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AN APPROACH TO PREDICTION OF LOUDNESS DISCOMFORT LEVELS USING THE FREQUENCY-SPECIFIC AUDITORY BRAINSTEM RESPONSE

A THESIS IN OTOLARYNGOLOGY

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ABSTRACT

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AN APPROACH TO PREDICTION OF LDLS USING THE FREQUENCY-SPECIFIC AUDITORY BRAINSTEM RESPONSE

by Dr. M. Bülent Şerbetcioğlu

This experiment was designed to establish an electrophysiological option for the measurement of Loudness Discomfort Level. One of the methods proposed for LDL estimation using the auditory brainstem response (ABR) relies on the click response parameters. In the present study, using frequency-specific ABR, an attempt was made to predict the LDL of the subjects. Frequency-specificity in the ABR was reviewed according to recent literature where it was emphasized that at high-intensities there is a limit to obtaining frequency-specific information in the ABR. The 16 adult volunteers who were tested all had hearing thresholds within 15 dB HL of audiometric zero. The ABR stimuli were 2 kHz tone pips with 2900 Hz high-pass masking noise. LDLs for 2 kHz tone pips were correlated with the ABR JV latency measurements.

The slope of the latency-intensity function of JV latency at high intensities of the 2 kHz tone pips was decreased by increasing the intensity. The shifts in JV latency by increasing the intensity, yielded no statistically significant difference between the different LDL relative intensity levels.

CHAPTER 1

INTRODUCTION

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Measurement of the upper limit of hearing is very important in audiological medicine for various reasons. For instance, the upper limit of hearing is necessary both for differential diagnosis and for the purpose of fitting hearing aids. In trying to measure this limit, the most frequently used parameter is the subjective Loudness Discomfort Level (LDL) of the individual.

The subjective LDL measurement seems to be an easy and useful audiological procedure, especially for setting the maximum acoustic output of a hearing aid. However, while it seems that it is a very straightforward test, there are some factors which make the measurement of subjective LDL neither wholly reliable nor consistent. Mental attitude, experience of noise (Priede & Coles, 1971), attention and personality (Stephens, 1970) of the individual being tested are some of these factors.

One of the most obvious reasons for hearing aid rejection among very young or uncooperative patients is the lack of subjective LDL data. Furthermore, there is another aspect of amplification, i.e. "high-level amplification" which has the potential of causing hearing loss in children. Rintelmann and Bess (1988) revealed the existence of a few case reports demonstrating threshold shifts in the aided ear, in comparison with the unaided ear, following the use of amplification. For these cases, setting the maximum output of hearing aids at much more reasonable levels might be an effective

measure against any damage to the cochlea, thus acting as a "safety mechanism".

In order to establish effective and consistent amplification, LDL estimation is perhaps more important for very young children than for adults. Unlike adults, children are unable to give feedback or manipulate the volume controls in order to adjust the maximum acoustic output of their hearing aids.

For very young hearing aid candidates, in audiology clinics, subjective LDL measurements have been developed and applied. In addition to subjective measurements for very young children, objective LDL estimations have been developed.

One of the most commonly referred to techniques for estimation of LDL is the Acoustic Reflex Threshold (ART). Unfortunately there is no conclusive relationship between LDL and ART. Even though supported by some authors (Fitzzaland & Borton, 1977; Helmann & Scharf, 1984), the idea of ART correlating well with subjective LDL is subject to question (Ritter et al., 1979).

Apart from the inconsistent correlation between LDL and ART, over half of neonates and infants may not exhibit an ART (Kiessling, 1982). Another problem with the ART is that it is either weak or undetectable in most middle ear disorders, even at the highest sound intensities (Metz, 1952; Zwislocki & Feldman, 1969). The middle ear disorder is a fairly common type of disorder in the very beginning period of life.

Another objective method of LDL estimation relies on wave V latency (JV) parameters of the auditory evoked brainstem response. Changing the intensity of the stimulus will alter the latency, amplitude and morphology of the evoked response. The latency of all the components of the evoked response increases with decreasing intensity of the stimulus. The latency-intensity function of the click stimulus is said to be fitted reasonably well by a linear regression line (Picton et al., 1981), from lower to middle intensities. For high intensities, it is claimed that very much smaller latency shifts occur in the ABR to broad-band click stimulus (Thornton et al., 1989). In another study, Klein and Teas (1978) established the latency-intensity function of filtered clicks with different frequencies. They pointed out that the latency-intensity function of each stimulus is different from the others.

By using subjective judgments to estimate LDL, it is inevitable that many psychological variables will affect the results. In addition to psychological variables which possibly may cause subjective judgments to be less consistent, subjective LDLs are assumed to have some sort of physiological foundation as well (Thornton et al., 1987). The physiological aspects of loudness discomfort levels may possibly be investigated using auditory evoked response parameters. Thornton et al. (1987) attempted to establish a statistical model as a predictor of LDL by using ABR parameters. In their study a click stimulus was used. As the ABR to click stimulus alone lacks frequency-specific information, using such a stimulus does not provide frequency-specific LDL.

However, since the LDL may vary across the speech spectrum (Morgan, Wilson and Dirks, 1974), in determining LDL of each hearing aid candidate, it is necessary to estimate the LDL for frequency-specific stimuli (Berger, 1976; Cox, 1981 in Walker and Dillon, 1974). If the maximum acoustic output of a hearing aid is set uniformly across the speech frequency spectrum, this approach might be satisfactory for mildly hearing-impaired individuals with a flat type of pure tone audiogram. But for the severely hearing-impaired subjects, this type of uniform amplification may reach the limit of the reduced dynamic range of hearing. If it is desired to utilize all the dynamic range of hearing at all frequencies across the speech spectrum, it is necessary to establish estimation of LDLs for frequency-specific stimuli.

The hypothesis of this study is, that there is a relationship between the subjective LDL and the latency-intensity function of the ABR wave V. By establishing a statistical model, LDL may be predictable from the ABR data obtained using frequency-specific stimuli, such as tone pips in high-pass filtered noise masking.

Since only adults can give subjective judgments to establish the relationship between the LDL with the absolute latency of wave V, in this experiment it is necessary to test normal hearing adult subjects.

CHAPTER 2

LITERATURE REVIEW

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2.1 A Brief History of the Auditory Brainstem Response(ABR)

In 1875, Caton recorded electrical potentials in the brain of animals. It took over fifty years to apply this recording technique to human beings. Hans Berger, a neurologist, recorded the first human electroencephalogram (EEG) from electrodes placed on the scalp (Berger, 1929). One year later, he described changes that he observed in the EEG in response to loud sound (Berger,1930). Some other authors introduced sensory stimuli in order to get stimulus related EEG patterns (Loomis, Harvey, and Hobart, 1938). They used tactile stimulation during sleep and managed to record diphasic or triphasic potentials from the vertex of the head. In the following year, H.Davis and co-workers described some specific changes of the EEG in response to auditory stimuli. The most interesting contribution to this field came from the developments in electronics. In 1951 Dawson introduced signal averaging, and in 1958 Clark developed the digital averaging computer (this type of computer can convert analog data into a digital form, so that averages can easily be computed). Clark and co-workers (1961), introduced the principle of algebraic summation of bioelectric potentials elicited by repeated sensory stimulation. With the help of this system, it was possible to cancel out random cortical and myogenic electrical activity. These responses were generally called "Auditory Evoked Potentials", because they were not spontaneous potentials and were evoked by a particular auditory stimulus. In 1967, first Sohmer and Feinmesser described the auditory brainstem response (ABR). This special type of evoked response consisted of five to seven wave peaks within the first

10 msec following click stimulus onset. After this, Jewett (1970), and co-workers (Jewett, Romano & Williston, 1970; Jewett & Williston, 1971) were able to identify and describe the origin of the ABR. The ABR, gained great popularity, because it was useful and noninvasive. The ABR is considered to be a series of neuroelectric responses generated at cochlear and brainstem levels of the auditory nervous system, and found to be a robust measurement of auditory function.

2.2 The Auditory System

2.2.1 Ear.

Anatomically and physiologically, the peripheral organ of hearing, can be divided into three parts: the external, middle and inner ears.

2.2.1.A External and Middle Ears.

The external ear is mainly composed of two basic structures, the auricle and meatus acousticus externus. The auricle, to a certain extent, improves the localization of the sounds in space. The other contribution of the auricle is to enhance stimulus strength, particularly at high frequencies, with a maximum pressure gain less than 10 dB SPL. Meatus is a small canal, in which sound waves travel and cause the tympanic membrane to vibrate. Because the tympanic membrane closes the meatus proximally, auricle, meatus and tympanic membrane act as a complex acoustic resonator cavity. At around 3000 Hz, the acoustic gain due to this acoustic resonance is approximately 10 dB SPL. The vibrations that are transmitted from the tympanic membrane through three tiny ossicles, which are situated in the middle ear, travel to an opening in the bony wall of the cochlea. These three ossicles are called malleus, incus and

stapes. While the malleus is connected to the tympanic membrane, at the other end of the ossicular chain, the footplate of the stapes is inserted into the membrane-covered opening in the bony wall of the cochlea. This opening is called the oval window. The ossicles are connected to each other by fibrous ligaments. The function of the ossicles is to transform vibrations of the tympanic membrane into vibrations of the fluids that fill the cochlea. The result of the vibrations of the fluids is the stimulation of the sensory receptors in the cochlea.

2.2.1.B Inner ear

The petrous portion of the temporal bone contains a cavity called osseous labyrinth. The osseous labyrinth contains a complex system of tubes and sacs, known as the membranous labyrinth. The membranous labyrinth is surrounded by a fluid known as perilymph and contains another type of fluid called endolymph. These fluids are almost incompressible, hence the stapes can not move medially unless some sort of pressure relief is provided. The second opening of the osseous labyrinth into the middle ear, the round window, helps the pressure relief, and it is covered by an elastic membrane. The membranous labyrinth has two major divisions, one of them is devoted to vestibular system, and the other to auditory system. The part of the labyrinth involved with hearing is known as cochlea. The cochlea is longitudinally divided into three canals: scala vestibuli, scala media (ductus cochlearis), and scala tympani. The scala vestibuli and the scala media are separated from each other by a very delicate structure called Reissner's membrane. Near the apical end of the cochlea, there is a small opening which links scala vestibuli and scala tympani called helicotrema. Unlike the other two canals, scala media is a self-contained membranous

sac. This canal is filled with endolymph and the base of the canal is called the basilar membrane. Auditory sensory receptors are found within a complex neuroepithelium called organ of Corti lying on the basilar membrane. Within each organ of Corti, there are two types of auditory receptors: three rows of outer hair cells, and a single row of inner hair cells. Figure 2.1 shows the organ of Corti within the scala media.

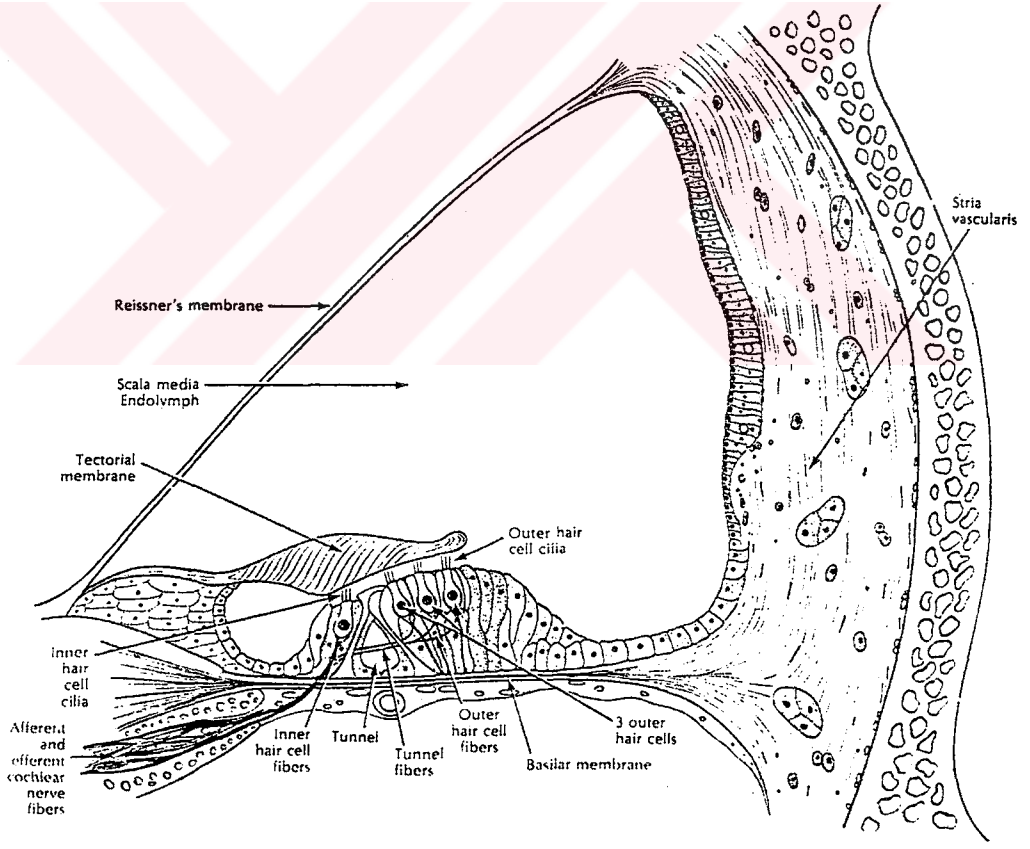

Figure 2.1 The organ of Corti within the scala media

(From Goodhill, 1979).

