.42(.18)	2.18(.15)	10	10
		75-82	2.34(.22)	2.29(.24)	10	10
	40	18-34	3.22(.47)	3.26(.33)	9	9
		55-64	2.35(.31)	3.27(.56)	9	9
		65-74	3.55(.37)	3.44(.34)	9	8
		75-82	3.45(.32)	3.40(.34)	9	10
	20	18-34	4.62(.34)	4.31(.15)	2	5
		55-64	4.33(.30)	4.36(.11)	7	4
		65-74	4.27(.65)	4.78(.35)	4	6
		75-84	4.47(.76)	4.58(.64)	4	7
II	80	18-34	2.47(.12)	2.48(.17)	10	10
		55-64	2.65(.18)	2.66(.20)	10	9
		65-74	2.65(.08)	2.45(.15)	6	7
		75-82	2.77(.15)	2.52(.30)	4	2
	60	18-34	2.70(.13)	2.78(.14)	10	10
		55-64	2.79(.19)	2.73(.13)	10	10
		65-74	2.88(.24)	2.68(.15)	10	10
		75-82	2.85(.18)	2.86(.24)	10	10
	40	18-34	3.50(.44)	3.30(.40)	5	3

Table A.4. Means and standard deviations of absolute latencies in msec. horizontally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
		55-64	3.86(.31)	3.22(.45)	3	4
		65-74	4.09(.60)	3.79(.59)	6	3
		75-82	3.53(.09)	3.88(.36)	3	7
III	80	18-34	3.70(.15)	3.75(.17)	10	10
		55-64	3.92(.15)	3.82(.19)	10	10
		65-74	3.93(.25)	3.89(.15)	6	8
		75-82	4.04(.19)	3.75(.01)	5	2
	60	18-34	3.92(.17)	3.85(.16)	10	10
		55-64	4.02(.20)	3.89(.19)	10	10
		65-74	4.34(.14)	3.89(.20)	10	10
		75-82	4.02(.18)	4.07(.15)	10	10
	40	18-34	4.68(.27)	4.55(.28)	9	9
		55-64	4.57(.38)	4.56(.56)	8	10
		65-74	4.88(.48)	4.76(.29)	9	8
		75-82	4.75(.23)	4.76(.33)	9	10
	20	18-34	5.78(.37)	5.56(.23)	8	7
		55-64	5.73(.42)	5.56(.25)	6	4
		65-74	5.79(.19)	5.87(.30)	4	4
		75-82	6.34(.25)	5.81(.76)	4	5
IV	80	18-34	4.97(.33)	4.96(.29)	8	7
		55-64	5.05(.27)	5.12(.19)	9	6
		65-74	5.22(.21)	5.05(.16)	6	8
		75-82	5.24(.25)	4.71(.34)	4	2
	60	18-34	5.18(.16)	5.10(.17)	8	6
		55-64	5.20(.14)	5.09(.21)	10	6
		65-74	5.58(.23)	5.24(.20)	9	7
		75-82	5.16(.22)	5.18(.16)	9	8
	40	18-34	5.97(.30)	5.75(.29)	5	4
		55-64	5.60(.16)	6.22(.17)	4	3
		65-74	5.89(.32)	5.75(.36)	7	4
		75-82	5.78(.31)	5.66(.29)	2	8
V^+	80	18-34	5.39(.06)	5.45(.09)	8	7
		55-64	5.52(.10)	5.58(.15)	9	6
		65-74	5.70(.15)	5.50(.14)	6	8
		75-82	5.66(.26)	5.41(.11)	5	2
	60	18-34	5.55(.14)	5.62(.11)	9	5
		55-64	5.65(.20)	5.74(.23)	10	7

Table A.4. Means and standard deviations of absolute latencies in msec. horizontally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
		65-74	6.02(.20)	5.58(.16)	10	7
		74-82	5.83(.21)	5.74(.14)	10	9
	40	18-34	6.37(.17)	6.11(.19)	9	8
		55-64	6.22(.36)	6.35(.52)	9	9
		65-74	6.50(.37)	6.31(.31)	9	5
		75-82	6.42(.32)	6.31(.23)	6	9
	20	18-34	7.73(.31)	7.18(.22)	8	9
		55-64	7.58(.40)	7.48(.61)	7	8
		65-74	7.56(.46)	7.55(.38)	8	4
		75-82	7.77(.88)	7.45(.51)	4	7
V^-	80	18-34	5.88(.19)	6.07(.19)	8	7
		55-64	6.09(.25)	6.13(.11)	9	6
		65-74	6.42(.16)	6.21(.32)	6	8
		75-82	6.11(.17)	5.88(.03)	5	2
	60	18-34	6.14(.15)	6.27(.19)	9	5
		55-64	6.29(.31)	6.28(.33)	10	7
		65-74	6.79(.25)	6.28(.47)	10	7
		75-82	6.55(.44)	6.34(.29)	10	9
	40	18-34	7.06(.25)	6.66(.26)	9	8
		55-64	6.95(.53)	7.04(.66)	9	9
		65-74	7.12(.37)	6.99(.27)	9	5
		75-82	6.94(.37)	6.91(.47)	6	9
	20	18-34	8.34(.34)	7.90(.34)	8	9
		55-64	8.47(.46)	8.37(.92)	7	8
		65-74	8.33(.51)	8.52(.57)	8	4
		75-82	8.59(.94)	8.25(.80)	4	7

Table A.5. Means and standard deviations of interpeak latencies in msec. ipsilaterally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
I^+-III	80	18-34	2.13(.11)	2.12(.13)	10	10
		55-64	2.19(.19)	2.16(.19)	10	10
		65-74	2.21(.15)	2.19(.19)	5	8
		75-82	2.25(.13)	1.87(.17)	4	2
	60	18-34	2.05(.13)	2.06(.15)	10	10
		55-64	2.18(.09)	2.11(.17)	10	10
		65-74	2.23(.19)	2.18(.15)	10	9
		75-82	2.21(.14)	2.27(.19)	9	10
	40	18-34	1.94(.13)	1.97(.20)	10	9
		55-64	1.91(.41)	1.85(.26)	10	8
		65-74	1.83(.40)	1.83(.37)	9	10
		75-82	2.07(.26)	1.88(.47)	7	9
I^--III	80	18-34	1.51(.12)	1.50(.10)	10	10
		55-64	1.52(.08)	1.44(.12)	10	10
		65-74	1.59(.06)	1.59(.13)	6	8
		75-82	1.45(.19)	1.43(.01)	5	2
	60	18-34	1.51(.08)	1.49(.11)	10	10
		55-64	1.60(.08)	1.53(.12)	10	10
		65-74	1.69(.25)	1.61(.12)	10	10
		75-82	1.72(.24)	1.63(.16)	10	10
	40	18-34	1.37(.15)	1.41(.23)	10	10
		55-64	1.32(.36)	1.38(.24)	10	9
		65-74	1.15(.31)	1.40(.34)	10	10
		75-84	1.55(.35)	1.32(.45)	10	10
	20	18-34	1.34(.20)	1.08(.23)	5	7
		55-64	1.53(.40)	1.33(.18)	6	7
		65-74	1.79(.47)	1.58(.72)	6	4
		75-82	1.58(.42)	1.41(.55)	5	9
I^+-V^+	80	18-34	4.00(.13)	4.01(.16)	10	10
		55-64	3.95(.12)	3.95(.19)	10	10
		65-74	4.17(.25)	4.02(.19)	5	8
		75-82	4.19(.22)	3.59(.04)	4	2
	60	18-34	3.96(.16)	3.96(.15)	10	10
		55-64	4.05(.15)	4.01(.20)	10	10
		65-74	4.19(.20)	4.01(.27)	10	9
		75-82	4.05(.26)	4.02(.28)	9	10
	40	18-34	3.77(.17)	3.69(.23)	10	9

Table A.5. Means and standard deviations of interpeak latencies in msec. ipsilaterally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
		55-64	3.68(.38)	3.71(.24)	10	8
		65-74	3.59(.39)	3.44(.31)	9	10
		75-82	3.93(.50)	3.45(.30)	7	9
I^+-V^-	80	18-34	4.92(.35)	4.72(.17)	10	10
		55-64	4.85(.22)	4.73(.23)	10	10
		65-74	4.88(.24)	4.80(.24)	5	8
		75-82	4.99(.23)	4.45(.18)	4	2
	60	18-34	4.92(.43)	4.83(.56)	10	10
		55-64	4.95(.53)	4.69(.24)	10	10
		65-74	5.14(.29)	4.76(.37)	10	9
		75-82	4.96(.31)	4.80(.35)	9	10
	40	18-34	5.21(.60)	4.94(.82)	10	9
		55-64	4.73(.64)	4.55(.31)	10	8
		65-74	4.56(.53)	4.29(.51)	9	10
		75-82	4.68(.39)	4.26(.42)	7	9
I^--V^-	80	18-34	4.50(.41)	4.22(.23)	10	10
		55-64	4.33(.20)	4.29(.27)	10	10
		65-74	4.48(.49)	4.25(.22)	6	8
		75-82	4.28(.45)	3.99(.23)	5	2
	60	18-34	4.37(.45)	4.26(.58)	10	10
		55-64	4.37(.53)	4.10(.24)	10	10
		65-74	4.59(.40)	4.19(.31)	10	10
		75-82	4.44(.37)	4.16(.32)	10	10
	40	18-34	4.63(.67)	4.36(.89)	10	10
		55-64	4.14(.56)	4.07(.31)	10	9
		65-74	3.91(.56)	3.85(.56)	10	10
		75-82	4.24(.42)	3.71(.40)	10	10
	20	18-34	4.36(.75)	3.84(.59)	5	8
		55-64	4.72(.54)	4.25(.80)	8	7
		65-74	4.29(.27)	3.86(.66)	7	6
		75-82	4.08(1.14)	3.82(.39)	6	10
I^--V^+	80	18-34	3.38(.16)	3.39(.16)	10	10
		55-64	3.28(.08)	3.24(.20)	10	10
		65-74	3.55(.09)	3.42(.18)	6	8
		75-82	3.36(.19)	3.14(.11)	5	2
	60	18-34	3.41(.17)	3.38(.15)	10	10
		55-64	3.46(.14)	3.42(.18)	10	10

Table A.5. Means and standard deviations of interpeak latencies in msec. ipsilaterally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
		65-74	3.64(.28)	3.45(.21)	10	10
		75-82	3.58(.15)	3.38(.22)	10	10
	40	18-34	3.19(.29)	3.15(.35)	10	10
		55-64	3.09(.37)	3.23(.24)	10	9
		65-74	2.91(.29)	3.00(.40)	10	10
		75-82	3.47(.50)	2.89(.28)	10	10
	20	18-34	3.51(.68)	2.82(.33)	5	8
		55-64	3.48(.29)	3.15(.58)	8	7
		65-74	3.49(.28)	3.06(.46)	6	6
		75-82	3.25(.76)	3.03(.46)	7	10
III-V$^-$	80	18-34	2.79(.43)	2.60(.23)	10	10
		55-64	2.66(.26)	2.57(.28)	10	10
		65-74	2.85(.44)	2.60(.22)	6	8
		75-82	2.69(.18)	2.58(.35)	5	2
	60	18-34	2.86(.47)	2.76(.58)	10	10
		55-64	2.76(.51)	2.57(.19)	10	10
		65-74	2.90(.24)	2.58(.24)	10	10
		75-82	2.71(.33)	2.53(.24)	10	10
	40	18-34	3.26(.63)	2.95(.73)	10	10
		55-64	2.81(.48)	2.64(.23)	10	10
		65-74	2.76(.38)	2.45(.59)	10	10
		75-82	2.68(.25)	2.38(.21)	10	10
	20	18-34	3.04(.56)	2.72(.45)	9	9
		55-64	3.11(.57)	2.91(.61)	8	9
		65-74	2.49(.34)	2.52(.45)	6	7
		75-82	2.88(.66)	2.31(.49)	5	9
III-V$^+$	80	18-34	1.86(.16)	1.89(.15)	10	10
		55-64	1.76(.11)	1.79(.17)	10	10
		65-75	1.96(.10)	1.82(.15)	6	8
		75-82	1.91(.11)	1.71(.12)	5	2
	60	18-34	1.90(.20)	1.89(.16)	10	10
		55-64	1.86(.13)	1.89(.15)	10	10
		65-74	1.95(.22)	1.84(.15)	10	10
		75-82	1.85(.21)	1.75(.16)	10	10
	40	18-34	1.82(.26)	1.73(.23)	10	10
		55-64	1.77(.25)	1.83(.17)	10	10
		65-74	1.76(.25)	1.60(.34)	10	10

Table A.5. Means and standard deviations of interpeak latencies in msec. ipsilaterally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
		75-82	1.91(.31)	1.56(.32)	10	10
III-V+	20	18-34	2.12(.47)	1.76(.22)	9	9
		55-64	1.96(.45)	1.81(.43)	8	9
		65-74	1.70(.30)	1.62(.36)	6	7
		75-82	2.02(.31)	1.51(.37)	5	9

Table A.6. Means and standard deviations of interpeak latencies in msec. contralaterally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
I^{+}-III	80	18-34	1.97(.20)	1.88(.16)	7	8
		55-64	1.97(.15)	1.81(.09)	6	3
		65-74	2.09(.24)	1.95(.11)	5	6
		75-82	1.97(.10)	1.57(.00)	4	2
	60	18-34	1.97(.12)	1.91(.09)	9	7
		55-64	2.08(.17)	2.12(.16)	5	9
		65-74	1.98(.15)	2.09(.15)	6	6
		75-82	2.04(.21)	2.00(.16)	5	7
	40	18-34	1.88(.27)	1.73(.22)	7	3
		55-64	1.97(.29)	1.76(.31)	4	4
		65-74	1.88(.37)	1.80(.16)	7	5
		75-82	2.24(.36)	2.21(.46)	5	5
I^{-}-III	80	18-34	1.42(.10)	1.35(.12)	10	10
		55-64	1.40(.10)	1.40(.10)	10	10
		65-74	1.44(.11)	1.41(.13)	6	8
		75-84	1.38(.08)	1.21(.06)	5	2
	60	18-34	1.38(.11)	1.44(.12)	10	10
		55-64	1.43(.13)	1.49(.14)	10	10
		65-74	1.51(.19)	1.48(.10)	10	10
		75-82	1.56(.15)	1.37(.22)	10	10
	40	18-34	1.48(.31)	1.33(.20)	9	9
		55-64	1.34(.36)	1.32(.25)	10	9
		65-74	1.32(.37)	1.38(.23)	10	8
		75-82	1.44(.49)	1.55(.39)	10	10
	20	18-34	1.39(.37)	1.26(.31)	7	6
		55-64	1.38(.39)	1.62(.42)	8	6
		65-74	1.56(.27)	1.15(.32)	4	3
		75-82	1.47(.69)	1.40(.40)	5	8
I^{+}-V^{+}	8-	18-34	3.97(.22)	3.95(.14)	7	8
		55-64	3.92(.07)	3.90(.25)	6	3
		65-74	4.02(.33)	3.89(.15)	5	6
		75-82	3.97(.12)	3.49(.00)	4	2
	60	18-34	4.00(.24)	3.95(.15)	9	7
		55-64	4.03(.16)	4.11(.18)	5	9
		65-74	4.08(.20)	4.03(.17)	6	6
		75-82	4.00(.31)	4.03(.22)	5	7
	40	18-34	3.72(.12)	3.78(.22)	7	3

Table A.6. Means and standard deviations of interpeak latencies in msec. contralaterally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
		55-64	4.00(.19)	3.65(.17)	4	4
		65-74	3.64(.52)	3.38(.32)	7	5
		75-92	3.96(.39)	3.60(.53)	5	5
I^+-V^-	80	18-34	5.16(.36)	4.72(.22)	7	8
		55-64	4.98(.14)	4.74(.46)	6	3
		65-74	5.17(.57)	4.72(.27)	5	6
		75-82	4.93(.54)	4.35(.16)	4	2
	60	18-34	5.05(.40)	5.19(.91)	9	7
		55-64	5.20(.38)	5.25(.53)	5	9
		65-74	5.04(.26)	4.97(.36)	6	6
		75-82	5.03(.53)	4.86(.42)	5	7
	40	18-34	5.31(.58)	4.95(.31)	7	3
		55-64	4.91(.22)	4.55(.26)	4	4
		65-74	4.69(.62)	4.28(.35)	7	5
		75-82	4.98(.36)	4.87(.78)	5	5
I^--V^-	80	18-34	4.50(.41)	4.22(.23)	10	10
		55-64	4.33(.20)	4.29(.27)	10	10
		65-74	4.48(.49)	4.25(.22)	6	8
		75-82	4.28(.45)	3.99(.23)	5	2
	60	18-34	4.45(.41)	4.82(.85)	10	10
		55-64	4.47(.45)	4.58(.47)	10	10
		65-74	4.63(.34)	4.43(.30)	10	10
		75-82	4.73(.53)	4.18(.40)	10	10
	40	18-34	4.86(.60)	5.01(.87)	9	9
		55-64	4.21(.40)	4.20(.44)	10	9
		65-74	4.06(.60)	3.81(.77)	10	9
		75-82	4.21(.43)	4.39(.67)	10	10
	20	18-34	4.70(.53)	4.13(.52)	8	7
		55-64	4.61(.30)	4.76(1.07)	8	7
		65-74	4.80(.60)	3.83(.45)	4	6
		75-82	4.27(1.28)	4.13(.67)	5	9
I^--V^+	80	18-34	3.42(.23)	3.39(.13)	10	10
		55-64	3.31(.17)	3.35(.18)	10	10
		65-74	3.42(.16)	3.39(.16)	6	8
		75-82	3.34(.13)	3.12(.06)	5	2
	60	18-34	3.40(.27)	3.44(.13)	10	10
		55-64	3.42(.12)	3.47(.15)	10	10

Table A.6. Means and standard deviations of interpeak latencies in msec. contralaterally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
		65-74	3.62(.21)	3.50(.15)	10	10
		75-82	3.58(.28)	3.37(.32)	10	10
	40	18-34	3.39(.14)	3.32(.23)	9	9
		65-74	3.03(.44)	2.89(.70)	10	9
		75-82	3.27(.49)	3.14(.39)	10	10
	20	18-34	3.63(.34)	3.10(.32)	8	7
		55-64	3.54(.31)	3.45(.66)	8	7
		65-74	3.73(.61)	2.93(.28)	4	6
		75-82	3.06(.85)	3.15(.49)	5	9
III-V$^-$	80	18-34	3.07(.42)	2.87(.28)	10	10
		55-64	2.92(.20)	2.88(.24)	10	10
		65-74	3.03(.39)	2.84(.21)	6	8
		75-82	2.89(.41)	2.77(.17)	5	2
	60	18-34	3.06(.40)	3.38(.81)	10	10
		55-64	3.04(.49)	3.09(.38)	10	10
		65-74	3.11(.24)	2.95(.29)	10	10
		75-82	3.17(.48)	2.80(.31)	10	10
	40	18-34	3.27(.57)	3.58(.77)	10	10
		55-64	2.87(.50)	2.87(.37)	10	10
		65-74	2.74(.40)	2.63(.50)	10	8
		75-84	2.77(.28)	2.83(.54)	10	10
	20	18-34	3.20(.34)	2.97(.65)	8	8
		55-64	3.16(.49)	3.45(1.02)	8	8
		65-74	3.00(.52)	3.08(.46)	6	4
		75-82	2.79(.62)	2.81(.63)	5	8
III-V$^+$	80	18-34	2.00(.19)	2.03(.12)	10	10
		55-64	1.91(.12)	1.94(.19)	10	10
		65-74	1.97(.16)	1.97(.11)	6	8
		75-82	1.94(.11)	1.91(.00)	5	2
	60	18-34	2.01(.24)	2.00(.11)	10	10
		55-64	1.99(.11)	1.97(.14)	10	10
		65-74	2.10(.16)	2.01(.13)	10	10
		75-82	2.02(.17)	2.00(.19)	10	10
	40	18-34	1.85(.29)	1.98(.20)	10	10
		55-64	1.87(.31)	1.96(.20)	10	10
		65-74	1.71(.27)	1.69(.42)	10	8
		75-82	1.82(.30)	1.58(.35)	10	10

Table A.6. Means and standard deviations of interpeak latencies in msec. contralaterally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
III-V+	20	18-34	2.25(.33)	1.85(.26)	8	8
		55-64	2.12(.41)	2.00(.64)	8	8
		65-74	1.99(.45)	1.85(.27)	6	4
		75-82	1.58(.32)	1.75(.29)	5	8

Table A.7. Means and standard deviations of interpeak latencies in msec. horizontally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
I^+-III	80	18-34	2.21(.12)	2.25(.16)	10	10
		55-64	2.32(.17)	2.24(.20)	10	10
		65-74	2.28(.22)	2.26(.17)	6	8
		75-82	2.53(.27)	2.07(.00)	3	2
	60	18-34	2.12(.13)	2.05(.17)	10	10
		55-64	2.22(.14)	2.17(.18)	10	10
		65-74	2.46(.13)	2.18(.12)	9	10
		75-82	2.23(.14)	2.32(.24)	8	10
	40	18-34	1.99(.06)	2.05(.30)	8	8
		55-64	1.83(.39)	1.65(.25)	7	7
		65-74	1.89(.39)	2.00(.42)	8	5
		75-82	1.98(.46)	1.91(.45)	5	9
I^--III	80	18-34	1.65(.15)	1.62(.24)	10	10
		55-64	1.68(.12)	1.61(.26)	10	10
		65-74	1.76(.24)	1.84(.16)	6	8
		75-82	1.59(.64)	1.59(.00)	5	2
	60	18-34	1.56(.19)	1.52(.12)	10	10
		55-64	1.72(.11)	1.57(.25)	10	10
		65-74	1.91(.17)	1.70(.11)	10	10
		75-82	1.67(.19)	1.77(.32)	10	10
	40	18-34	1.39(.32)	1.29(.33)	8	9
		55-64	1.24(.32)	1.15(.24)	7	9
		65-74	1.32(.37)	1.26(.42)	9	7
		75-82	1.29(.50)	1.36(.37)	9	10
	20	18-34	1.34(.24)	1.18(.33)	2	5
		55-64	1.32(.29)	1.17(.18)	6	3
		65-74	1.52(.58)	1.04(.24)	4	3
		75-82	1.51(.23)	1.28(.36)	3	5
I^+-V^+	80	18-34	3.93(.09)	3.92(.14)	8	7
		55-64	3.92(.11)	3.99(.12)	9	6
		65-74	4.06(.17)	3.97(.16)	6	8
		75-82	4.17(.34)	3.73(.11)	3	2
	60	18-34	3.75(.12)	3.84(.12)	9	6
		55-64	3.85(.14)	4.00(.22)	10	7
		65-74	4.17(.17)	3.90(.15)	9	7
		75-82	4.07(.23)	3.95(.22)	8	9
	40	18-34	3.70(.20)	3.67(.24)	8	7

Table A.7. Means and standard deviations of interpeak latencies in msec. horizontally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
		55-64	3.44(.38)	3.43(.26)	8	6
		65-74	3.51(.20)	3.57(.47)	8	3
		75-82	3.83(.71)	3.49(.37)	3	8
I^+-V^-	80	18-34	4.42(.14)	4.54(.21)	8	7
		55-64	4.50(.24)	4.54(.11)	9	6
		65-74	4.77(.21)	4.69(.30)	6	8
		75-82	4.52(.19)	4.20(.02)	3	2
	60	18-34	4.35(.09)	4.50(.18)	9	5
		55-64	4.49(.26)	4.52(.29)	10	7
		65-74	4.96(.15)	4.59(.42)	9	7
		75-82	4.82(.43)	4.56(.28)	8	9
	40	18-34	4.33(.26)	4.24(.29)	8	7
		55-64	4.18(.55)	4.07(.21)	8	6
		65-74	4.06(.27)	4.22(.44)	8	3
		75-82	4.38(.81)	4.12(.62)	3	8
I^--V^-	8-	18-34	3.83(.22)	3.98(.20)	8	7
		55-64	3.85(.21)	4.01(.16)	9	6
		65-74	4.25(.14)	4.16(.34)	6	8
		75-82	3.66(.52)	3.73(.01)	5	2
	60	18-34	3.78(.12)	3.93(.24)	9	5
		55-64	3.99(.25)	4.02(.36)	10	7
		65-74	4.36(.31)	4.09(.43)	10	7
		75-82	4.20(.46)	4.03(.39)	10	9
	40	18-34	3.73(.50)	3.39(.45)	8	8
		55-64	3.65(.61)	3.50(.23)	8	8
		65-74	3.57(.32)	3.47(.47	9	5
		75-82	3.51(.70)	3.53(.62)	6	9
	20	18-34	3.43(.28)	3.43(.28)	2	5
		55-64	4.33(.52)	4.00(1.16)	5	4
		65-74	3.97(.10)	3.85(.95)	4	4
		75-82	3.86(.28)	3.67(.36)	3	6
I^--V^+	80	18-34	3.34(.11)	3.35(.13)	8	7
		55-64	3.28(.10)	3.46(.17)	9	6
		65-74	3.53(.12)	3.45(.15)	6	8
		75-82	3.31(.64)	3.25(.10)	5	2
	60	18-34	3.18(.16)	3.27(.13)	9	5
		55-64	3.35(.17)	3.48(.26)	10	7