There is a tectorial membrane, attached to the spiral limbus, which overlies these hair cells. The majority of the afferent auditory neurons (95%), which carry auditory information from the cochlea to higher auditory structures, connect to the inner hair cells. The rest of the afferent auditory neurons (5%) attach to the outer hair cells. Whereas the upper portion of the inner hair cells serves to transduce mechanical energy into an electrochemical form of energy, their lower parts serve to release neurotransmitter substances which are capable of stimulating the dentrites of the auditory nerve fibres. According to recent studies, the basic function of the outer hair cells seems to be related to the mechanics of the cochlea, so as to produce high sensitivity and sharp tuning (Pickles, 1982; Moore, 1989). Since Békésy (1951), it has been established that the outer hair cells are the main origin of the cochlear microphonics (a receptor potential in the cochlea). The Cochlear microphonics comes about through the mechanical deformation of the outer hair cells (Gulick et al., 1989).

The basilar membrane is about 10 times wider near the apical end as it is at the basal end of the cochlea. Also towards the apical end of the cochlea, the basilar membrane decreases in its stiffness as becomes wider. Throughout the basilar membrane, the pattern of the travelling wave that starts with high velocity (about 30 m/sec) and low amplitude at the basal end gradually gains in amplitude but travels more and more slowly (about 1 m/sec) to the apical end of basilar membrane (Davis, 1976).

Whenever the basilar membrane is set into motion by a vibration of the stapes, a wave travels along the basilar membrane from the basal end of the the cochlea to the apical end. According to the experiments done by Békésy (1960), the pattern of vibrations of the basilar membrane during acoustic stimulation can be described as "travelling waves". The point of maximal vibration of the basilar membrane varies with the frequency of the sound; high frequency sounds produce maximal vibration near the oval window and low frequency sounds produce maximal vibration closer to the apical end of the cochlea. Briefly, in effect, the cochlea behaves like a spectral analyser with a limited power (Mechanical Filter). Generally this theory is known as "place principle" and seems to operate especially for sounds above about 1000 Hz (Rosenzweig & Leiman, 1989).

Recently, it has been shown that individual hair cells respond in a more frequency-specific manner. This means that very small areas on the basilar membrane acts like a bandpass filter with a certain centre frequency and bandwidth (Pickles, 1982; Moore, 1989).

Impulsive sounds, such as brief clicks have flat frequency spectra. Their travelling wave envelope is broad and does not show a peaked pattern as in tonal stimulation.

2.2.1.C Central auditory pathways

Along the central auditory pathways, nerves can be classified as afferent and efferent nerves. The afferent fibres of the auditory nerve process and transmit

information from the auditory receptor cells. The other type of nerves, efferent fibres originate from the olivocochlear bundle. They process and transmit information in the opposite direction, i.e. from the auditory cortex to lower auditory centers and eventually to the hair cells. These afferent and efferent pathways run together throughout their course and innervate the hair cells.

First-order bipolar auditory neurons situated near the base of hair cells have axons that enter the cochlear nucleus. These auditory neurons originate from bipolar neurons of the spiral ganglion situated in the modiolus of the cochlea. They bifurcate to send a branch to both the dorsal and ventral cochlear nuclei. The cochlear nuclei are unique among the nuclei in the brainstem, in that they receive only ipsilateral inputs from auditory nerves (Musiek & Baran, 1986). Each cochlear nucleus sends a number of second-order fibres directly to the lateral lemniscus, to the inferior colliculus and indirectly to the superior olivary complex. However, at this level of the brainstem, there are auditory fibres both in ipsilateral and contralateral projections, although contralateral fibres dominate. The superior olivary complex contains mainly third-order neurons and serves as the first relay nucleus that receives input from both ears. Lateral lemniscus connects the superior olivary complex to the inferior colliculus. The fibres that leave the inferior colliculus and terminate in the medial geniculate body of the thalamus, are called brachium of the inferior colliculus. From this nucleus, auditory information ends up at the primary auditory cortex which is located high on the superior temporal gyrus of the temporal lobe (Gulick et al., 1989). Figure 2.2 illustrates the main ascending auditory pathways.

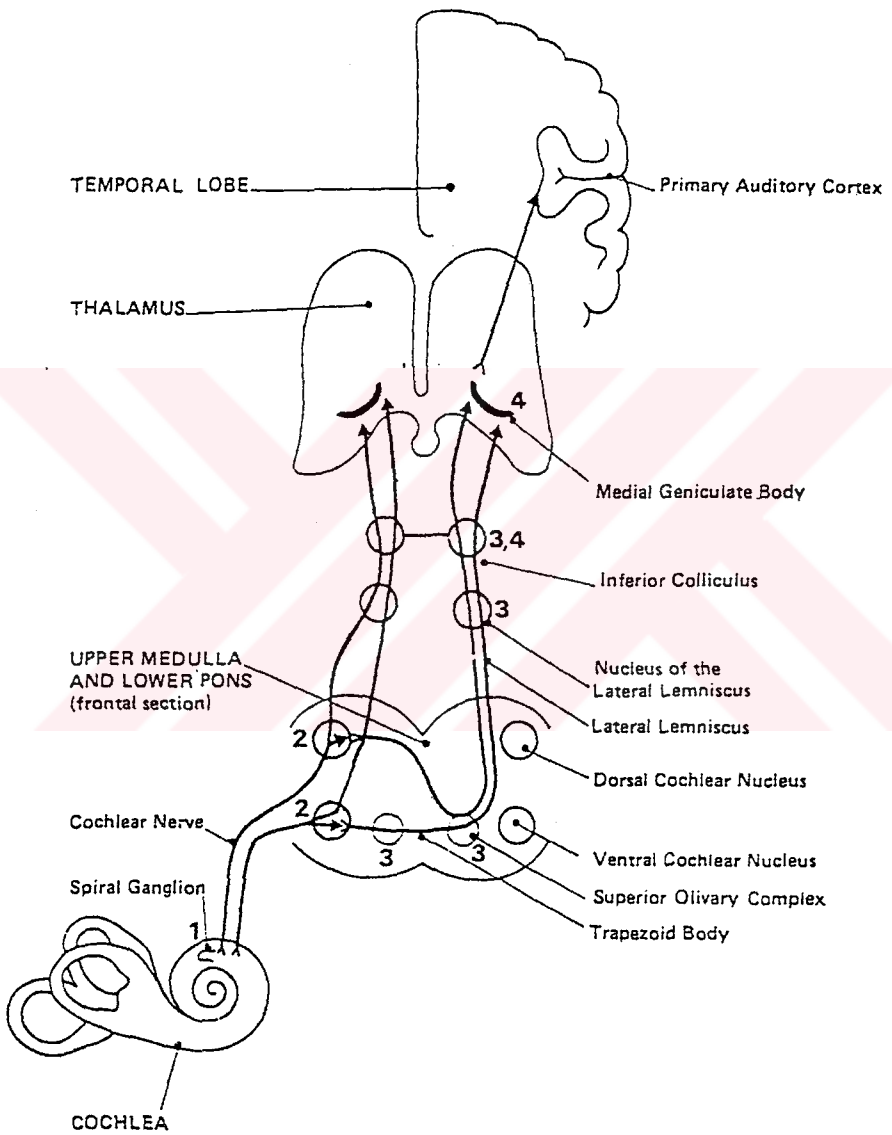

Figure 2.2 Main ascending auditory pathways. The numbers 1 to 4 indicate the order of neurones. (from Abramovich, 1990).

2.2.2 Neural generators of the ABR

Precise neural generators of the ABR are not very clear. This partly owes to the interactions along the afferent auditory pathway which are mainly obscure (hence, the conventional term of "auditory pathway" can be misleading, since it implies a passive transmission from periphery to cortex). Another complicating problem arises because there are mainly two types of auditory fibres that carry information, afferent and efferent fibres. However, even though it is generally accepted that the neural generators of the ABR are the afferent auditory fibres (Møller, 1985), one can not easily rule out the contributions from the efferent fibres.

However, another factor further complicates the issue. Since evoked potentials (ABR) are recorded at remote electrode sites, they considered to be far-field recording (generators of the potential are far away from the recording electrodes). Comparisons between the near-field/far-field evoked potentials showed that there is an overlapping of the components from the generating sources (Jewett, 1970). One of the reasons of overlapping is suggested to be due to onset delay and travelling wave characteristics (Parker, 1977).

Accumulating observations make it clear that there is no strict ABR-anatomical relationship for the afferent auditory fibres. Nevertheless, there is a good possibility that the first five waves of the ABR may originate within the auditory nerve and pons (Musiek & Baran, 1986). Møller's current work indicates that wave I originates exclusively from the distal part of the cochlear nerve and wave II from the proximal part of it (1985). Wave III probably has more than one generator, but seems to be

generated mainly by the neurons in the cochlear nucleus (Møller & Janetta, 1984). Another wave with multiple generator is Wave IV. It probably originates from the superior olivary complex. Several investigators have suggested that the primary origin of wave JV is in the area of the inferior colliculus (Allen & Starr, 1978; Caird & Klinke, 1987). But according to another study, wave V is generated by lateral lemniscus rather than the inferior colliculus (Møller & Janetta, 1986). Their oversimplified scheme indicates that the first five waves of the ABR are generated between the auditory nerve and pons, but they do not represent the response from the midbrain and the inferior colliculus, especially in human (Møller 1985; Musiek & Baran, 1986). Waves VI and VII are thought to arise from a higher centre, inferior colliculus (Møller & Janetta, 1985).

It will be easy to follow the argument, if one can consider that there is no single neural generators of the ABR waves but more than one anatomical structure contributes to each wave. That is why finding primary generators of each wave becomes a complex issue.

2.3 FREQUENCY SPECIFICITY IN THE ABR

From the brief overview of cochlear physiology, it becomes clear that the basic frequency selectivity of the auditory system is mainly determined in the cochlea (Evans & Wilson 1973; Gorga & Worthington, 1985). Furthermore there are some features of the cochlea which are related to achieving frequency-specific ABR. These will be the main theme of the following section.

2.3.1 The recruitment of auditory nerve fibres with high characteristic-frequency at increased intensity levels

As a response to auditory stimuli, the travelling wave moves along the basilar membrane from the basal end of the cochlea towards the other end of it. The place of maximum displacement is frequency dependent so that the maximum response to high-frequency stimulus is nearer to the basal section of the cochlea. As the frequency of the stimulus decreases, the maximum response moves towards the apical end (See Chapter 2.2.1.B). When any sound is delivered by air conduction, the course of the sound is the same: initially stimulation will pass through the basal end of the cochlea, then this stimulation proceeds to the other parts of the cochlea. In other words, a low-frequency sound will also use the same route as a high-frequency sound and cause vibrations which begin at the basal end of the basilar membrane. As long as the neurons from the basal region are more easily synchronizable than the more widespread neurons of the apical end of the cochlea, ABR to low-frequency stimuli may be predominantly derived from regions of the cochlea nearer to the oval window (Picton et al., 1979). To put this feature of the basilar membrane into context, low-frequency energy at moderate-to-high intensities can cause basal portions of the

cochlea to respond (this is explained according to the tuning curve discussion in Gorga & Worthington, 1983).

The relationship between the latency and intensity of the ABR has been investigated by several authors. In one of the studies carried out by application of electrocochleography, the stimulus was the 2 kHz tone pip and the subjects were normal hearing adults (Eggermont et al., 1974). In this analysis of the cochlear compound action potential response, 2 kHz tone pip with band-reject or high-pass noise masking were used. It has been shown that the major area of the basilar membrane contributing to the response shifts basally at higher intensities, particularly above 60 dB HL. This study supports the view that the brainstem response to tone pip stimuli at moderate and high intensities is mediated by the more basal regions of the cochlea than the regions that are specific to 2 kHz. Again, the most reasonable explanation is that the high-frequency fibres from the basal region of the cochlea are more easily syncronizable than the more apical regions of the cochlea.

2.3.2 The effects of the spectral splatter at high intensity levels

As regards the ABR to tone pip stimuli, there will be a spectral splatter, which means that there will be a stimulation of the regions of the basilar membrane outside the octave band being tested. The acoustic spectrum of the tone pip contains main peak at its nominal frequency. Additionally there are second and third order spectral peaks, which are comparatively at lower levels around the nominal frequency of the tone pip (e.g. the acoustic spectrum of the stimulus used in the present experiment

consisted of a main peak at 2 kHz and second spectral peaks at the frequencies of 1250 Hz and 2775 Hz. These peaks were approximately 15 dB below the main peak) Thus when the stimulus is presented at lower-to-moderate levels, this spectral splatter of the tone pip stays sub-threshold. But at high stimulus levels, tone pip can evoke a response which contains components from outside the region of the basilar membrane at its nominal frequency.

2.3.3 The response areas of single auditory nerve units

There have been some attempts to describe the response areas of single auditory nerves to different frequencies of sound (see text by Gulick et al. 1989). These studies have focused on the observation that the nerve units tuned to high-frequencies which are terminated in the basal turn of the cochlea can be stimulated by low-frequency sounds as well. It is suggested that high-frequency threshold curves have sharply tuned "tips" only sensitive to their characteristic frequency, and long, less sensitive broadly tuned "tails" that are influenced by low-frequency stimuli as well (Jacobson, 1983). Figure 2.3 shows a typical response area of an auditory neuron tuned to a frequency of 10 kHz. Low-frequency sounds, at moderate intensities, may often be at subthreshold level for the single units that are tuned to higher frequency sounds. But as soon as the intensity of the low-frequency sound is increased, it is possible to reach the threshold levels of these single units eventually (Evans, 1982).

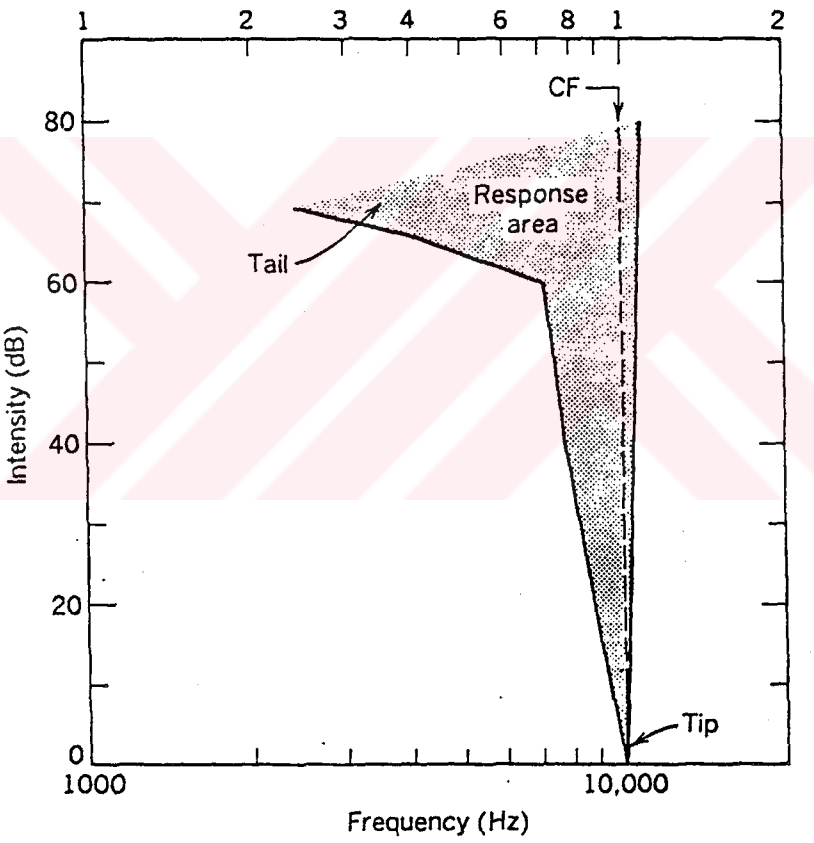

Figure 2.3 A typical response area of an auditory neuron tuned to a frequency of 10 kHz (Characteristic frequency). (From Gulick et al., 1989).

2.3.4 Post-stimulus time histograms of single auditory nerve units

A method of measuring the physiological time pattern of discharges in single auditory nerve fibres responding to sound is to collect poststimulus time (PST) histograms from the animal. This technique makes it possible to measure the thresholds of each single unit in an auditory nerve. In a study with an application of electrocochleography, Elberling concluded that according to the post-stimulus time histograms, at high intensities of 2 kHz half sinusoid rarefaction click, the entire cochlea is activated and only at low intensities some sort of frequency-specific recording might occur (1976). The result of similar PST histograms further indicates the difficulty of obtaining frequency-specificity at moderate-to-high intensity levels of any type of auditory stimuli (Candela, Jr & Kiang, 1978).

As explained above, some cochlear features make it difficult to record frequency-specific ABR, especially at moderate-to-high stimulus levels. An equally important aspect of the frequency-specific ABR is the stimulus to be presented. The choice of stimuli, which affects the frequency-specificity in ABR will be discussed below.

2.3.5 Stimulus to be used in frequency-specific ABR

There are several types of acoustic stimuli used to elicit ABR. The most common is the click. Generally, ABR is generated by the onset of the stimulus rather than the continuation of it. Thus, the rise time of a stimulus becomes an important consideration. The click has a fast rise time. Since a click stimulates a large number of auditory nerve fibres and they are fired in close synchrony, it evokes a clear

waveform. But this sort of transient excitation of a considerable length of cochlear basilar membrane has acoustic energy over a wide range of frequencies. That is to say that click response alone lacks frequency-specific information.

2.3.6 Frequency-specific ABR using masked clicks

In order to improve the frequency-specificity of click response, a number of experiments have been carried out. The first workers in this field were Teas, Eldridge and Davis at 1962. In their masking experiments, they attempted to improve the frequency-specificity of the action potentials from the cochlear partition. They concluded that an Electrocochleography technique, combining broad-band click with high-pass noise gives the most selective derived action potential. By this high-pass masking technique, it is possible to restrict the responsive cochlear region to a specific place on the basilar membrane. But unlike high-pass masking, low-pass masking causes a spread of masking to the higher frequencies (i.e. contrast to high-frequency sounds, low-frequencies activate both basal and apical regions of the cochlea). Thus, in terms of frequency specificity, using high-pass masking technique is comparatively safer than low-pass masking. As a result, several techniques have been devised to improve the frequency specificity of the click ABR. These techniques involve various types of masking: clicks in notched noise (Eggermont & Odenthal, 1974), derived response using narrow-band masking (Stapells et al., 1985), derived-response using clicks in high-pass masking noise (Parker & Thornton, 1978; Eggermont & Don, 1980). In comparing these techniques, it is concluded that derived-response using high-pass masking method is probably the best approach (Stapells et al., 1985; Abramovich, 1990).

2.3.7 Tone pip ABRs

Tone pips evoke fewer discharges from cochlear nerve fibres than click stimuli. Thus, they produce a smaller amplitude and higher ABR threshold. Through the tone pip stimulus, the basal turn of the cochlea tends to evoke better synchronized discharges than the apical part of the cochlea (Davis, 1976). As explained above (see section 2.3.3), in the high-frequency response, such as a 4 kHz tone pip response, there are not many components from the low characteristic frequency fibres. On the other hand, low-frequency tones do stimulate units that are best tuned to high-frequencies. Due to the large numbers of fired nerve fibres and better synchronization pattern, basal units may dominate the ABR to low-frequency tone pip stimuli (Davis, 1976).

2.3.7.1 Masking procedures in ABR to tone pips

If the responses are expected to be more frequency-specific, especially for higher intensities, it is necessary to use ipsilateral masking noise with the tone pip stimulus (Davis and Hirsch, 1976; Suzuki et al., 1977; Picton et al., 1979; Jacobson and Hyde, 1985). This is in order to eliminate the responses of the basal units from the ABR, there is no other choice, but to use ipsilateral masking noise (Davis, 1976).

In the ABR to tone pips, there are several routes of masking. The first of these is, as with any audiometric procedure, a masking noise administered to the nontest ear. The second of these is an ipsilateral masking noise to the test ear. This is to improve the frequency-specificity of the auditory stimulus (e.g. notched masking noise as in the studies of Picton et al. 1979).

The masking noise is administered to the nontest ear whenever the stimulus to the test ear (poor ear) is likely to crossover the head and stimulate the nontest (better ear) ear. The interaural attenuation of the click stimulus has been examined using patients with unilateral hearing loss. Results of these interaural attenuation studies range from 45 to 70 dB (Elberling, 1978; Humes and Ochs, 1982). Thus, even if the test ear is nonfunctional, ABR waveform can be recorded because of the cross-stimulation of the opposite ear. When hearing is bilaterally normal, this is probably not so important since the ipsilateral ear potentials are recorded earlier and of greater amplitude and set up inhibitory influences at the level of the cochlear nuclei coming later in time from the contralateral ear (Chiappa, 1983). In order to suppress contralateral evoked potentials, broad-band noise would be an appropriate masker for tone pip in ipsilateral masking.

The second type of masking which is employed ipsilaterally and simultaneously is necessary to improve the frequency-specificity of the tone pip. There is a concept of ipsilateral masking called "line-busy" hypothesis (Stapells et al., 1985). This hypothesis proposes that the response of auditory neurons to the masker makes them unable to respond further to any other stimulus, as long as the masker is presented to the test ear. This hypothesis can partly explain the concept of the ipsilateral masking.

The method mostly encountered in the literature as a preferred means of improving the frequency-specificity of the ABR to tone pips is ipsilateral high-pass filtered or notched-noise masking. By using high-pass filtered or notched-noise masking

techniques, it is assumed to eliminate the responses from those regions of the cochlear partition where there has been an acoustic spread of excitation (Sohmer and Kinarti, 1984). Stapells et al. (1985) carried out a review in this problem and recommended notched-noise masking in the testing of the middle-to-high-frequencies and high-pass filtered noise masking in the testing of low frequencies. Stapells and Picton (1981), believe that the notched-noise masking yields less effect on the ABR to 2 kHz tone pip, because of the relatively higher frequency specificity of the stimulus and the fact that the location of the place of initiation of the response can not shift to an earlier or more synchronizable region of the cochlea.

In view of the masking procedures, there is no spread of masking from high to lower frequencies (Mason, 1988). This is probably due to the asymmetry of the travelling wave. However, there is a spread of masking with notched-noise masking (Picton et al., 1979; Mason, 1988) and from low-frequency masker to response of high-frequency fibres (Stapells et al., 1985). This is the reason for choosing high-pass filtered noise masking in the present study.

2.3.7.2 Other aspects of ABR to tone pips

Tone pips are used as stimuli between the frequencies of 0.5 and 4 kHz. Below the 2 kHz stimulus frequency, there are difficulties with waveform interpretation. Below the stimulus frequency of 2 kHz, the ABR waveform degrades and makes identification of the waves close-to-threshold much more difficult. This difficulty is attributed to a reduction in the synchronisation in the firing of auditory nerve fibres (Hawes and Greenberg, 1981).

It is stated that the most direct approach to obtaining frequency-specific ABR is to use short duration tone pips (Mason, 1988). Tone pips are very brief signals (2.5 to 7 msec), and their acoustic spectrum has energy centered at the selected tone pip frequency with relatively limited spectral splash to adjacent frequencies. But tone pips with a very brief duration contain a fairly broad range of frequencies in the acoustic energy because of very rapid rise time (Brinkmann and Scherg, 1979). Furthermore, as the rise time of tone pip is abbreviated, it is much more difficult for the transducer to produce an acoustic analogue of the electrical signal (Jacobson, 1983). Thus, this limits the rise time and the transducer acts like a low-pass filter.

There are two types of established latency measurements of ABR to tone pips in the literature. According to a review by Davis and Hirsch, the reference point for JV latency measurements might be taken from the very beginning of the acoustic stimulus or relative to the action potential of the auditory nerve (Davis and Hirsch, 1981).