Table A.7. Means and standard deviations of interpeak latencies in msec. horizontally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
		65-74	3.60(.30)	3.39(.14)	10	7
		75-82	3.48(.29)	3.41(.31)	10	9
	40	18-34	3.10(.42)	2.84(.39)	8	8
		55-64	2.91(.47)	2.86(.25)	8	8
		65-74	2.94(.27)	2.78(.50)	9	5
		75-82	2.99(.63)	2.93(.31)	6	9
	20	18-34	2.81(.10)	2.85(.31)	2	5
		55-64	3.41(.41)	3.02(.68)	5	4
		65-74	3.15(.37)	2.88(.57)	4	4
		75-82	3.21(.17)	2.76(.22)	3	6
III-V$^-$	80	18-34	2.20(.13)	2.28(.26)	8	7
		55-64	2.17(.12)	2.22(.11)	9	6
		65-74	2.49(.32)	2.32(.24)	6	8
		75-82	2.07(.17)	2.13(.01)	5	2
	60	18-34	2.24(.10)	2.40(.30)	9	5
		55-64	2.27(.27)	2.35(.21)	10	7
		65-74	2.44(.29)	2.36(.38)	10	7
		75-82	2.52(.40)	2.26(.34)	10	9
	40	18-34	2.28(.29)	2.12(.29)	9	8
		55-64	2.21(.58)	2.42(.18)	7	9
		65-74	2.24(.38)	2.34(.25)	9	5
		75-82	2.25(.18)	2.11(.38)	6	9
	20	18-34	2.65(.62)	2.20(.18)	7	7
		55-64	3.07(.81)	2.36(.64)	4	4
		65-74	2.45(.68)	2.34(.55)	4	3
		75-82	2.35(.12)	2.54(.16)	2	4
III-V$^+$	80	18-34	1.71(.14)	1.66(.14)	8	7
		55-64	1.59(.10)	1.67(.14)	9	6
		65-74	1.77(.20)	1.61(.08)	6	8
		75-82	1.62(.19)	1.65(.10)	5	2
	60	18-34	1.64(.18)	1.74(.16)	9	5
		55-64	1.63(.13)	1.81(.18)	10	7
		65-74	1.68(.17)	1.67(.13)	10	7
		75-82	1.81(.25)	1.64(.09)	10	9
	40	18-34	1.68(.22)	1.57(.27)	9	8
		55-64	1.59(.46)	1.73(.16)	7	9
		65-74	1.61(.32)	1.66(.36)	9	5

Table A.7. Means and standard deviations of interpeak latencies in msec. horizontally recorded. Values are given separately for each age group and for males and females. (Standard deviations are given in parentheses.)

Waves	dB SL	Age Group	Mean and Standard Deviation		Number	
			Males	Females	M	F
		75-82	1.73(.22)	1.51(.21)	6	9
III-V+	20	18-34	1.99(.65)	1.61(.29)	7	7
		55-64	2.08(.69)	1.57(.31)	4	4
		65-74	1.62(.51)	1.56(.36)	4	3
		75-82	1.86(.37)	1.48(.19)	2	4

Table A.8. Results of two way analysis of of variance (age by sex) of absolute latencies. Asterisk indicates significant effects (p< .05). (d.f.: Sex = 1, Age = 3)

Waves	dB SL	Source of Variation	Significance of F		
			Ipsilateral	Contralateral	Horizontal
I+	80	sex	.699	.962	.496
		age	.003*	.019*	.010*
		age x sex	.005*	.599	.019*
I-	80	sex	.351	.064	.476
		age	.000*	.013*	.021*
		age x sex	.368	.411	.262
II	80	sex	.183	.030*	.161
		age	.032*	.018*	.006*
		age x sex	.793	.420	.140
III	80	sex	.115	.006*	.265
		age	.005*	.012*	.007*
		age x sex	.062	.300	.216
IV	80	sex	.504	.352	.236
		age	.538	.002*	.377
		age x sex	.453	.560	.134
V+	80	sex	.033*	.047*	.195
		sex	.024	.171	.011*
		age x sex	.031*	.196	.014
V-	80	sex	.003*	.006*	.780
		age	.310	.624	.002*
		age x sex	.764	.587	.066
I+	60	sex	.029*	.123	.060
		age	.827	.012*	.888
		age x sex	.394	.047*	.346
I-	60	sex	.387	.243	.080
		age	.885	.920	.932
		age x sex	.042*	.094	.185
II	60	sex	.120	.147	.308
		age	.156	.436	.238
		age x sex	.100	.122	.078
III	60	sex	.012*	.029*	.000*
		age	.005*	.314	.001*
		age x sex	.047*	.211	.000*
IV	60	sex	.000*	.000*	.013*
		age	.013*	.004*	.000*
		age x sex	.038*	.021*	.053
V+	60	sex	.001*	.018*	.021*

Table A.8. Results of two way analysis of of variance (age by sex) of absolute latencies. Asterisk indicates significant effects ($p < .05$). (d.f.: Sex = 1, Age = 3)

Waves	dB SL	Source of Variation	Significance of F		
			Ipsilateral	Contralateral	Horizontal
		age	.184	.187	.001*
		age x sex	.023*	.164	.000*
V⁻	60	sex	.001*	.285	.042*
		age	.739	.794	.006*
		age x sex	.257	.057	.053
I⁺	40	sex	.175	.425	.158
		age	.003*	.078	.100
		age x sex	.206	.378	.463
I⁻	40	sex	.075	.107	.576
		age	.018*	.001*	.222
		age x sex	.032*	.950	.951
II	40	sex	.109	.069	.293
		age	.134	.219	.064
		age x sex	.364	.476	.213
III	40	sex	.189	.044*	.529
		age	.132	.012*	.178
		age x sex	.762	.642	.912
IV	[illegible]	sex	.030*	.024*	.988
		age	.806	.819	.502
		age x sex	.975	.975	.036*
V⁺	40	sex	.002*	.007*	.255
		age	.370	.414	.489
		age x sex	.013	.343	.376
V⁻	40	sex	.002*	.238	.290
		age	.154	.059	.667
		age x sex	.882	.403	.418
I⁻	20	sex	.564	.539	.431
		age	.533	.101	.700
		age x sex	.649	.178	.420
III	20	sex	.291	.185	.089
		age	.019*	.020*	.093
		age x sex	.754	.820	.478
V⁺	20	sex	.010*	.004*	.046*
		age	.772	.684	.851
		age x sex	.669	.687	.432
V⁻	20	sex	.015*	.055	.257
		age	.362	.519	.490
		age x sex	.797	.323	.609

Table A.9. Results of two way analysis of of variance (age by sex) of interpeak latencies. Asterisk indicates significant effects (p< .05). (d.f.: Sex = 1, Age = 3)

Waves	dB SL	Source of Variation	Significance of F		
			Ipsilateral	Contralateral	Horizontal
I^+-III	80	sex	.233	.005*	.500
		age	.503	.123	.345
		age x sex	.155	.365	.038*
I^--III	80	sex	.339	.121	.866
		age	.023*	.290	.205
		age x sex	.747	.341	.875
I^+-V^+	80	sex	.073	.074	.254
		age	.184	.271	.404
		age x sex	.004*	.120	.025*
I^+-V^-	80	sex	.009*	.001*	.919
		age	.917	.421	.007*
		age x sex	.360	.858	.223
I^--V^-	80	sex	.015*	.033*	.350
		age	.169	.524	.002*
		age x sex	.979	.652	.622
I^--V^+	80	sex	.146	.596	.582
		age	.002*	.226	.153
		age x sex	.370	.498	.528
III-V	80	sex	.048*	.091	.977
		age	.771	.741	.014*
		age x sex	.895	.841	.371
III-V^+	80	sex	.404	.597	.374
		age	.096	.294	.559
		age x sex	.174	.957	.186
I^+-III	60	sex	.709	.860	.037*
		age	.004*	.052*	.000*
		age x sex	.587	.464	.015*
I^--III	60	sex	.077	.433	.101
		age	.004*	.374	.001*
		age x sex	.880	.048*	.082
I^+-V^+	60	sex	.214	.957	.306
		age	.247	.617	.001*
		age x sex	.611	.821	.007*
I^+-V^-	60	sex	.019*	.982	.103
		age	.790	.491	.001*
		age x sex	.715	.883	.058
I^--V^-	60	sex	.006*	.557	.342

Table A.9. Results of two way analysis of of variance (age by sex) of interpeak latencies. Asterisk indicates significant effects (p< .05). (d.f.: Sex = 1, Age = 3)

Waves	dB SL	Source of Variation	Significance of F		
			Ipsilateral	Contralateral	Horizontal
		age	.685	.726	.008*
		age x sex	.760	.029*	.331
I^--V^+	60	sex	.012*	.225	.714
		age	.119	.218	.008*
		age x sex	.362	.207	.188
III-V^-	60	sex	.022*	.706	.555
		age	.409	.413	.560
		age x sex	.837	.117	.207
III-V^+	60	sex	.212	.366	.741
		age	.286	.518	.815
		age x sex	.525	.840	.028*
I^+-III	40	sex	.538	.298	.834
		age	.599	.029*	.199
		age x sex	.785	.935	.694
I^--III	40	sex	.687	.956	.654
		age	.419	.443	.651
		age x sex	.142	.679	.891
I^+-V^+	40	sex	.043*	.053	.498
		age	.220	.240	.224
		age x sex	.153	.609	.594
I^+-V^-	40	sex	.041*	.073	.546
		age	.003*	.041*	.671
		age x sex	.948	.911	.787
I^--V^-	40	sex	.073	.909	.262
		age	.007*	.000*	.984
		age x sex	.542	.700	.794
I^--V^+	40	sex	.215	.474	.220
		age	.160	.035*	.861
		age x sex	.009*	.850	.871
III-V^-	40	sex	.013*	.536	.729
		age	.002*	.000*	.643
		age x sex	.958	.639	.230
III-V^+	40	sex	.036*	.889	.577
		age	.555	.025*	.924
		age x sex	.140	.215	.337
I^--III	20	sex	.095	.697	.066
		age	.080	.816	.790
		age x sex	.995	.391	.790

Table A.9. Results of two way analysis of of variance (age by sex) of interpeak latencies. Asterisk indicates significant effects (p< .05). (d.f.: Sex = 1, Age = 3)

Waves	dB SL	Source of Variation	Significance of F		
			Ipsilateral	Contralateral	Horizontal
I^{-}-V^{-}	20	sex	.027*	.101	.423
		age	.180	.356	.178
		age x sex	.956	.250	.963
I^{-}-V^{+}	20	sex	.004*	.033*	.060
		age	.712	.356	.436
		age x sex	.649	.132	.721
III-V^{-}	20	sex	.052	.828	.078
		age	.029*	.222	.591
		age x sex	.542	.726	.460
III-V^{+}	20	sex	.007*	.199	.042*
		age	.180	.082	.691
		age x sex	.446	.343	.827

Table A.10. Mean absolute latencies in msec. of waves and number of observations (n) by age group across sex. Asterisks (*) indicate significance of waves affected by age by recording montage.
(*: p< .05; **: p< .01; ***: p< .001)

					Age Group											
		Signif.			18-34			55-64			65-74			75-82		
Wave	dB SL	I	C	H	I	C	H	I	C	H	I	C	H	I	C	H
I^+	80	***	*	**	1.5 (20)	1.63 (15)	1.5 (20)	1.59 (20)	1.70 (9)	1.59 (20)	1.59 (13)	1.75 (11)	1.57 (14)	1.65 (6)	1.83 (6)	1.58 (5)
I^-		***	*	*	2.12 (20)	2.18 (20)	2.09 (20)	2.28 (20)	2.28 (20)	2.22 (20)	2.19 (20)	2.31 (20)	2.10 (14)	2.33 (20)	2.35 (20	2.37 (7)
II		*	*	**	2.64 (20)	2.74 (20)	2.48 (20)	2.80 (20)	2.90 (20)	2.66 (19)	2.72 (14)	2.86 (14)	2.55 (13)	2.83 (7)	2.91 (7)	2.69 (6)
III		**	*	**	3.63 (20)	3.57 (20)	3.73 (20)	3.77 (20)	3.69 (20)	3.88 (20)	3.79 (14)	3.74 (14)	3.91 (14)	3.78 (7)	3.69 (7)	3.96 (7)
IV			**		4.91 (20)	4.80 (20)	4.97 (15)	5.00 (20)	4.98 (20)	5.09 (15)	5.02 (14)	5.01 (14)	5.13 (14)	4.98 (7)	5.05 (7)	5.07 (6)
V^+		*		*	5.51 (20)	5.59 (20)	5.43 (15)	5.54 (20)	5.62 (20)	5.55 (15)	5.67 (14)	5.71 (14)	5.59 (14)	5.63 (7)	5.63 (7)	5.60 (7)
V^-				**	6.32 (20)	6.55 (20)	5.98 (15)	6.39 (20)	6.59 (20)	6.11 (15)	6.50 (14)	6.66 (14)	6.30 (14)	6.44 (7)	6.55 (7)	6.35 (7)
I^+	60		*		1.79 (20)	1.84 (16)	1.80 (20)	1.76 (20)	1.71 (14)	1.76 (20)	1.78 (19)	1.84 (12)	1.78 (19)	1.80 (19)	1.89 (12)	1.77 (18)
I^-					2.35 (20)	2.40 (20)	2.34 (20)	2.34 (20)	2.40 (20)	2.31 (20)	2.32 (20)	2.39 (20)	2.30 (20)	2.35 (20)	2.43 (20)	2.32 (20)
II					2.86 (20)	2.95 (20)	2.74 (20)	2.88 (20)	3.01 (20)	2.76 (20)	2.92 (20)	3.02 (20)	2.78 (20)	2.97 (20)	3.04 (20)	2.86 (20)
III		**		***	3.85 (20)	3.81 (20)	3.89 (20)	3.91 (20)	3.87 (20)	3.96 (20)	3.97 (20)	3.89 (20)	4.12 (20)	4.03 (20)	3.90 (20)	4.05 (20)
IV		**	**	***	5.10 (20)	5.02 (20)	5.15 (14)	5.11 (20)	5.06 (20)	5.16 (16)	5.30 (20)	5.24 (20)	5.44 (16)	5.16 (20)	5.16 (20)	5.17 (17)
V^+				***	5.75 (20)	5.82 (20)	5.58 (14)	5.79 (20)	5.85 (20)	5.69 (17)	5.87 (20)	5.95 (20)	5.85 (17)	5.84 (20)	5.91 (20)	5.79 (19)
V^-				**	6.67 (20)	7.04 (20)	6.19 (14)	6.58 (20)	6.93 (20)	6.29 (17)	6.72 (20)	6.93 (20)	6.58 (17)	6.66 (20)	6.89 (20)	6.45 (19)
I^+	40	**			2.55 (19)	2.62 (10)	2.59 (17)	2.67 (18)	2.64 (8)	2.75 (16)	2.95 (19)	2.93 (12)	2.89 (13)	2.74 (16)	2.72 (10)	2.79 (14)
I^-		*	**		3.12 (20)	2.97 (18)	3.24 (18)	3.20 (19)	3.20 (19)	3.32 (18)	3.51 (20)	3.56 (19)	3.50 (17)	3.27 (20)	3.27 (20)	3.43 (19)
II					3.53 (17)	3.61 (12)	3.43 (8)	3.65 (14)	3.73 (14)	3.50 (7)	3.92 (14)	3.90 (15)	3.99 (9)	3.72 (14)	3.80 (16)	3.78 (10)

Table A.10. Mean absolute latencies in msec. of waves and number of observations (n) by age group across sex. Asterisks (*) indicate significance of waves affected by age by recording montage. (*: $p < .05$; **: $p < .01$; ***: $p < .001$)

					Age Group											
		Signif.			18-34			55-64			65-74			75-82		
Wave	dB SL	I	C	H	I	C	H	I	C	H	I	C	H	I	C	H
III			*		4.51 (20)	4.43 (20)	4.62 (18)	4.57 (20)	4.52 (20)	4.57 (18)	4.78 (20)	4.85 (18)	4.83 (17)	4.72 (20)	4.78 (20)	4.76 (19)
IV					5.77 (15)	5.73 (18)	5.88 (9)	5.72 (18)	5.84 (19)	5.87 (7)	5.83 (17)	5.82 (17)	5.84 (11)	5.69 (17)	5.81 (17)	5.69 (10)
V^+					6.29 (20)	6.35 (20)	6.25 (17)	6.37 (20)	6.44 (20)	6.29 (18)	6.47 (20)	6.53 (19)	6.43 (14)	6.46 (20)	6.48 (20)	6.36 (15)
V^-					7.62 (20)	7.86 (20)	6.88 (17)	7.30 (20)	7.40 (20)	7.00 (18)	7.40 (20)	7.51 (19)	7.08 (14)	7.25 (20)	7.58 (20)	6.93 (15)
I^-	20				4.37 (13)	4.23 (15)	4.40 (7)	4.26 (15)	4.26 (16)	4.34 (11)	4.35 (12)	4.55 (10)	4.58 (10)	4.50 (17)	4.49 (14)	4.55 (11)
III		*	*		5.62 (18)	5.56 (16)	5.68 (15)	5.72 (17)	5.74 (17)	5.66 (10)	6.03 (13)	5.96 (10)	5.84 (8)	6.01 (14)	6.00 (13)	6.05 (9)
V^+					7.55 (20)	7.62 (20)	7.44 (17)	7.65 (20)	7.75 (19)	7.53 (15)	7.70 (18)	7.80 (18)	7.56 (12)	7.69 (20)	7.75 (18)	7.57 (11)
V^-					8.53 (20)	8.70 (20)	8.11 (17)	8.82 (20)	9.01 (19)	8.42 (15)	8.51 (18)	8.75 (18)	8.40 (12)	8.53 (20)	8.89 (18)	8.38 (11)

Table A.11. Mean interpeak latency values in msec., ipsilaterally recorded, by age group across sex. Asterisks (*) indicate IPLs significantly affected by age.
(*: p< .05; **: p< .01; ***: p< .001)

		Age Group			
Waves	dB SL	A	B	C	D
I^{+}-III	80	2.13 (20)	2.18 (20)	2.20 (13)	2.13 (6)
I^{-}-III*		1.51 (20)	1.49 (20)	1.59 (14)	1.45 (7)
I^{+}-V^{+}		4.01 (20)	3.95 (20)	4.08 (13)	4.00 (6)
$I^{=}$-V^{-}		4.82 (20)	4.80 (20)	4.83 (13)	4.81 (6)
I^{+}-V^{-}		4.21 (20)	4.11 (20)	4.30 (14)	4.11 (7)
I^{-}-V^{+}**		3.39 (20)	3.26 (20)	3.48 (14)	3.30 (7)
III-V^{-}		2.70 (20)	2,62 (20)	2.71 (14)	2.66 (7)
III-V^{+}		1.88 (20)	1.78 (20)	1.89 (14)	1.86 (7)
I^{+}-III**	60	2.06 (20)	2.15 (20)	2.21 (19)	2.24 (19)
I^{-}-III**		1.50 (20)	1.57 (20)	1.65 (20)	1.68 (20)
I^{+}-V^{+}		3.96 (20)	4.03 (20)	4.11 (19)	4.04 (19)
I^{+}-V^{-}		4.88 (20)	4.82 (20)	4.96 (19)	4.88 (19)
I^{-}-V^{-}		4.32 (20)	4.24 (20	4.40 (20)	4.30 (20)
I^{-}-V^{+}		3.40 (20)	3.44 (20)	3.55 (20)	3.48 (20)
II-V^{-}		2.82 (20)	2.67 (20)	2.75 (20)	2.62 (20)
III-V^{+}		1.90 (20)	1.88 (20)	1.90 (20)	1.80 (20)
I^{+}-III	40	1.96 (19)	1.89 (18)	1.84 (19)	1.97 (16)
I^{-}-III		1.39 (20)	1.35 (19)	1.28 (20)	1.44 (20)

Table A.11. Mean interpeak latency values in msec., ipsilaterally recorded, by age group across sex. Asterisks (*) indicate IPLs significantly affected by age. (*: p< .05; **: p< .01; ***: p< .001)

		Age Group			
Waves	dB SL	A	B	C	D
$I^{+}-V^{+}$		3.73 (19)	3.70 (18)	3.51 (19)	3.67 (16)
$I^{+}-V^{-}$**		5.09 (19)	4.65 (18)	4.42 (19)	4.45 (16)
$I^{-}-V^{-}$**		4.50 (20)	4.11 (19)	3.89 (20)	3.98 (20)
$I^{-}-V^{+}$		3.17 (20)	3.16 (19)	2.96 (20)	3.18 (20)
$III-V^{-}$**		3.11 (20)	2.73 (20)	2.61 (20)	2.54 (20)
$III-V^{+}$		1.78 (20)	1.80 (20)	1.69 (20)	1.74 (20)
$I^{+}-III$	20	-- --	-- --	-- --	-- --
$I^{-}-III$		1.19 (12)	1.43 (13)	1.71 (10)	1.48 (14)
$I^{+}-V^{+}$		-- --	-- --	-- --	-- --
$I^{+}-V^{-}$		-- --	-- --	-- --	-- --
$I^{-}-V^{-}$		4.04 (13)	4.50 (15)	4.08 (12)	3.93 (17)
$I^{-}-V^{+}$		3.09 (13)	3.33 (15)	3.28 (12)	3.13 (17)
$III-V^{-}$*		2.89 (18)	3.01 (17)	2.51 (13)	2.52 (14)
$III-V^{+}$		1.94 (18)	1.88 (17)	1.66 (13)	1.70 (14)

Table A.12. Mean interpeak latency values in msec., contralaterally recorded, by age group across sex. Asterisks (*) indicate IPLs significantly affected by age. (*: p< .05; **: p< .01; ***: p< .001)

		Age Group			
Waves	dB SL	A	B	C	D
I^+-III	80	1.93 (15)	1.92 (9)	2.01 (11)	1.84 (6)
I^--III		1.39 (20)	1.41 (20)	1.43 (14)	1.34 (7)
I^+-V^+		3.97 (15)	3,92 (9)	3.95 (11)	3.81 (6)
I^+-V^-		4.93 (15)	4.90 (9)	4.93 (11)	4.74 (6)
I^--V^-		4.37 (20)	4.31 (20)	4.35 (14)	4.20 (7)
I^--V^+		3.41 (20)	3.33 (20)	3.41 (14)	3.28 (7)
III-V^-		2.98 (20)	2.91 (20)	2.92 (14)	2.86 (7)
III-V^+		2.02 (20)	1.93 (20)	1.98 (14)	1.94 (7)
I^+-III*	60	1.95 (16)	2.11 (14)	2.04 (12)	2.02 (12)
I^--III		1.42 (20)	1.46 (20)	1.50 (20)	1.47 (20)
I^+-V^+		3.98 (16)	4.08 (14)	4.06 (12)	4.02 (12)
I^+-V^-		5.12 (16)	5.24 (14)	5.01 (12)	4.94 (12)
I^--V^-		4.64 (20)	4.53 (20)	4.54 (20)	4.46 (20)
I^--V^+		3.42 (20)	3.45 (20)	3.56 (20)	3.48 (20)
III-V^-		3.22 (20)	3.07 (20)	3.03 (20)	2.99 (20)
III-V^+		2.01 (20)	1.99 (20)	2.06 (20)	2.01 (20)
I^+-III*	40	1.84 (10)	1.87 (8)	1.86 (12)	2.23 (10)
I^--III		1.41 (18)	1.33 (19)	1.35 (18)	1.50 (20)

Table A.12. Mean interpeak latency values in msec., contralaterally recorded, by age group across sex. Asterisks (*) indicate IPLs significantly affected by age. (*: p< .05; **: p< .01; ***: p< .001)

		Age Group			
Waves	dB SL	A	B	C	D
I^+-V^+		3.74 (10)	3.83 (8)	3.54 (12)	3.78 (10)
I^+-V^-*		5.21 (10)	4.74 (8)	4.52 (12)	4.93 (10)
I^--V^-***		4.94 (18)	4.21 (19)	3.95 (19)	4.31 (20)
I^--V^+*		3.36 (18)	3.25 (19)	2.97 (19)	3.21 (20)
$III-V^-$***		3.43 (20)	2.87 (20)	2.69 (18)	2.80 (20)
$III-V^+$*		1.92 (20)	1.92 (20)	1.70 (18)	1.71 (20)
I^--III	20	1.33 (13)	1.48 (14)	1.39 (7)	1.43 (13)
I^--V^-		4.44 (15)	4.69 (15)	4.23 (10)	4.19 (14)
I^--V^+		3.39 (15)	3.51 (15)	3.26 (10)	3.12 (14)
$III-V^-$		3.09 (16)	3.31 (16)	3.04 (10)	2.81 (13)
$III-V^+$		2.05 (16)	2.07 (16)	1.94 (10)	1.69 (13)