The stimulus repetition rate has considerable effect on the latency and amplitude of the ABR (Jewett and Williston, 1971). But if the latency prolongation is expected, as in the development of a latency-intensity function, then it might be a better solution to use higher repetition rates of stimulus presentation. Since it might take a long time to achieve the whole latency-intensity function, it is more acceptable to use higher repetition rates.

If a tone pip stimulus is employed at high intensity levels, there may be limitations related to the stimulus artifact. In an ABR to tone pip, the electro-magnetic stimulus artifacts might overlap the response. Especially at high intensities of tone pip stimulus, there might be stimulus artifact in the beginning of the response (e.g. in the first 3 msecond of the response, as it can be observed from the traces of Picton & Fitzgerald, 1983). This artifact problem may be encountered at high intensity levels, such as 50, 60 or 70 dB HL, at the onset of the ABR. Indeed the position of the peak of wave V (JV) is usually later than 5 msecond in an ABR to tone pip.

Other investigators (Suzuki and Horiuchi, 1981) have directed their attention to the relation between the stimulus and response parameters. Their conclusion was that frequency-specificity was closely linked to the onset time of the stimuli, especially to the rise time of the stimuli. Shorter rise time correlated with broad range of frequency information, and longer rise time correlated with narrow frequency information (Maurizi et al., 1984). But regardless the stimulus rise time, at high intensities, the response to tone pip alone provides insufficient frequency-specific information (Stapells and Picton, 1981).

2.4 LDL AND CLINICAL APPLICATIONS OF THE LDL

Measurement of the upper limit of the auditory area is very important in audiological medicine. In trying to define this area, subjective Loudness Discomfort Level (LDL), is probably the most frequently used parameter. Additionally, there are behavioural (ABLB, SISI, etc.) and objective (acoustic reflex threshold and electrophysiological procedures) tests to define the upper limit of the auditory area.

To describe this test, the terms 'uncomfortable loudness level' and 'threshold of discomfort' are used in the audiological medicine literature. In this study, loudness discomfort level is the preferred term.

Loudness is a perceptual correlate of a sound intensity. Although the intensity of a sound is largely responsible for perception of loudness, there are some other factors that are also involved. Frequency and duration of the sound are two of the factors which have an effect on the loudness. Thus, it is possible to suggest that subjective LDL for continuous pure tone sound will differ from subjective LDL for click with very brief duration.

The objective of the LDL measurement is to measure the minimum intensity level which is judged to be uncomfortably loud to the patient when applied monaurally (Recommended Procedure by British Society of Audiology, 1987).

Reliability of the LDL measurement depends on the ability of a subject to define the threshold of the uncomfortably loud sound. How subjects judge loudness, varies

according to various factors. In part, loudness jugdments relate to mental attitude, recent experience of noise (Priede & Coles, 1971), attention (Moore, 1989), and personality (Stephens, 1970) of the individual being tested. These are the sources of variability related to subjects. Other sources of variability in LDL measurements are related to instructions, methods, stimulus type, and calibration effects (Hawkins, 1980).

The choice of precise instructions is fairly important. If the instructions are not selected clear enough, LDL results may be inconsistent within the study as well. It would be better if the instructions contain the reason for obtaining the LDL, so that subjects can achieve a better performance and give reliable responses during the testing process (Bentler & Pavlovic, 1989).

Obviously due to its subjective nature, it is too difficult for a child or for an uncooperative patient to engage in this type of LDL test. Especially as the hearing aid fitting age decreases, LDL measurements will be much more difficult, if not impossible to obtain. In this sense, there is an age limit for this test and it is recommended not to use this test under age of 6 years (Arlinger, 1989). In order achieve valid test results in this test, it is necessary to ensure that the subject is mature and cooperative.

There are some other type of LDL tests, which will be discussed later. These, however, are only proposals and appear to be open to discussion.

The choice of stimuli adds another factor which may affect the judgments of

listeners. It remains unclear which type of stimuli should be used to establish the loudness discomfort levels. Many types of stimuli have been used in order to obtain LDL (Hawkins, 1980). Running speech (Carhart, 1946; Schmitz, 1969, etc.), pure tone (Watson, 1944; Zink & Alpiner, 1968; Morgan & Dirks, 1974; etc.), narrow band of noise (Wallenfels, 1967; Morgan et al.,1974), spondaic words (Dirks & Kamm, 1976) are some of them. It is very difficult to compare LDL results which have been determined for a particular stimuli, with another set of results, unless they have been exactly replicated. It is difficult to replicate any LDL study because of the sources of variability.

Changing the type of stimulus inevitably alters the frequency spectrum of the stimulus. Difference in frequency spectrum will alter the level of the loudness discomfort. Testing LDL with narrow-band stimulus may end up with maximum power output being set too high for listening to broad-band signal, such as speech. This is due to fact that while testing with narrow-band stimulus, loudness summation phenomena are not taken into account (Walker et al., 1984).

Although for people with normal hearing LDLs for pure tones generally follow the equal loudness contour pattern, LDLs may vary with the frequency for hearing-impaired subjects (Morgan, Wilson & Dirks, 1974; Hawkins, 1980; Skinner, 1988). Thus, it seems necessary to measure the LDL of each individual over a wide range of frequencies (particularly between 500 to 2000 Hz), so as to highlight any variations across the frequencies (Berger, 1976). Precise SSPL90 settings across the frequency range is not available in conventional hearing aids (McSporran, 1987).

There are preset SSPL90 choices in the hearing aids. With these presettings it is difficult to adjust the maximum output of the aid to the user's need. In the future, the developing digital technology in hearing aids will allow the SSPL90 to be set at each frequency independently (Smaldino et al., 1985).

2.4.1 The Reasons for obtaining LDL

The major reason for measuring LDL for the hearing-impaired persons is to adjust the frequency response, gain, and maximum acoustic output of hearing aids appropriately for each individual. Generally the instructions and testing methods of LDL are designed with this goal in mind (Skinner, 1988).

The second reason to obtaining LDL from hearing-impaired persons is for differential diagnostic purposes (Hawkins, 1980). There are some evidences that the subjects with normal hearing or with cochlear pathologies will yield similar LDLs, whereas those having lesions with conductive, mixed, or retrocochlear localisations will have LDLs at more intense levels. In audiological medicine, this phenomenon is called, loudness recruitment, or abnormal growth of loudness. Loudness recruitment may be associated with hair cell damage within the cochlea (Moore, 1989), rather than retrocochlear and conductive type of ear pathologies.

2.4.2 The use of LDL for designing the maximum output of hearing aid

One of the parameters of hearing aids is maximum power output (MPO), which is set for each hearing-impaired person individually. Similarly, Saturation Sound Pressure Level 90 dB (SSPL90) is used to define the maximum sound pressure level the hearing aid is capable of generating regardless of the intensity. There are basically two factors which make the output limitation of the hearing aids necessary. First of these is related with sound amplifying system of an aid. Amplifiers in a hearing aid reach a saturation level at which further increases in signal input will not produce linear increase in output. Thus, the output of the aid becomes distorted. The other reason for limiting the output of the hearing aid is much more important: high level of sound signal may cause discomfort or auditory damage to the user.

Turning back to the SSPL90, it can be described as follows: "sound pressure level developed in a 2 cc coupler when the input sound presure level is 90 dB with the gain control of the hearing aid full-on" (ANSI, 1987). In other words, SSPL90 is the upper limit of output in SPL that the hearing aid is capable of producing. In order to make easier to categorize hearing aids according to their SSPL90 values, a three frequency averaging method is established. The high frequency average SSPL90 is defined as the average of the 1000 Hz, 1600 Hz and 2500 Hz SSPL90 values. The wearer may use the volume control to reduce the output of the aid whenever it reaches a high level but this would require frequent adjustments of volume controls and could not prevent short periods of discomfort. Indeed, there is no general agreement on how to set SSPL90 of a hearing aid. It is generally agreed that SSPL90 of a hearing aid should be set to a level equal or just below the LDL of an individual (Byrne, 1978; Tucker

and Nolan, 1984; Beattie & Sheffler, 1981). On the other hand, Dillon et al. believe that SSPL90 may exceed a patient's subjective LDL by a few dB without causing much problem. The main logic of using LDL in limiting the output of the hearing aid seems fairly simple: a hearing aid should not deliver any output above the level at which person experiences discomfort on his/her impaired ear. It has been pointed out that the delivery of intolerably loud sound is the greatest single cause of hearing aid rejecting (Griffing and Hinz, 1972). If SSPL is set too high, high intensity inputs may cause the wearer discomfort and may result in further damage to the cochlea (Rintelmann & Bess, 1988). Conversely, if SSPL90 is set too low, hearing aid output levels may be inadequate (especially for severely hearing-impaired user) and the available dynamic range (between hearing aid gain and SSPL) may be unnecessarily reduced. In designing maximum output power of a hearing aid, the LDL measurement is one of the methods established a long time ago (Watson, 1944), but was not used as effectively as it could have been.

2.4.3 The dynamic range of the auditory area and its relevance to cochlear function

The dynamic range of the auditory area of the individual is the range of intensities between the hearing threshold and the loudness discomfort level in the frequency range of the human ear. The value of the range between the hearing threshold and LDL probably reflects the composite effect of sites of dysfunction in the auditory organ.

2.4.4 The measurement of loudness recruitment

Using LDL measurements as an indicator of cochlear hearing loss is a fairly well discussed topic. For a normal hearing subject, a tone becomes uncomfortably loud at approximately 100 dB SPL (Evans, 1982), though its exact level will change upon the stimuli and instructions that are chosen.

However, the hearing threshold of a hearing-impaired patient with a loudness recruitment, is expected to be elevated up to an abnormal level, the LDL may remain at normal or near-normal levels. This results in a much reduced range between the hearing threshold and the LDL of the individual compared to normal. Such a case is called, "loudness recruitment positive", which is commonly associated, but not exclusively, with cochlear pathology that affect the hair cells of organ of Corti (Hood & Poole, 1966).

Alternatives to the LDL approach for detecting loudness recruitment are alternate binaural loudness balance (ABLB), short increment sensitivity index test (SISI), electrocochleography (ECoG), ABR, and acoustic reflex threshold estimation. ABLB is a "binaural" test and compares loudness growth between the same frequencies for the two ears. Hearing-impaired person has to perform a highly subjective task, in order to state whether the variable tone is "softer than", "louder than" or "equal" in loudness to the reference ear. In other words, it is a technique for unilateral hearing losses. Since the bilateral loss is common, the monaural loudness balance test technique has also been described (Reger, 1936). These measures of loudness recruitment are open to discussion due to very large individual differences

owing to subjective and sophisticated judgments required by the hearing-impaired patient (Dillon et al., 1984). SISI measures the ability of the ear for detecting small changes (1 or 5 dB) in intensity at the suprathreshold level. The relationship between SISI and the loudness recruitment seems fairly controversial (Moore, 1988). It is much more correct to define this test as a test of intensity resolution, rather than recruitment indicator (Lutman, 1987). An agreement exists between behavioural tests of loudness recruitment (SISI, ABLB, Monoaural Loudness Balance tests) and the Metz acoustic reflex test to identify cochlear hearing loss (Northern et al., 1985). The basic rationale of the Metz test rests on an assumption that the acoustic reflex threshold produced at a reduced level in an impaired ear, gives conclusive evidence of cochlear pathology manifesting loudness recruitment. This is called "Metz positive". It is an objective and quicker test compared to behavioural tests of recruitment, but only if there is a detectable acoustic reflex. Due to middle ear dysfunctions and the extent of most sensorineural hearing losses, the reflex threshold is beyond the limit of the equipment capabilities. Furthermore, it is possible to record acoustic reflexes at a reduced sensation level on patients who actually do not demonstrate loudness recruitment (Beedle, 1970).

2.4.5 Auditory evoked potential correlates of loudness recruitment

Other investigators have directed their attention to the application of electrocochleography to estimate the loudness recruitment (Eggermont & Odenthal, 1974). The study of Eggermont and Odenthal gives some clues for differentiating recruiting ears from the normal ears by using short-tone bursts. In normal ears intensity-amplitude curve is composed

of two parts, first a shallow part and then a steep part. The first shallow part disappears in the recordings of the ears with loudness recruitment.

Intensity-amplitude correlations of ABR have also been studied thoroughly (e.g. Kiessling, 1982), in order to make correlations with the loudness growth function. But, since amplitude may be a too variable measure, it tends to be a unreliable measure of loudness growth (Clayton & Rose, 1970; Marco, 1972).