Table A.13. Mean interpeak latency values in msec., horizontally recorded, by age group across sex. Asterisks (*) indicate IPLs significantly affected by age.
(*: p< .05; **: p< .01; ***: p< .001)

		Age Group			
Waves	dB SL	A	B	C	D
I^{+}-III	80	2.23	2.28	2.33	2.35
		(20)	(20)	(14)	(5)
I^{-}-III		1.64	1.65	1.81	1.59
		(20)	(20)	(14	(7)
I^{+}-V^{+}		3.93	3.95	4.02	4.00
		(15)	(15)	(14)	(5)
I^{+}-V^{-}**		4.48	4.52	4.73	4.40
		(15)	(15)	(14)	(5)
I_-V^{-}**		3.90	3.92	4.20	3.68
		(15)	(15)	(14)	(7)
I^{-}-V^{+}		3.35	3.35	3.49	3.23
		(15)	(15)	(14)	(7)
III-V^{-}*		2.24	2.19	2.39	2.09
		(15)	(15)	(14)	(7)
III-V^{+}		1.69	1.63	1.68	1.64
		(15)	(15)	(14)	(7)
I^{+}-III***	60	2.09	2.20	2.32	2.28
		(20)	(20)	(19)	(18)
I^{-}-III***		1.54	1.65	1.81	1.73
		(20)	(20)	(20)	(20)
I^{+}-V^{+}***		3.79	3.92	4.05	4.01
		(14)	(17)	(16)	(17)
I^{+}-V^{-}***		4.41	4.51	4.80	4.69
		(14)	(17)	(16)	(17)
I^{-}-V^{-}**		3.83	4.01	4.26	4.12
		(14)	(17)	(17)	(19)
I^{-}-V^{+}**		3.22	3.41	3.52	3.46
		(14)	(17)	(17)	(19)
III-V^{-}		2.30	2.30	2.42	2.40
		(14)	(17)	(17)	(19)
III-V^{+}		1.68	1.71	1.68	1.73
		(14)	(17)	(17)	(19)
I^{+}-III	40	2.03	1.74	1.94	1.94
		(16)	(14)	(13)	(14)
I^{-}-III		1.34	1.19	1.30	1.33
		(17)	(16)	(16)	(19)

Table A.13. Mean interpeak latency values in msec., horizontally recorded, by age group across sex. Asterisks (*) indicate IPLs significantly affected by age. (*: p< .Ø5; **: p< .Ø1; ***: p< .ØØ1)

		Age Group			
Waves	dB SL	A	B	C	D
I^+-V^+		3.69 (15)	3.44 (14)	3.53 (11)	3.58 (11)
I^+-V^-		4.29 (15)	4.14 (14)	4.11 (11)	4.19 (11)
I^--V^-		3.56 (16)	3.58 (16)	3.54 (14)	3.52 (15)
I^--V^+		2.98 (16)	2.89 (16)	2.89 (14)	2.96 (15)
$III-V^-$		2.26 (17)	2.33 (16)	2.28 (14)	2.17 (15)
$III-V^+$		1.63 (17)	1.67 (16)	1.64 (14)	1.6Ø (15)
I^--III	2Ø	1.23 (7)	1.27 (9)	1.32 (7)	1.37 (8)
I^--V^-		3.44 (7)	4.19 (9)	3.91 (8)	3.74 (9)
I^--V^+		2.84 (7)	3.24 (9)	3.Ø2 (8)	2.92 (9)
$III-V^-$		2.43 (14)	2.72 (8)	2.41 (7)	2.48 (6)
$III-V^+$		1.8Ø (14)	1.83 (8)	1.6Ø (7)	1.61 (6)

Table A.14. Mean absolute latency values in msec.
for males and females across age.
Asterisks (*) indicate absolute latencies
significantly affected by sex.
(*: p< .05; **: p< .01; ***: p < .001)

		Ipsilateral		Contralateral		Horizontal	
Waves	dB SL	M	F	M	F	M	F
I^+	80	1.57	1.56	1.71	1.70	1.56	1.55
		(29)	(30)	(22)	(19)	(29)	(30)
I^-		2.23	2.19	2.30	2.23	2.20	2.14
		(31)	(30)	(31)	(30)	(31)	(30)
II		2.77	2.70	2.89	2.79	2.61	2.54
		(31)	(30)	(31)	(30)	(31)	(28)
III		3.76	3.70	3.71	3.61**	3.87	3.82
		(31)	(30)	(31)	(30)	(31)	(30)
IV		4.99	4.95	4.96	4.91	5.10	5.02
		(31)	(30)	(31)	(30)	(27)	(23)
V^+		5.62	5.53*	5.67	5.59*	5.55	5.50
		(31)	(30)	(31)	(30)	(28)	(23)
V^-		6.50	6.29**	6.70	6.47	6.11	6.12
		(31)	(30)	(31)	(30)	(28)	(23)
I^+	60	1.82	1.74*	1.85	1.78	1.81	1.75
		(39)	(39)	(25)	(29)	(37)	(40)
I^-		2.26	2.33	2.43	2.48	2.36	2.28
		(40)	(40)	(40)	(40)	(40)	(40)
II		2.93	2.88	3.04	2.97	2.81	2.77
		(40)	(40)	(40)	(40)	(40	(40)
III		3.99	3.89*	3.91	3.83*	4.08	3.93***
		(40)	(40)	(40)	(40)	40	(40)
IV		5.26	5.08**	5.21	5.02***	5.28	5.16*
		(40)	(40)	(40)	(40)	(36)	(27)
V^+		5.88	5.74***	5.94	5.83*	5.77	5.68*
		(40)	(40)	(40)	(40)	(39)	(28)
V^-		6.80	6.51***	7.00	6.89	6.46	6.30*
		(40)	(40)	(40)	(40)	(39)	(28)
I^+	40	2.77	2.68	2.77	2.70	2.80	2.68
		(36)	(36)	(23)	(17)	(31)	(29)
I^-		3.35	3.19	3.33	3.17	3.40	3.34
		(40)	(39)	(39)	(37)	(36)	(30)
II		3.79	3.60	3.85	3.68	3.78	3.61
		(30)	(29)	(29)	(28)	(17)	(17)
III		4.70	4.58	4.74	4.53*	4.73	4.66
		(40)	(40)	(40)	(38)	(35)	(37)

Table A.14. Mean absolute latency values in msec. for males and females across age. Asterisks (*) indicate absolute latencies significantly affected by sex. (*: p< .05; **: p< .01; ***: p < .001)

		Ipsilateral		Contralateral		Horizontal	
Waves	dB SL	M	F	M	F	M	F
IV		5.85	5.64*	5.90	5.68*	5.84	5.79
		(36)	(31)	(38)	(33)	(18)	(19)
V+		6.52	6.27**	6.56	6.34**	6.38	6.28
		(40)	(40)	(40)	(39)	(33)	(31)
V−		7.59	7.20**	7.66	7.51	7.03	6.90
		(40)	(40)	(40)	(39)	(33)	(31)
		(26)	(31)	(26)	(29)		
		(26)	(31)	(26)	(29)	(17)	(22)
III		5.87	5.78	5.85	5.72	5.87	5.69
		(28)	(34)	(28)	(28)	(22)	(22)
V+		7.80	7.49**	7.90	7.56**	7.65	7.39*
		(39)	(39)	(37)	(38)	(27)	(27)
V−		8.78	8.42**	9.00	8.68*	8.41	8.22
		(39)	(39)	(37)	(38)	(27)	(27)

Table A.15. Mean interpeak latency values in msec. for males and females across age. Asterisks (*) indicate interpeak latencies significantly affected by age. (*: p< .05; **: p< .01; ***: p < .001)

		Ipsilateral		Contralateral		Horizontal	
Waves	dB SL	M	F	M	F	M	F
I^{+}-III	80	2.18 (29)	2.14 (30)	2.00 (22)	1.86** (19)	2.30 (29)	2.27 (30)
I^{-}-III		1.52 (31)	1.51 (30)	1.42 (31)	1.38 (30)	1.68 (30)	1.68 (30)
I^{+}-V^{+}		4.04 (29)	3.97 (30)	3.97 (22)	3.88 (19)	3.99 (26)	3.94 (23)
I^{+}-V^{-}		4.91 (29)	4.73** (30)	5.08 (22)	4.69*** (19)	4.54 (26)	4.57 (23)
$I^{-}V^{-}$		4.27 (31)	4.10** (30)	4.41 (31)	4.24* (30)	3.90 (28)	4.03 (23)
I^{-}-V^{+}		3.38 (31)	3.34 (30)	3.38 (31)	3.36 (30)	3.34 (28)	3.41 (23)
III-V^{-}		2.75 (31)	2.59* (30)	2.99 (31)	2.86 (30)	2.23 (28)	2.27 (23)
II-V^{+}		1.86 (31)	1.83 (30)	1.96 (31)	1.98 (30)	1.67 (28)	1.65 (23)
I^{+}-III	60	2.17 (39)	2.16 (39)	2.01 (25)	2.04 (29)	2.26 (37)	2.18* (40)
I^{-}-III		1.63 (40)	1.57 (40)	1.48 (40)	1.45 (40)	1.72 (40)	1.65 (40)
I^{+}-V^{+}		4.07 (39)	4.00 (39)	4.03 (25)	4.04 (29)	3.96 (36)	3.93 (28)
I^{+}-V^{-}		5.00 (39)	4.77 (39)	5.08 (25)	5.09 (29)	4.65 (36)	4.56 (28)
I^{-}-V^{-}		4.45 (40)	4.18** (40)	4.57 (40)	4.51 (40)	4.09 (39)	4.03 (28)
I^{-}-V^{+}		3.53 (40)	3.41* (40)	3.51 (40)	3.45 (40)	3.41 (39)	3.40 (38)
III-V^{-}		2.82 (40)	2.61* (40)	3.10 (40)	3.06 (40)	2.38 (39)	2.34 (28)
III-V^{+}		1.90 (40)	1.84 (40)	2.03 (40)	2.00 (40)	1.70 (39)	1.71 (28)
I^{+}-III	40	1.94 (36)	1.89 (36)	1.98 (23)	1.90 (17)	1.92 (28)	1.91 (29)
I^{-}-III		1.35 (40)	1.38 (39)	1.40 (39)	1.41 (36)	1.32 (33)	1.27 (35)

Table A.15. Mean interpeak latency values in msec. for males and females across age. Asterisks (*) indicate interpeak latencies significantly affected by age. (*: p< .Ø5; **: p< .Ø1; ***: p < .ØØ1)

		Ipsilateral		Contralateral		Horizontal	
Waves	dB SL	M	F	M	F	M	F
I^+-V^+		3.74 (36)	3.57* (36)	3.8Ø (23)	3.58 (17)	3.59 (27)	3.54 (24)
I^+-V^-		4.81 (36)	4.51* (36)	4.99 (23)	4.64 (17)	4.22 (27)	4.16 (24)
I^--V^-		4.24 (39)	4.ØØ (39)	4.33 (39)	4.36 (37)	3.62 (31)	3.48 (3Ø)
I^--V^+		3.17 (4Ø)	3.Ø7 (39)	3.22 (39)	3.16 (37)	2.99 (31)	2.87 (3Ø)
$III-V^-$		2.89 (4Ø)	2.61* (4Ø)	2.92 (4Ø)	3.ØØ (38)	2.28 (31)	2.24 (31)
$III-V^+$		1.82 (4Ø)	1.69* (4Ø)	1.82 (4Ø)	1.81 (38)	1.66 (31)	1.62 (31)
I^--III	2Ø	1.58 (22)	1.33 (27)	1.44 (24)	1.39 (23)	1.42 (15)	1.19 (16)
I^--V^-		4.38 (26)	3.93* (31)	4.61 (25)	4.23 (29)	4.ØØ (14)	3.72 (19)
I^--V^+		3.43 (26)	3.Ø1** (31)	3.51 (29)	3.17* (29)	3.21 (14)	2.87 (19)
$III-V^-$		2.92 (28)	2.62 (34)	3.Ø7 (27)	3.Ø9 (28)	2.67 (17)	2.34 (18)
$III-V^+$		1.97 (28)	1.68** (34)	2.Ø4 (27)	1.87 (28)	1.91 (17)	1.57* (18)

Table A.16. Results of two way analysis of variance (age by sex) on amplitude ratio of waves V:I. Asterisks (*) identify amplitude ratios significantly affected by age. (d.f. for Sex = 1)

		Significance of F		
dB SL	Source of Variation	Ipsilat'l	Contralat'l	Horizont'l
8Ø	Age	Ø.442	Ø.861	Ø.639
	sex	Ø.5Ø1	Ø.291	Ø.348
	age x sex	Ø.5Ø5	Ø.3Ø1	Ø.356
6Ø	age	Ø.25Ø	Ø.569	Ø.836
	sex	Ø.Ø43	Ø.164	Ø.469
	age x sex	Ø.419	Ø.Ø7Ø	Ø.11Ø
4Ø	age	Ø.313	Ø.121	Ø.5Ø2
	sex	Ø.615	Ø.542	Ø.498
	age x sex	Ø.639	Ø.Ø27	Ø.319

Table A.17. Main effect results of four way analysis of variance for amplitudes of waves I and V. Asterisk indicates significant main effects at $p < .05$.

Source	D.F.	Significance of F
sex	1	Ø.5249
age	3	Ø.Ø2Ø5*
intensity	1	Ø.ØØØ*
wave	1	Ø.ØØØ*

Table A.18. Results of four way repeated measures analysis (age by sex by intensity by montage). Results of main effects only are reported. Asterisk indicates significant main effect at $p < .Ø5$.

Wave	Source of Variation	D.F.	Significance
I^-	sex	1	Ø.Ø61
	age	3	Ø.Ø16*
	intensity	1	< Ø.ØØ1*
	montage	1	Ø.Ø61
III	sex	1	Ø.Ø33*
	age	3	Ø.Ø24*
	intensity	1	< Ø.ØØ1*
	montage	1	< Ø.ØØ1*
V^+	sex	1	Ø.ØØ2*
	age	3	Ø.2Ø1
	intensity	1	< Ø.ØØ1*
	montage	1	< Ø.ØØ1*
V^-	sex	1	Ø.ØØ4*
	age	3	Ø.16Ø*
	intensity	1	< Ø.ØØ1*
	montage	1	< Ø.ØØ1*
I^--III	sex	1	> Ø.5ØØ
	age	3	Ø.211
	intensity	1	< Ø.ØØ1*
	montage	1	Ø.ØØ2*
I^--V^-	sex	1	Ø.Ø54
	age	3	Ø.ØØ4*
	intensity	1	Ø.ØØ5*
	montage	1	< Ø.ØØ1*
I^--V^+	sex	1	Ø.Ø39*
	age	3	> Ø.5ØØ
	intensity	1	< Ø.ØØ1*
	montage	1	Ø.Ø65
III-V^-	sex	1	Ø.Ø96
	age	3	< Ø.ØØ1*
	intensity	1	Ø.414
	montage	1	< Ø.ØØ1*
III-V^+	sex	1	Ø.135
	age	3	Ø.269
	intensity	1	< Ø.ØØ1*
	montage	1	< Ø.ØØ1*

Table A.19. Mean Absolute Latencies in msec. for males and females: four age groups, repeated measures design.

			Age Group							
			18-34		55-64		65-74		75-82	
Montage	dB SL	Wave	M	F	M	F	M	F	M	F
Ipsi.	60	I^-	2.33	2.36	2.37	2.31	2.40	2.23	2.31	2.39
		III	3.84	3.85	3.97	3.84	4.09	3.84	4.03	4.03
		V^+	5.75	5.75	5.84	5.73	6.05	5.69	5.89	5.78
		V^-	6.71	6.62	6.74	6.41	7.00	6.43	6.75	6.56
	40	I^-	3.20	3.04	3.34	3.10	3.74	3.27	3.14	3.40
		III	4.56	4.45	4.56	4.48	4.89	4.68	4.69	4.74
		V^+	6.39	6.19	6.43	6.31	6.66	6.28	6.60	6.30
		V^-	7.84	7.40	7.50	7.13	7.66	7.13	7.39	7.12
Contr.	60	I^-	2.41	2.48	2.47	2.34	2.47	2.31	2.37	2.49
		III	3.80	3.82	3.90	3.83	3.99	3.80	3.93	3.87
		V^+	5.82	5.82	5.90	5.81	6.10	5.81	5.95	5.97
		V^-	6.87	7.21	6.95	6.92	7.10	6.75	7.10	6.67
	40	I^-	3.07	2.99	3.26	3.15	3.68	3.45	3.34	3.20
		III	4.58	4.28	4.60	4.44	5.00	4.63	4.79	4.77
		V^+	6.43	6.26	6.47	6.41	6.72	6.36	6.61	6.35
		V^-	7.85	7.86	7.47	7.32	7.75	7.25	7.26	7.60

Table A.2Ø. Results of four way repeated measures analysis (age by sex by intensity by montage) for number of waves missing.
Results of main effects only are reported.
Asterisk indicates significant main effect at p< .Ø5.

Wave	Source of Variation	D.F.	Significance
I^+	sex	1	Ø.874
	age	3	Ø.ØØØ*
	montage	2	Ø.ØØØ*
	intensity	2	Ø.ØØØ*
I^-	sex	1	Ø.Ø71
	age	3	Ø.Ø11*
	montage	2	Ø.ØØØ*
	intensity	2	Ø.ØØØ*
II	sex	1	Ø.468
	age	3	Ø.998
	montage	2	Ø.ØØØ*
	intensity	2	Ø.ØØØ*
III	sex	1	Ø.157
	age	3	Ø.ØØØ*
	montage	2	Ø.ØØØ*
	intensity	2	Ø.ØØØ*
IV	sex	1	Ø.ØØØ*
	age	3	Ø.1Ø3
	montage	2	Ø.ØØØ*
	intensity	2	Ø.ØØØ*
V^+	sex	1	Ø.477
	age	3	Ø.ØØØ*
	montage	2	Ø.ØØØ*
	intensity	2	Ø.ØØØ*

APPENDIX B--FIGURES

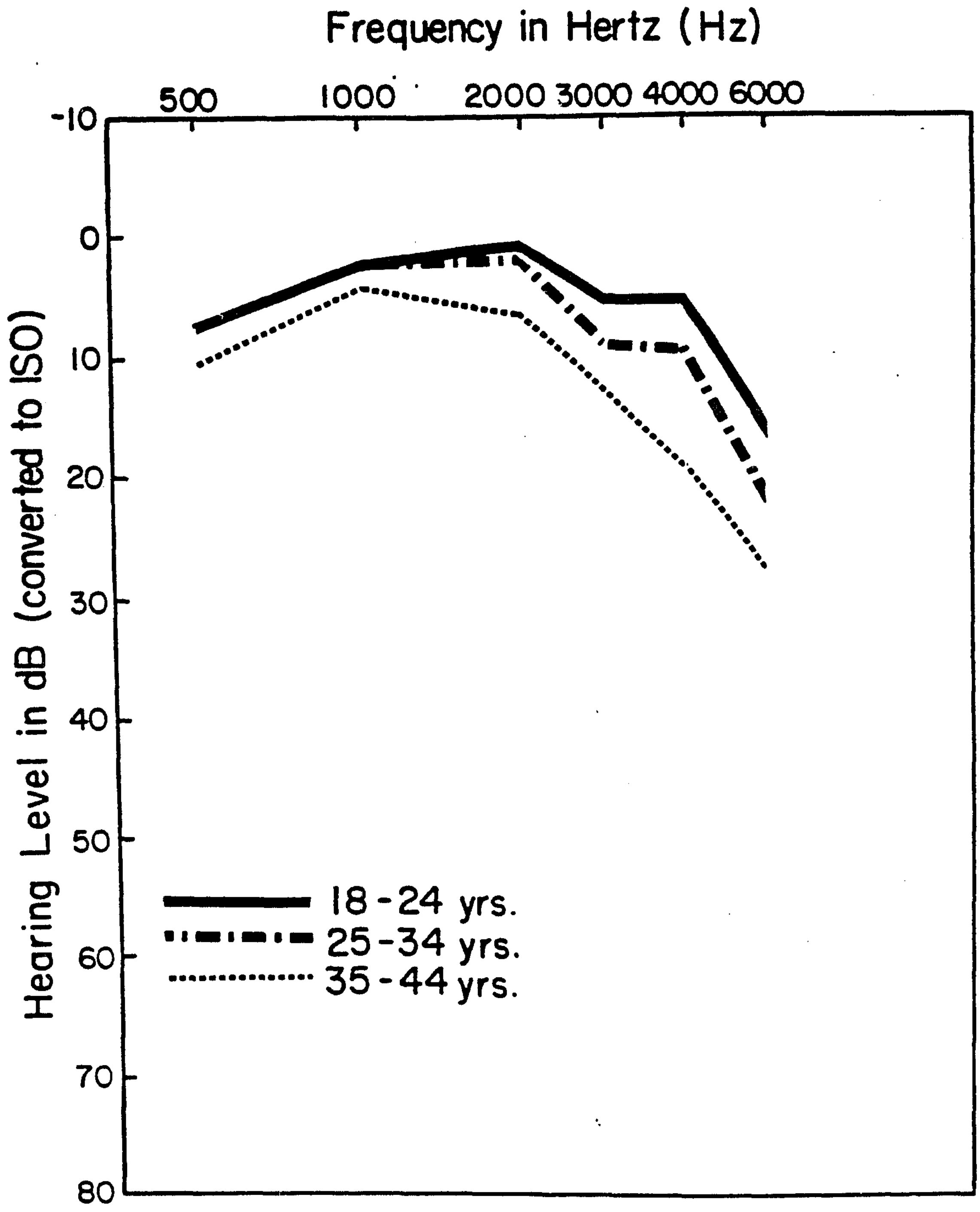

Figure B.1. Median hearing levels of better hearing ear (in dB) of men aged 18-44. United States National Health Survey, 1960. Source: US DHEW, 1963.

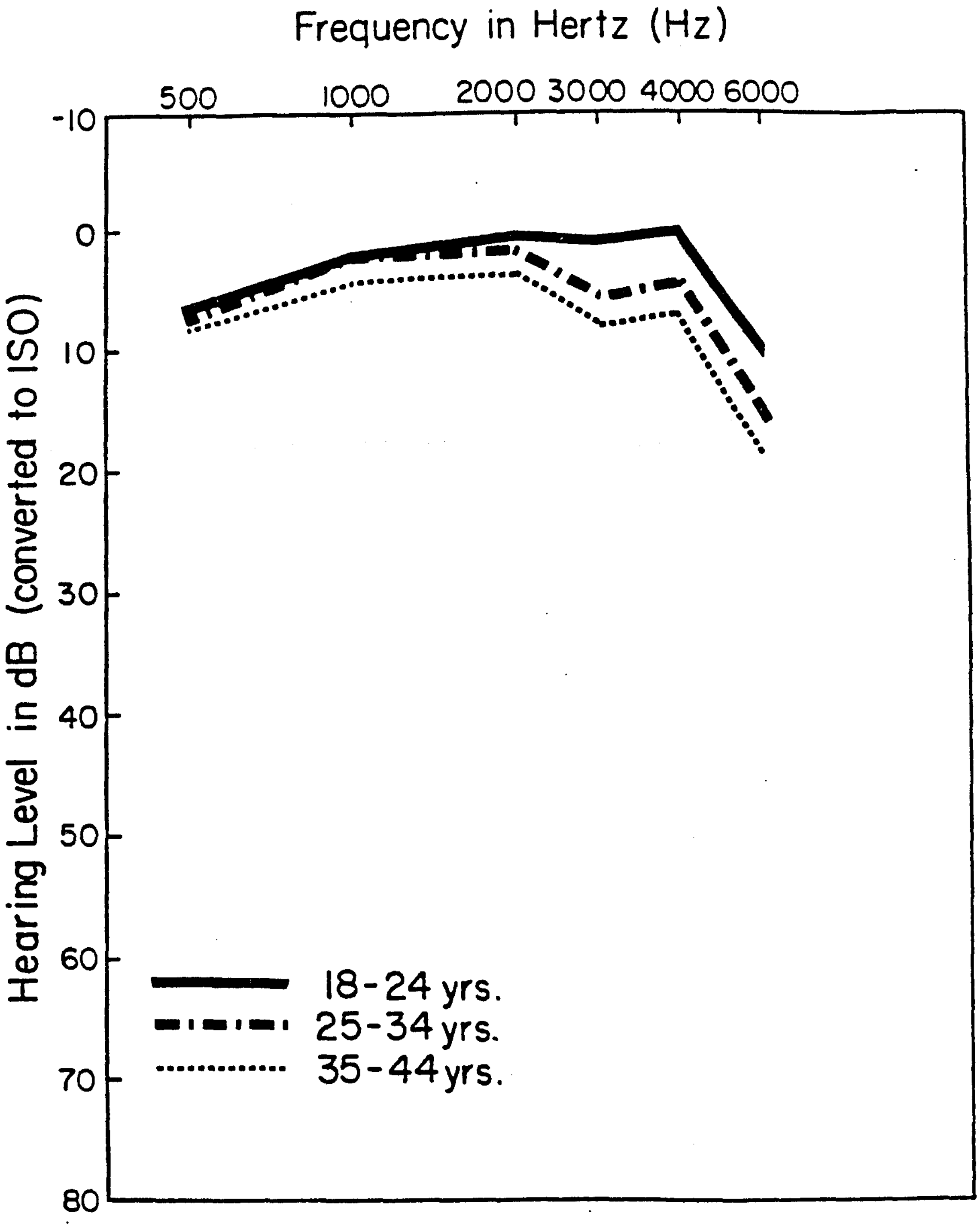

Figure B.2. Median hearing levels of better hearing ear (in dB) of women aged 18-44. United States National Health Survey, 1960. Source: US DHEW, 1963.