2.4.6 Conventional LDL procedures for children or uncooperative patients

For individuals who can not make any LDL judgments, but need a hearing aid, LDL can also be predicted from the audiometric threshold. But in order to use this method, type of hearing loss has to be differentiated as well (such as neural, cochlear or conductive type of hearing loss). There are established tables, according to the type of ear pathology and level of the hearing loss, on which LDL predictions are listed (Skinner, 1988). But it is very unusual to diagnose a uniform neural type, cochlear type or conductive type of ear pathology. The residual hearing of each subject probably reflects the composite effect of one or more sites of dysfunction in the auditory pathway. Thus, it is usually more correct to analyse each hearing-impaired subject individually, but not as an "cochlear hearing impairment" etc., while determining the hearing aid settings.

It is a difficult task to estimate the LDL in young children (Nolan, 1983). The most common method of obtaining the upper limit of auditory area of the very young

hearing-impaired children, relies on behavioural reactions. Such an LDL estimation approach for young children uses speech sounds such as "go" or "ba" (Markides, 1980), while the child is using a hearing aid. This type of response is purely behavioural (reactionary) response. While the stimulus was being raised from conversational level (e.g. 65 dB SPL) to a loud sound, an observation such as crying or reflex activity from the child was considered as indicative of LDL. As the pyschological attitude of very young children is unpredictable, reliability of these reactionary LDL tests are uncertain. The reason for using these reactionary LDL tests may be because there is no other established option for a clinician.

2.4.7 LDL estimations using electrophysiological procedures

Both acoustic reflex threshold and LDL are affected by the spectral configuration of sound energy that reaches the cochlea and is related to intensity coding of sound. In that sense, it is expected that there is a relationship between these two.In theory, it seems that acoustic reflex threshold and LDL might correlate with each other, but in fact the relationship between acoustic reflex threshold and LDL is described as controversial (Northern et al., 1985). Some of the authors believe that ART to a speech spectrum noise can be used to estimate the upper limit of auditory area in order to design the SSPL90 of hearing aids (e.g. McCandless & Miller, 1972). Kiessling (1982) proposed to use acoustic reflex intensity-amplitude functions as a tool for objective hearing aid evaluation. Studies done to make comparison between LDL for white noise and 1/3 octave band noise with the ART failed to show any correlation between these two (Skinner, 1988). Similarly, results of Ritter et al. (1979) support the view that ART correlate too poorly with the LDL to permit ART

levels to predict LDL objectively. First of all, in order to use ART to predict LDL, there would be a detectable acoustic reflex. But usually due to hearing impairment or simply because of middle ear pathology, the reflex may be absent in a considerable number of patients.

As stated, the most easily accesible test (ART), may not be detectable due to various reasons. LDL estimation may be a problem when the hearing-impaired patient is not able to give subjective responses. For these reasons, it seems necessary to establish a test which could be used with very young children and uncooperative patients. Attempts to establish an objective technique for estimation of LDL, have led to investigation of possible ABR correlates of subjective LDL, such as JV latency and amplitude (Stecker, 1982; Kiessling, 1982).

Among ABR parameters, JV, is the most easily recognizable and most robust peak and therefore attracted several authors to make correlations with subjective LDLs of individuals. Figure 4.1 (p.71) shows a typical ABR waveform to click stimuli and identification of the waves. If the click intensity increased, JV latency decreased progressively (e.g. Thornton, 1975; Rosenhamer et al., 1978). Additionally, JV latency stabilised at high intensities. The decrease in JV latency was more rapid at the high intensities in ears with recruitment than the normal or non-recruiting ears (Coats, 1978; Galambos & Hecox, 1978, Rosenhamer et al., 1981). But there is no agreement regarding whether the JV latency-intensity slope is a good or a poor indicator of recruitment (Suter & Brewer, 1983).

CHAPTER 3

INSTRUMENTATION

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INSTRUMENTATION

3.1 Basic system for an ABR

There are two basic components of an ABR recording system. First of these is stimulus generating component and the second one is the recording component of the ABR.

Various types of stimulus can be used to elicit ABR. Auditory stimuli such as clicks or tone pips which are generated by the stimulus generator can be delivered through the transducers. The electrode is the metallic conductor interface between the patient and the recording system. The amplification system increases the amplitude of the electrical signal picked up by the electrodes to bring it up to a level sufficient for processing by the signal averager. The signal averaging computer acquires and analyses the incoming electrical signal. This computer is time-locked to repeatable electrophysiological events and extracts these type of events from the non-time-locked activity such as muscle movements, EEG and nonphysiological signals. While recording the auditory evoked response, other large bioelectric signals and nonphysiological artifacts which may contaminate the response need to be eliminated from the average. Incorporation of an automatic artifact rejection system into the signal averaging instrument is one of the effective ways to improve the condition. The artifact rejection system eliminates large voltages from the averaged waveform. The ABR systems can acquire the data parameters (absolute latency of waves and amplitude of the peaks) and display on the visual display unit during the averaging. ABR data storage for subsequent retrieval and analysis may be achieved in different ways, depending on the

system of the ABR. Computer-based systems have an optional or built-in data interface for connection of external data storage systems. Most of ABR sytems have the means of making a permanent copy of the ABR waveforms.

3.2 Stimulus generation with Nicolet Pathfinder II

The electrodiagnostic system which was used in the present study was the Nicolet Pathfinder II. The basic parts of this electrodiagnostic system were as follows:

* NIC-1280 Central Processor Unit
* NIC SM-100 Stimulus Controller
* NIC SM-200 Physiological Amplifier
* NIC SM-700 Auditory Stimulator

The NIC-1280 Central Processor Unit (CPU) controls all functions of Pathfinder II. It allows all the functions of the Auditory Stimulator and the Stimulus Controller parameters (trigger and sweep times, channels, artifact rejection parameters, etc.) to be set.

The NIC SM-100 Stimulus Controller provides manual or automated control of the stimulus rate, stimulus duration, and band-pass filter settings.

The NIC SM-200 Physiological Amplifier provides two independent channels of differential amplification. The CPU individually controls the filter parameters and the sensitivity and calibration parameters of each channel of amplification.

The NIC SM-700 Auditory Stimulator incorporates two separate click and tone synthesizers which enables one to shape the stimulus by selecting the rise, fall and plateau times. This stimulator also contains a noise synthesizer which delivers white noise, in the range of 20 Hz to 20 kHz.

In order to obtain high-pass masking noise, the electrical output of the white noise synthesizer (the part of the NIC SM-700 Auditory Stimulator) was filtered by Kemo VBF/24 dual channel bandpass filter with cutoff slopes in excess of 100 dB per octave.

In this experiment, in order to elicit frequency-specific ABR, 2 kHz tone pip was combined with 2900 Hz high-pass noise. Thus, for contralateral masking it was decided to use broad-band noise. Among the available white noise sources, Amplaid ERA/ECochG Stimulus Generator was chosen as an appropriate broad-band noise source.

The Pathfinder II has another facility which allows the setting of the parameters from the keyboard by a command language, which is called MECOL. It is also possible to use the equipment by the MECOL. The complete control of the data processing, storage and retrieval is also possible with the use of The MECOL command language.

This software system (MECOL) allowed setting all of the parameters. The Pathfinder II could acquire the data parameters and display on the visual display unit also during the averaging. Data storage of the Pathfinder II was on a Winchester disc

of 10 megabytes or a floppy diskette. Completed averages of the ABR were plotted with an X-Y plotter (Hewlett Packard 7470 A Graphics Plotter).

3.3 Stimulus calibration

As in other audiological tests, it is essential to determine the magnitude of the stimulus in an ABR experiment. There is no established physical calibration technique for ABR stimuli. Two different calibration techniques, physical and biological, were considered to be sufficient for this experiment.

The physical calibration technique applied to the 2 kHz tone pip is called "peak-to-peak equivalent sound pressure level measurement". Diagram 3.1 illustrates the calibration procedure of the 2 kHz tone pip. The first step of this technique involves equating the maximum peak-to-peak voltage of the tone pip to that of a well-known calibrated pure tone stimulus. The amplitude of the tone pip were measured by the peak-to-peak, which can be described as the amplitude between the maximum positive peak and succeeding negative peak of the electrical spectrum. The 2 kHz tone pip stimulus was delivered through the TDH-39 transducer (300 ohm). The peak equivalent SPL (dB p.e. SPL) measurements of the tone pip were done by the 6-cc artificial ear (Brüel & Kjaer, type 4152), with a microphone (Brüel & Kjaer, type 4144) attached to the Audio Frequency Spectrometer (Brüel & Kjaer, type 2113) whose AC output was routed to an oscilloscope. The peak-to-peak voltage of the 2 kHz tone pip was matched to that of the continous sinusoid (i.e. 2 kHz pure tone, dB HL). These peak-to-peak amplitude calculations were done in 10 dB intervals between

70 dB to 120 dB value set by software control of the Pathfinder II. Finally, these matching dB HL levels were transferred to their dB SPL equivalents, by using the same Audio Frequency Spectrometer.

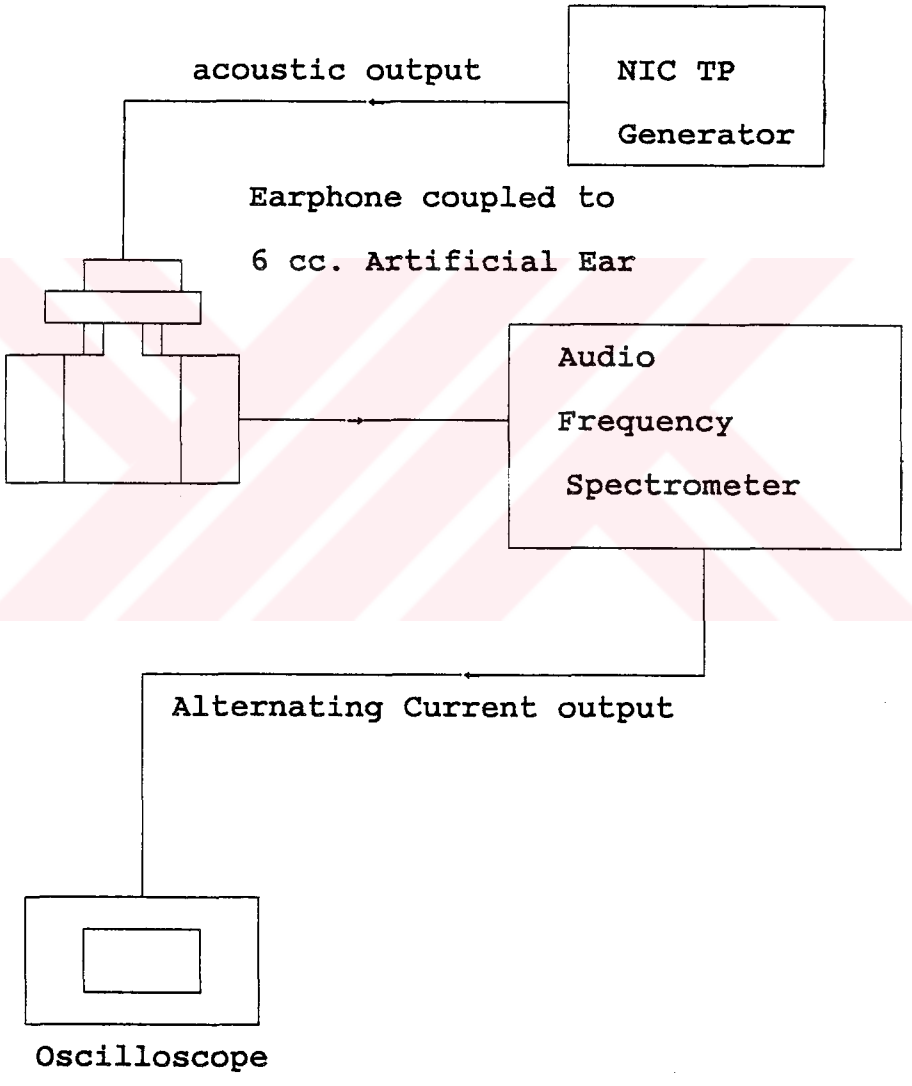

Diagram 3.1 The diagram of the calibration of the tone pip stimulus in the experiment.

According to the results of the calibration, the 2 kHz tone pip peak equivalent SPLs were 5 dB below the dial reading of the Pathfinder II (e.g. 100 dB value set by software control of the Pathfinder II was approximately equal to 95 dB p.e. SPL). The results of the calibration procedure are listed in table 3.1.

2 kHz TP stimulus	Peak-to-peak amp. of sti.	Equiv. of 2 kHz PT acc. to amp.	Equiv.of 2 kHz PT
Dial of NIC	in volts	in dB HL	in dB SPL
70	0.4	55	64.5
80	0.8	65	74
90	2.5	75	84.6
100	8	85	95
110	25	95	105
120	80	105	115

Table 3.1 The results of the peak-to-peak equivalent sound pressure level measurements (*).