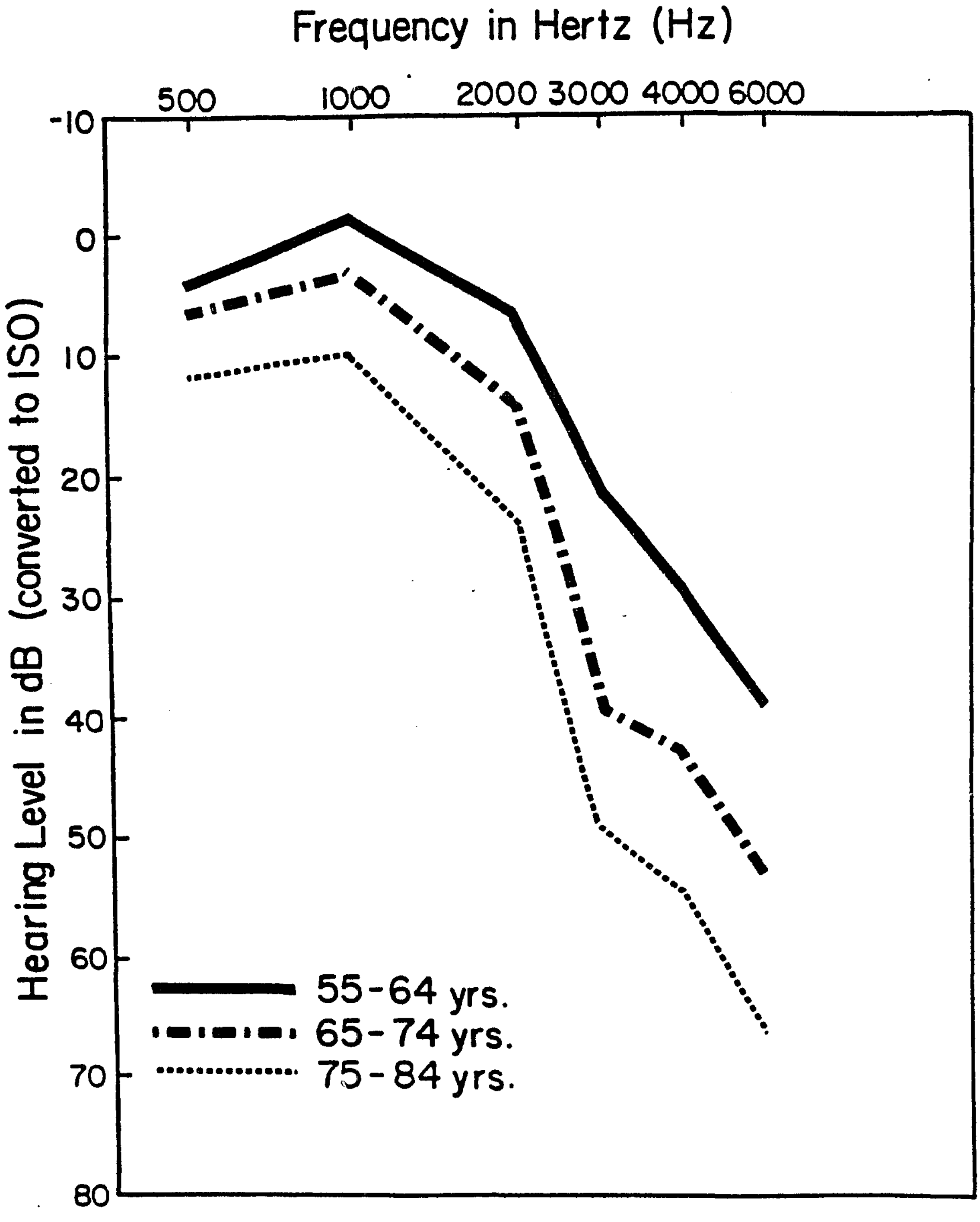

Figure B.3. Median hearing levels of better hearing ear (in dB) of men aged 55-84. United States National Health Survey, 1960. Source: US DHEW, 1963.

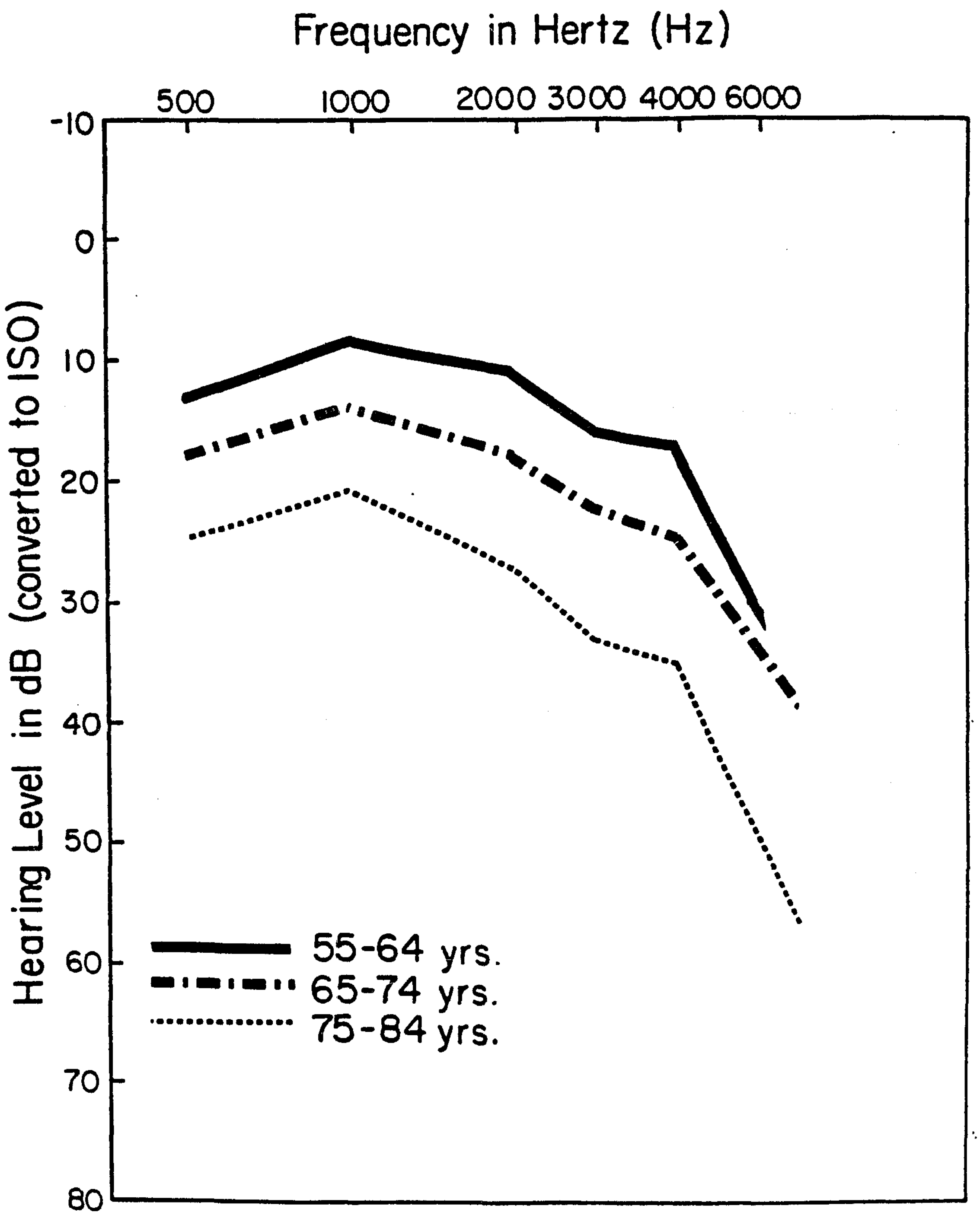

Figure B.4. Median hearing levels of better hearing ear (in dB) of women aged 55-84. United States National Health Survey, 1960. Source: US DHEW, 1963.

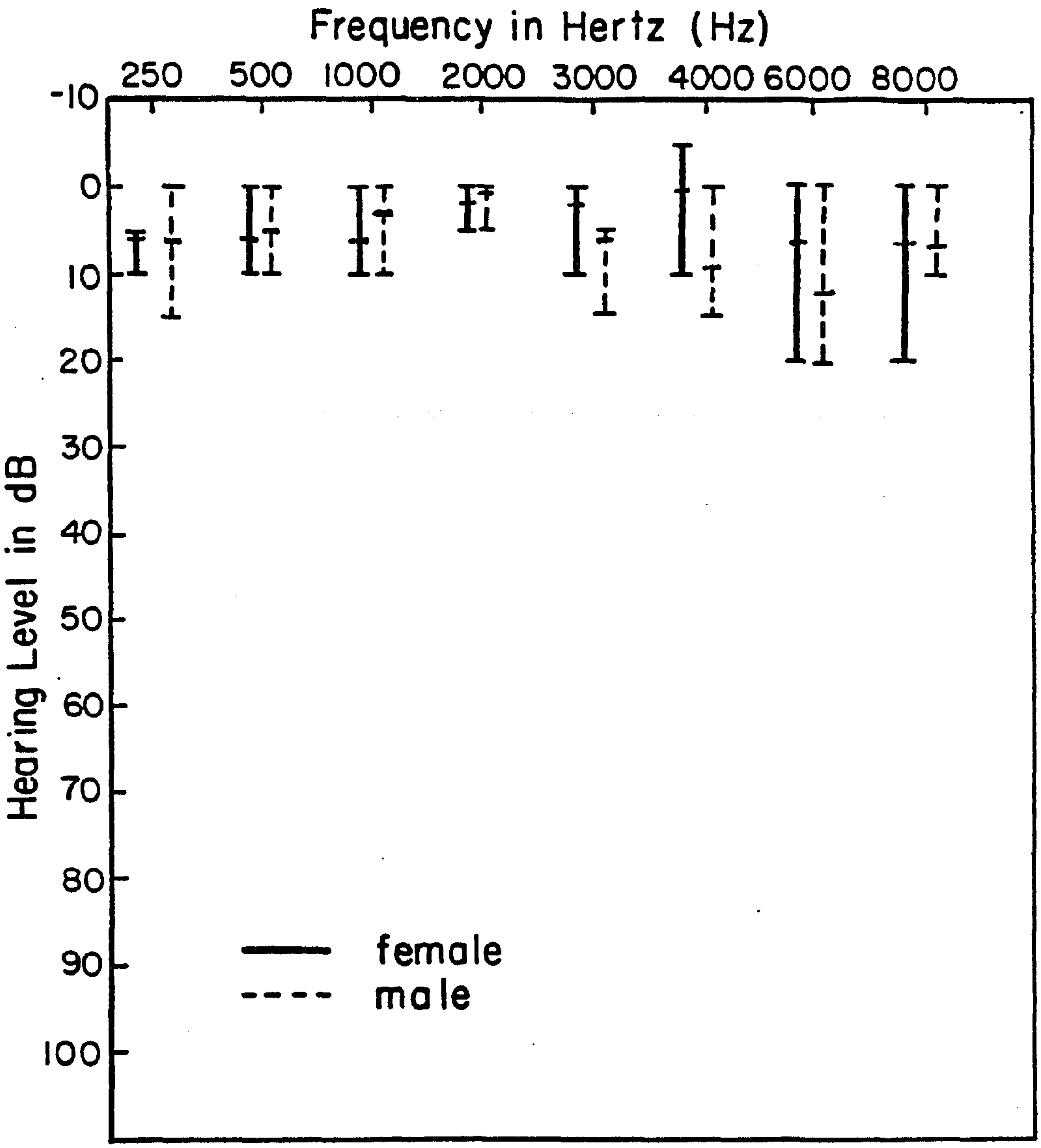

Figure B.5. Range of pure tone hearing of male and female subjects in the present study, aged 18-34, n= 20. Mid-range tics indicate pure tone means.