Dial of NIC Pathfinder II = value set by software control of the Pathfinder II.

(*) Peak-to-peak amplitude of the 2 kHz tone pip (TP) was equated to the 2 kHz pure tone (PT) on an oscilloscope using the electrical output from the Audio Frequency Spectrometer.

The acoustic spectrum of the 2 kHz tone pip was analysed using the same artificial ear and connecting it to the Audio Frequency Spectrometer. The main peak of the tone pip was exactly at 2 kHz and there were side lobes at higher and lower frequencies. The side lobe with higher-frequency was at 2775 Hz and was relatively 14 dB below the main peak of the tone pip acoustic spectrum. The other lower-frequency

side lobe was at 1250 Hz and 15 dB below the level of the 2 kHz peak. The second order side lobes were about 30 dB below the main peak. Figure 3.1 shows the acoustic spectrum of the 2 kHz tone pip stimulus.

The second calibration procedure, biological calibration of the 2 kHz tone pip, was done before each ABR recording session. The biological calibration procedure was done in 5 dB steps in the ascending and descending method. In this study, 0 dB nHL (the average threshold of the normally hearing subjects to the 2 kHz tone pip) was equal to 35 dB value set by the software control of the Pathfinder II. This level was equal to 30 dB peak equivalent SPL. Table 3.2 illustrates the comparison of the mean values of the psycho-acoustic threshold for the 2 kHz tone pip present study with the others.

Study	Stimulus rate (rate/sec)	Stimulus duration (msec)	Threshold (dB pe SPL)
Davis et al.	40	2.5	20
Present study	11.1	2.57	30
Purdy et al.	41.7	3	24.4
Stapells et al.	10	2.5	26.1

Table 3.2 Comparison of the psycho-acoustic thresholds for the 2 kHz tone pip by various studies (quoted from a study by Purdy et al. 1989).

Appendix 3 shows the psycho-acoustic thresholds of the all subjects.

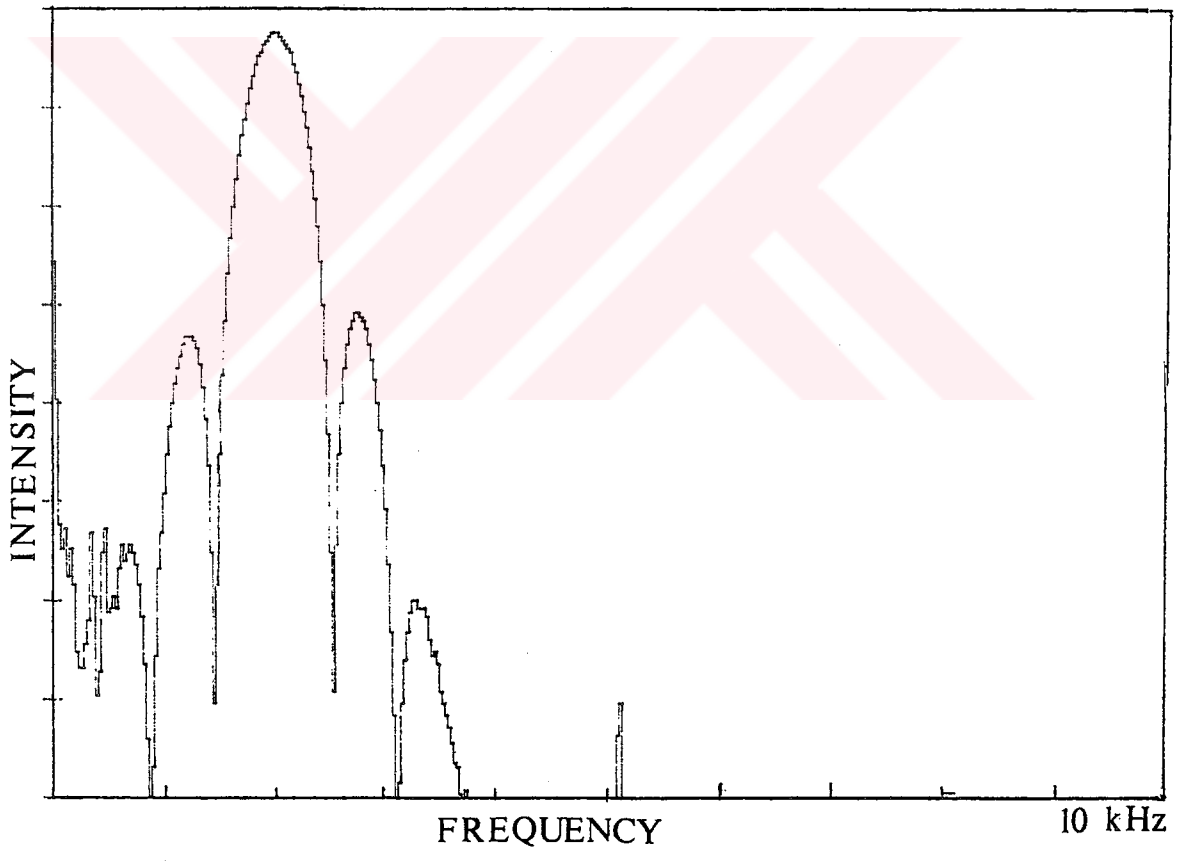

Figure 3.1 The acoustic spectrum of the 2 kHz tone pip

As stated, by analysing the acoustic spectrum of the 2 kHz tone pip, one of the major side lobes was at the frequency of 2775 Hz. In order to mask this side lobe, but not the the main peak, 2900 Hz was chosen as a suitable high-pass masker filter cutoff frequency. The spectrum of the 2900 high-pass filtered noise was fairly flat within the range of 5 dB between the frequencies of 2900 and 6000 Hz. Figure 3.2 illustrates the acoustic spectrum of the 2900 Hz high-pass noise. Noise levels fell about 26 dB from 2900 Hz to 2 kHz and approximately 26 dB from 6000 Hz to 8225 Hz. The noise level was calibrated in the 1/3 octave filter frequency values and were measured intensity levels in dB SPL (root mean square). The intensity level of the high-pass masking noise to be introduced ipsilaterally with the tone pip was fixed at 20 dB below the dB p.e. SPL equivalent of the 2 kHz tone pip. In a survey of frequency-specific ABRs, there is a similar proposal in setting the notched-noise with tone pip stimuli (Sohmer & Kinarti, 1984). They support the idea that the noise intensity can be set to 15 to 25 dB in intensity below the tone pip.

Broad-band noise was used for contralateral masking. As stated in section 3.2, some of the available white noise sources were evaluated. The Amplaid ERA/ECochG Stimulus Generator was chosen because of its fairly broad acoustic spectrum.

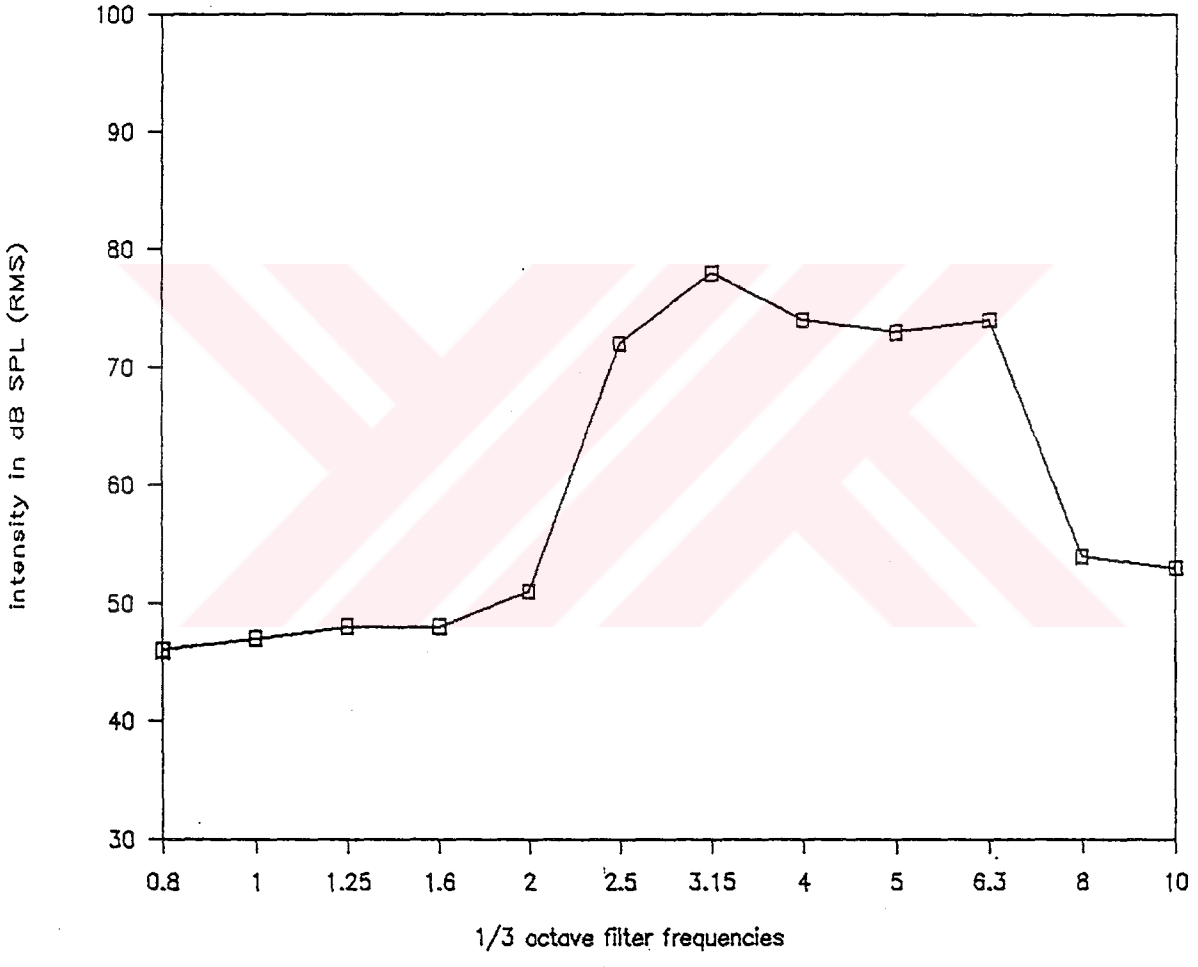

Figure 3.2 The acoustic spectrum of the 2900 Hz high-pass noise

Due to the characteristics of transducer, however, especially at high intensities, broad-band acoustic spectrum was disappearing. Appendix 8 illustrates the acoustic spectrum of the broad-band noise. The contralateral noise was employed 55 dB below the stimulus level. For click stimulus, it has been pointed out that the interaural attenuation is about 50 dB (Reid & Thornton, 1983).

3.4 ABR recording

Typically the ABR is recorded by measuring the potential difference between two points on the head (i.e. differential recording) In the differential recording and amplification processes, the measured total potential at the inverting electrode is subtracted from that of the total potential at the non-inverting electrode, and the difference multiplied by the gain factor, which is typically 100 000.

3.4.1 Electrode application procedure

Surface-applied silver/silver chloride dome-shaped electrodes were applied during the ABR recording. A three-electrode montage was employed according to the International 10-20 system. For a single differential recording channel, three electrodes were required: the non-inverting electrodes were labelled as A1 (left mastoid) or A2 (right mastoid) depending on the route of the auditory stimulus. The inverting (negative) electrode was labelled as Cz (vertex) and the common (ground) electrode was as Fpz (forehead). Figure 3.3 illustrates the electrode derivation applied in the study.

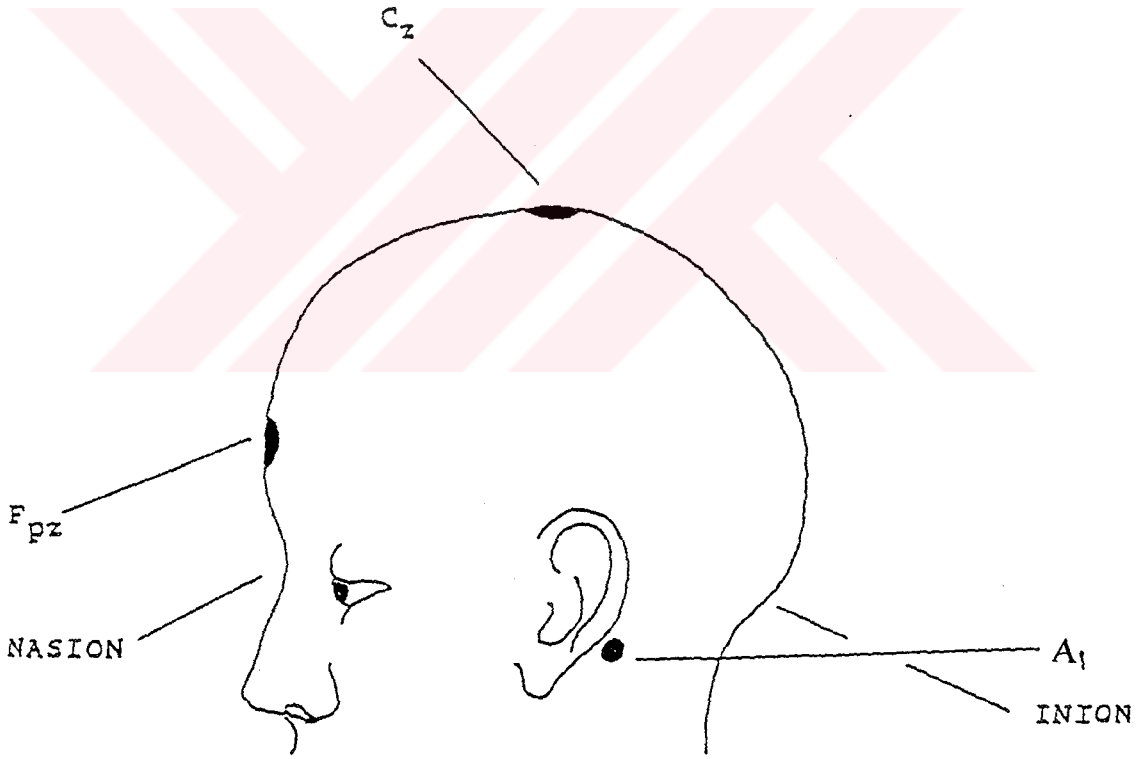

Figure 3.3 The electrode derivation applied in the study.

3.4.2 ABR waveform

As the evoked response is a bipolar recording, the visual appearance of the waveforms on the visual display unit was vertex negativity displayed upwards deflection. In the thesis, the waveforms were displayed with vertex negativity upwards.

3.4.3 Electromagnetic contamination of the ABR

At high stimulus levels, the ABR was contaminated with the electro-magnetic radiation pick-up (electromagnetic pick-up at both electrodes due to radiation from the transducer). To limit this problem, an unshielded TDH-39 transducer which was used to deliver the stimulus was fitted with a screened cable. Additional care was taken to reduce the electro-magnetic artifact, by placing all the electrodes as far away from the transducer as feasible. Nevertheless, it was not possible to record "noise free" ABR waveform, especially at high intensity levels, such as 120 and 125 dB p.e. SPL. This created only a slight problem in measuring the JV latency, because the artifact was affecting mainly the early components of the response.

3.4.4 Electrical impedance between the skin and the electrodes

Electrical impedance between the skin and the electrodes is an important issue, if it is expected to get reliable ABR results. It is recommended to keep impedances under the level of 5 kΩ (Hyde, 1985). Necessary care was taken to keep the impedances as low as possible. Most of the impedances were in the order of 1 to 2 kΩ. But to get reliable and clear ABR, it is also important to keep the elctrical impedances in balance (Hyde, 1985). To maintain the common-mode rejection facility

of the pre-amplifier effective, it is essential to obtain balanced impedance between the electrodes. One of the preamplifier's ability is to selectively reject a common-mode signal while passing a differential signal (for the function of the differential recording and amplification processes, see section 3.4). The preamplifier by this common-mode rejection facility rejects the signals which are common to both inverting and non-inverting electrodes.

3.4.5 Other parameters of ABR recording

For the research purposes, the recording bandwidth of the ABR was set to 30-3000 Hz. According to the results of a digital filtering experiment (Thornton, 1984), amplitude of the JV can be maximized for low-frequency limits of 20-40 Hz. A high-frequency cutoff of at least 3000 Hz is needed for resolution of the high-frequency components of the ABR (Jewett and Williston, 1971). The Electric Response Study Group recommended that the filter band-pass should be set in the range of 30 Hz to 3000 Hz (Thornton, 1983).

Table 3.3 summarizes the recording parameters of the ABR to 2 kHz tone pips.

Parameters of recording	Condition for ABR
Low cutoff frequency	30 Hz
High cutoff frequency	3000 Hz
Sensitivity of the amplifier	50 microvolt
Number of averages	2048
Analysis time	20 msec

Table 3.3 Recording parameters of the ABR to 2kHz tone pip in this experiment.

3.5 Stimulus parameters

In order to elicit the ABR, 2 kHz tone pip in 2900 kHz high-pass masking noise was used. The 2 kHz tone pip rise-plateau-fall periods were 2-2-2 cycles (nominally 3 msec). The tone pip was generated and attenuated by NIC SM-400 Auditoy Stimulator and fed to an unshielded TDH-39 transducer (the same transducer was used to deliver stimulus, during the calibration procedure and throughout the experiment). Broad-band stimulus was supplied by the NIC SM-700 Auditory stimulator noise synthesizer and then send to the Kemo filter to shape as a continous high-pass filtered white noise. The slope of the filter was set to 136 dB/octave. In order to rule out the contribution of the high-frequency basal end of the basilar membrane to responses elicited by the 2 kHz tone pip, the cutoff frequency of the masker was set to 2900 Hz. After white noise is filtered as a 2900 high-pass masking noise, it is routed to the Auditory Stimulator to be mixed with the 2 kHz tone pip stimulus.

The 2 kHz tone pip was presented in alternating polarity and a rate of 11.1 per second, with the duration of 2.57 msecond. Table 3.4 summarizes the stimulus parameters.

Stimulus parameter	Condition of the 2 kHz TP
Stimulus envelope	Hanning type
Stimulus duration	2.57 msec (measured)
Stimulus rate	11.1/sec
Interstimulus interval	87.34 msec
Stimulus polarity	Alternating

Table 3.4 Parameters of the stimulus used in the study.

In the form and limitations described in this chapter, the stimulus was presented and resulting ABR waveforms were averaged by the Pathfinder II. Finally, a set of averaged waveforms was saved on a floppy diskette for subsequent analysis.

CHAPTER 4

METHODOLOGY

CHAPTER 4

METHODOLOGY

4.1 Subjects

In this experiment, 16 otologically and audiologically normal adults (4 female, 12 male), ranging in age from 27 to 35, served as subjects. All subjects voluntarily participated in the study. The majority of them were postgraduate students in the University of Manchester. Some of the subjects attended two recording sessions (six subjects were tested bilaterally), others attended only one recording session (ten subjects were tested monaurally). All subjects had normal hearing thresholds within 15 dB of audiometric zero for the octave frequencies between 250 Hz to 8 kHz (ISO, 1964). Before each session they were asked to fill in the hearing questionnaire to ensure there were no significant otological problems that they were aware of (see appendix 1 for the hearing questionnaire).

Criteria established for the subjects included in this study were as follows:

1. No history of ear pathology,
2. Bilateral air conduction thresholds no poorer than 15 dB HL (re 1964 ISO audiometric standard) at the octave frequencies 250 Hz through 8 kHz,
3. Otoscopic examinations, tympanometric and acoustic reflex recordings would be within normal limits,
4. Age would be in the range of 25 to 35,
5. Estimated LDLs for 2 kHz pure tone and 2 kHz tone pips of subjects would be within the range of the audiometric equipment.

4.2 Experimental design

The experiment was designed to look at the relationship between the latency of the JV and LDL of the normally hearing adults, using frequency-specific stimuli. In both of these audiological procedures, in order to be able to make comparison between subjective LDL and ABR data, the 2 kHz tone pip was used.

Initially, the LDL of each subject for the 2 kHz tone pip was estimated. Subjects were asked to come back on another day for ABR recording. ABR waveforms were recorded under the condition of presenting a series of stimulus levels 5 dB apart. This stimulus level presentation was in random order (that is: LDL-35 dB p.e. SPL / LDL-15 dB p.e. SPL / LDL-20 dB p.e. SPL .. and so on). The maximum intensity level to be introduced was kept 5 dB below the LDL of each subject. In this experiment the upper limit of tone pip intensity used was 125 dB p.e. SPL. In each recording session, ABR waveforms were obtained for at least 5 intensity levels. Five intensity levels seemed to be a reasonable number, in order to compare the shifts in JV latency (five intensity levels would be enough to calculate JV latency shifts at 4 levels). All the waveforms were replicated at each intensity level on a regular basis.

4.3 Statistical methodology

The purpose of the project was to look at the relationship between the JV latency and the LDL. At each intensity level, averaged ABR recordings were replicated. After calculating the JV peak latency of the ABR waveforms, the mean JV latency for each pair of recordings was calculated. For further statistical analysis these mean JV values will be used.

The first step in the statistical analysis, will be to determine whether the JV latency and shift in JV latency values have distributions which are significantly different from normal. If their distributions are normal, parametric tests will be carried out. Otherwise, either non-parametric tests will be applied or there will be appropriate transformation for normalising the data.

Since these measurements are taken from an individual at a series of changing intensity levels, the statistical analysis must consider the repeated measures design of the experiment. The study done by Thornton et al. (1987) suggests a lack of homogeneity in the variances, so the analysis must also take account of this problem.

A repeated measures analysis of variance (using MANOVA on SPSS) will be estimated to compare the levels of both the JV latency and shift in JV latency over intensity. Intensity levels will be analysed with reference to the LDL and SL of each individual.

A justification of the result of the homogeneity of variances will also be made by using other tests (Greenhouse-Gessen, Huygn-Feldt and Lower Bound Statistics) which are avaliable on SPSS (a computer programme called Statistical Package for Social Sciences).

4.4 Experimental Procedure

First of all, the procedure and purpose of the experiment was explained to each subject. After that, subjects were asked to fill in the brief adult hearing questionnaire

and then their otoscopic examinations were conducted to establish that there were no contraindications to proceed with testing, such as any current infection in the external and middle ear, or excessive cerumen in the external auditory meatus.

In the preliminary audiological testing session, air conduction thresholds of both ears of each subject were determined using a regularly calibrated Amplaid Audiometer Model 400 (HL in dB re: ANSI S 3.6, 1969-ISO 389) by the standard ascending-descending method. This measure was used in order to eliminate the subjects who were not normally hearing. Normal limits of the hearing were defined for the purposes of this study as within 15 dB of 0 dB HL from 250 to 8000 Hz. Additionally, to eliminate certain middle ear diseases, tympanometric examinations were carried out and acoustic reflex thresholds were determined with a Grason Stadler GS1 28A impedancemeter.

To estimate the sensation level of each subject for the ABR stimulus, psycho-acoustic thresholds for the 2 kHz tone pip stimulus were determined. This was done in 5 dB steps with the standard ascending-descending method. The Nicolet Pathfinder II was used as a stimulus generator in estimating the psycho-acoustic threshold for the 2 kHz tone pip.

After testing the psycho-acoustic thresholds, LDL of each subject for pure tones and 2 kHz tone pip for both ears was estimated. This LDL estimation procedure was

designed in a way such that subjects were to judge the loudest level of any stimulus that they would not be able listen to for a short duration. For both LDL estimations, the instruction was exactly the same:

"Now you are going to hear some sounds. These sounds might gradually get louder. I would like you to tell me whenever the level of the sounds get "too loud", that you would not prefer to listen them for any for any duration of time."

For either stimuli, sound exposure of the subjects per stimulus presentation was not more than 5 seconds. The pure tone was presented for 1-2 seconds, first at 70 dB HL, and then by increasing in 5 dB steps with a few seconds pause between each presentation. LDLs for pure tones and tone pip of each subject were estimated using the ascending order method.

On another day, an ABR recording session was carried out. Preliminary audiological and ABR tests were performed in a quiet but not a sound insulated room. Before every recording, the ABR recording procedure was explained to subjects in detail. Basically, instructions were to keep movement at a minimum and to sleep if possible. Although all subjects were encouraged to end the experiment whenever they felt that they were unable to tolerate the loud stimulus, subjects did not report any uncomfortable session at all.