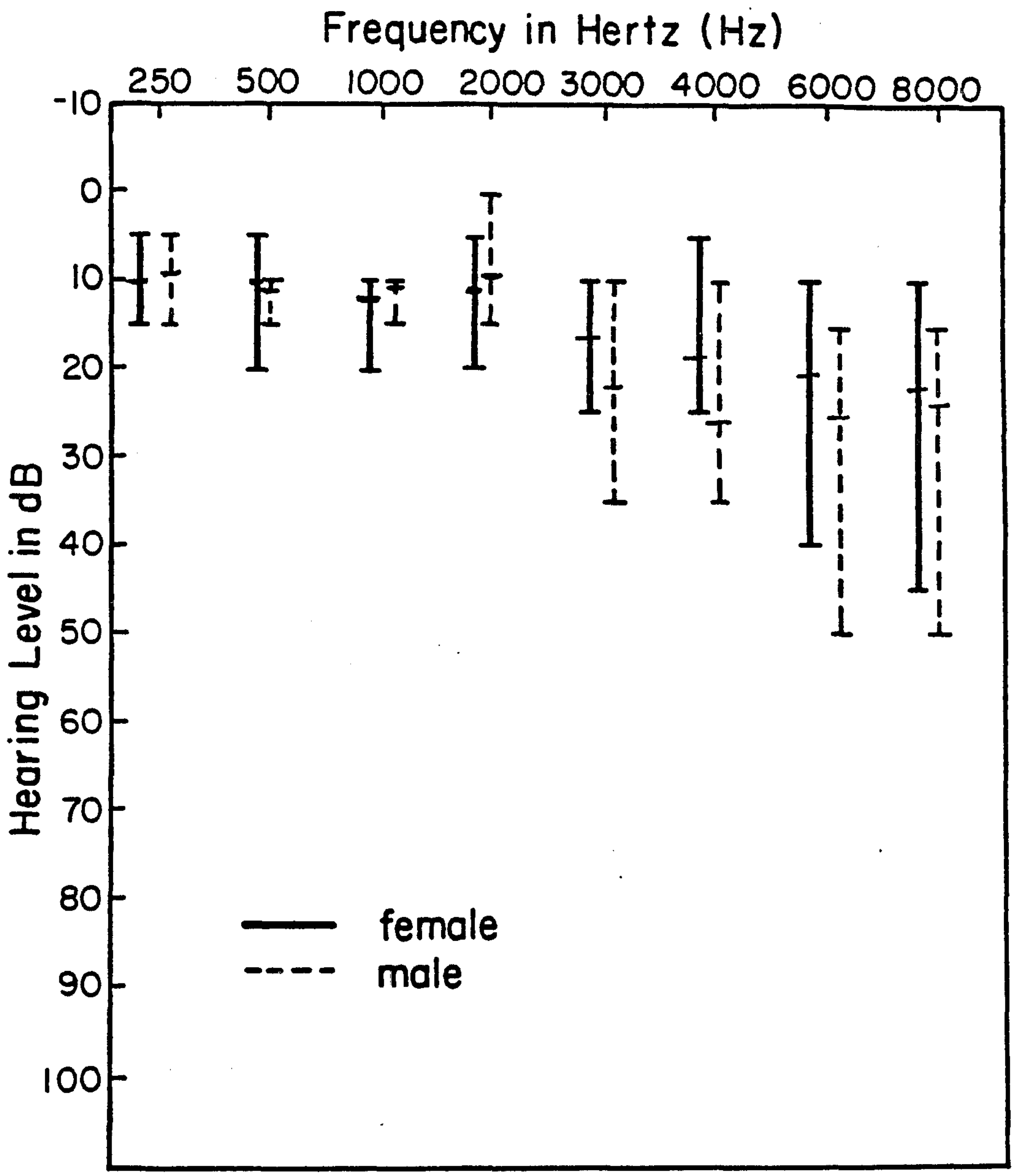

Figure B.6. Range of pure tone hearing of male and female subjects in the present study, aged 55-64, n= 20. Mid-range tics indicate pure tone means.

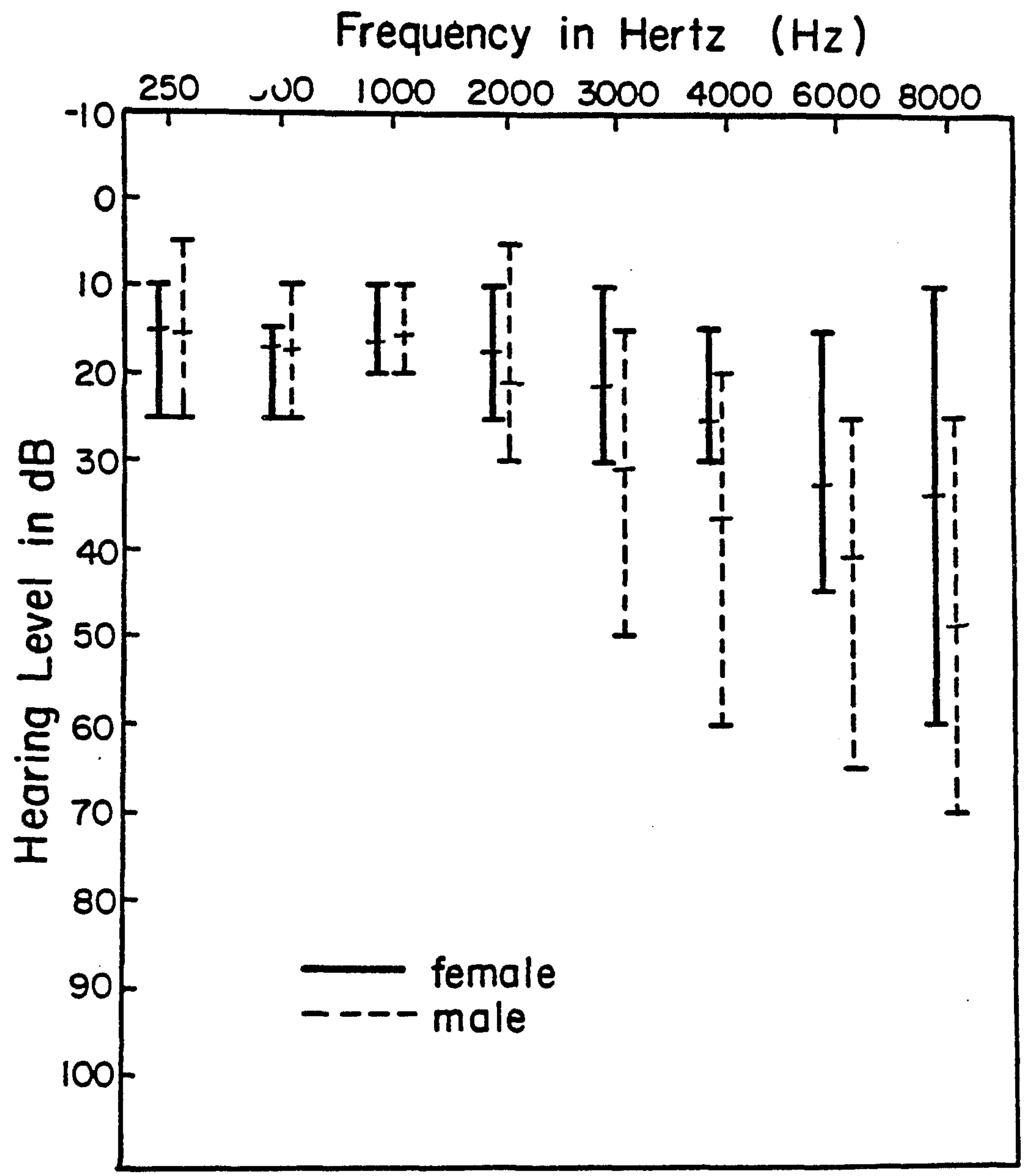

Figure B.7. Range of pure tone hearing of male and female subjects in the present study, aged 65-74, n=20. Mid-range tics indicate pure tone means.

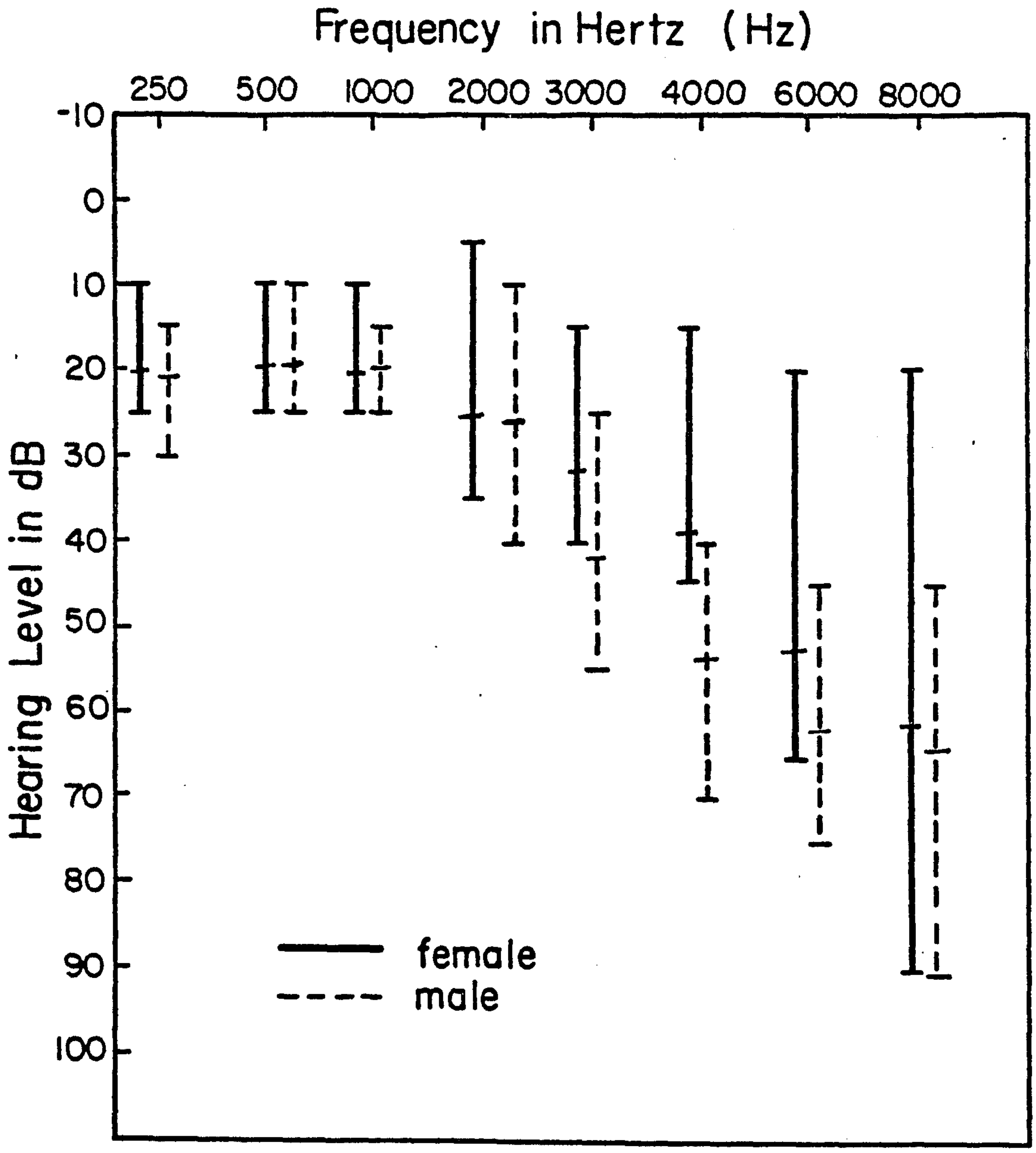

Figure B.8. Range of pure tone hearing of male and female subjects in the present study, aged 75-82, n= 20. Mid-range tics indicate pure tone means.

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