The ABR electrode sites were cleaned by cotton wool soaked in alcohol. The electrodes were attached with electrode gel and secured with surgical tape whenever necessary. The ABR recording apparatus consisted of an array of surface-applied

silver-silver chloride electrodes (the electrode application procedure described in section 3.4.1). A three-electrode montage was employed according to the International 10-20 system. These electrodes were attached on the head as follows: Fpz, forehead on the mid-sagittal axial near the hairline ; A1 or A2, high mastoid area ; Cz, vertex. 2 kHz tone pip and high-pass masking noise presented monaurally and the recording configuration was vertex to ipsilateral mastoid.

Following this, the electrodes were plugged into the electrode impedance box and their electrical impedances measured. An effort was made to drop the impedance as low as possible. Whenever the impedance dropped to an acceptable level (1 kiloΩ), the lights in the room were turned off and then the subject reclined in a comfortable armchair. In the last step of the experimental procedure, the ABR was recorded and an averaged series of waveforms saved on a floppy diskette for subsequent analysis.

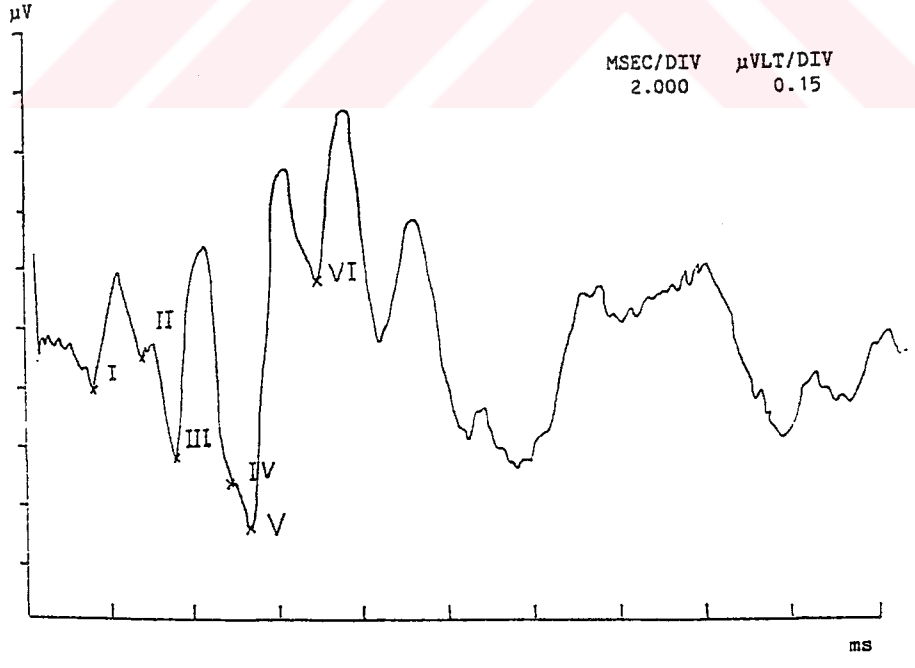

Figure 4.1 A typical ABR waveform to click stimulus.

Wave V : Jewett V (JV)

CHAPTER 5

RESULTS

CHAPTER 5

RESULTS

As stated earlier in the experimental design, ABR waveforms were recorded twice for each level of the stimulus. In order to develop the latency-intensity function of each subject in a reasonable time for the subjects, there was no chance to replicate the recordings at each intensity level more than twice. During on-line analysis of the waveforms, some of the waveforms which seemed to be contaminated by artifacts, due to movements of the subjects, were eliminated from the recordings. Otherwise, partly due to time limitations, there was limited a opportunity to eliminate the waveforms that were not securely replicated. The contaminated waveforms were not included in the statistical analysis.

5.1 Criteria for measuring the 2 kHz tone pip JV latency

For this particular study, in order to measure the absolute JV peak latency, it was necessary to define the relationship between the beginning of the stimulus and the onset of the waveforms in the averaging process. By measuring the onset of the electro-magnetic artifact in the averaged ABR waveform (which was due to stimulus), it was concluded that there was a 0.200 msec delay between the onset of the stimulus and the ABR averaging process. Thus, these latency measurements are calculated according to this delay.

The expected absolute latency time of the response to the 2 kHz tone pip stimuli at moderate-to-high intensity levels was in the range of 5 to 9 ms. This range of JV latency correlated with some of the results of Picton et al., (1979). At low-to-moderate

intensity levels, often the JV peaks were fairly well replicated and had an latency value of expected range in the ABR waveform. Only at very high intensities (such as 120 or 125 dB p.e. SPL) the JV peak identification was a problem.

The JV peak identification procedure was as follows:

-A single wave where expected was labelled as JV

-If many waves were displayed, the most prominent and consistent wave was taken as JV.

-If many local minima were displayed, the final peak before a large negative-going trough was labelled as JV.

A set of ABR waveform and JV identifications from a subject is illustrated in figure 5.1.

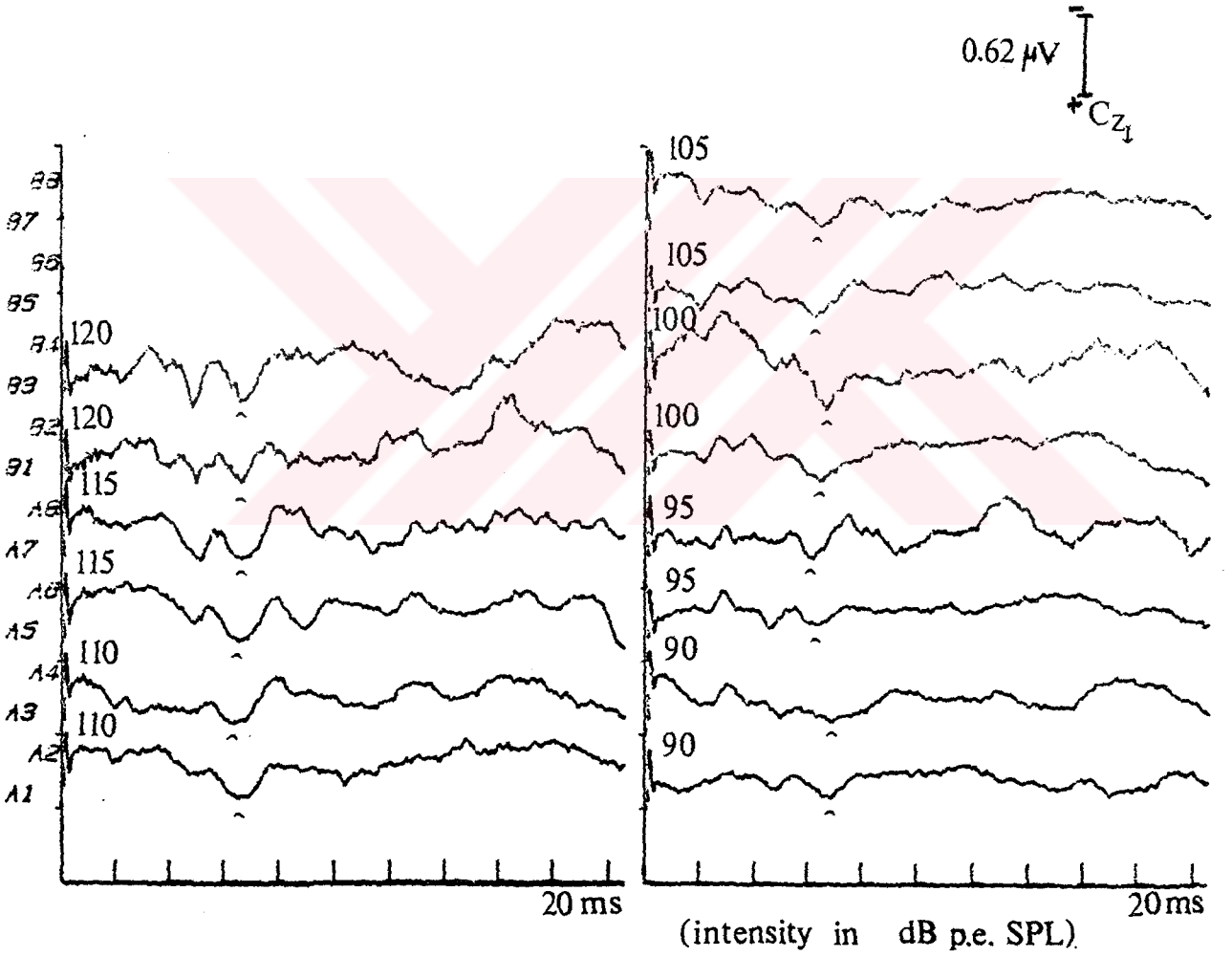

Figure 5.1 A set of representative waveform.

5.2 Analysis of the results

22 sets of ABR recordings from 16 subjects were completed. Each set of recordings contained responses to different intensity levels. At each intensity level, two recordings were made. Absolute JV latency results of each subject were obtained according to the criteria stated above. Appendix 4 shows the individual JV latency values of all subjects in 5 dB steps relative to their individual LDLs.

5.2.1 The relationship between the JV latency and stimulus intensity relative to LDL

In the first step of the analysis, the mean JV latency with decreasing intensity relative to LDL were calculated. These means and standard deviations of the JV latency values, at stimulus levels relative to LDL are shown in Table 5.1.

Stimulus Level (in dB re LDL)	Mean JV Latency (ms) & n	Standard Deviation (ms)
LDL-5	6.299 (n:22)	0.375
LDL-10	6.356 (n:22)	0.308
LDL-15	6.400 (n:22)	0.306
LDL-20	6.413 (n:22)	0.474
LDL-25	6.499 (n:22)	0.508
LDL-30	6.585 (n:19)	0.523
LDL-35	6.628 (n:17)	0.521
LDL-40	6.722 (n:9)	0.793

Table 5.1 Means and standard deviations of the JV latency values at intensity levels relative to LDL.

It can be seen that the mean peak latency values of the JV increase as the stimulus levels decrease relative to LDL. Estimated standard deviations of the mean JV latencies were fairly high and were increased as the JV latencies increase. But comparison of the measurements at the low stimulus intensity levels (e.g. LDL-40 dB) with the moderate-to-high levels would not be valid because of very small samples in the group of low stimulus levels.

5.2.2 The relationship between the rate of the change in the latency with LDL relative intensities

In the following step, the JV latency differences resulting from two intensities relative to LDL of each subject were calculated. This calculation can be expressed as follows:

(JV latency at LDL-10 dB) minus (JV latency at LDL-5 dB),
(JV latency at LDL-15 dB) minus (JV latency at LDL-10 dB),
(JV latency at LDL-20 dB) minus (JV latency at LDL-15 dB), ...etc.

The results of this calculation are listed in appendix 6. In the following discussion, the difference between the two JV latencies resulting from intensities 5 dB apart, is expressed as "slope" of JV latency. It was noted that (see appendix 6), the slope of the individual JV latency did not indicate any valid relationship within intensity levels.

5.2.3 The relationship of the JV latency with the stimulus intensity relative to sensation level of the subject

For further statistical analysis, the stimulus intensity levels were converted to sensation level dB. After this conversion, standard deviations of the JV latencies at

intensity levels relative to sensation levels were also calculated.

Stimulus intensity dB Sensation Level	Mean JV latency (ms) & n	Standard Deviation (ms)
95	6.283 (n:11)	0.381
90	6.358 (n:14)	0.290
85	6.385 (n:21)	0.313
80	6.402 (n:21)	0.496
75	6.490 (n:22)	0.533
70	6.587 (n:21)	0.554
65	6.630 (n:18)	0.538
60	6.722 (n:14)	0.763

Table 5.2 Mean and standard deviation of the JV latency values after conversion of intensity into dB SL.

5.2.4 The JV latency as a function of the stimulus intensity

In order to establish the latency-intensity function of JV, the stimulus was converted to dB p.e. SPL. Figure 5.2 shows the mean latency of JV for 2 kHz tone pip as a function of intensity. Table 5.2 illustrates the mean and standard deviation values of the JV latency at corresponding intensities.

Stimulus Intensity (dB p.e. SPL)	Mean JV latency (ms) & n	Standard Deviation (ms)
120	6.223 (n:15)	0.405
115	6.363 (n:20)	0.357
110	6.387 (n:22)	0.363
105	6.418 (n:22)	0.480
100	6.446 (n:21)	0.440
95	6.606 (n:21)	0.497
90	6.590 (n:16)	0.443
85	6.844 (n:9)	0.672

Table 5.3 The means and standard deviations of the JV latency values (intensity in dB p.e. SPL).

There was a decrease in the mean JV latency with increasing stimulus intensity. It can be recognized from these tables (tables 5.2 and 5.3), that the same relationship can be observed when the stimulus is converted into other parameters (dB SL and p.e.SPL). But this relationship was not present in the latency-intensity functions of JV for all subjects.

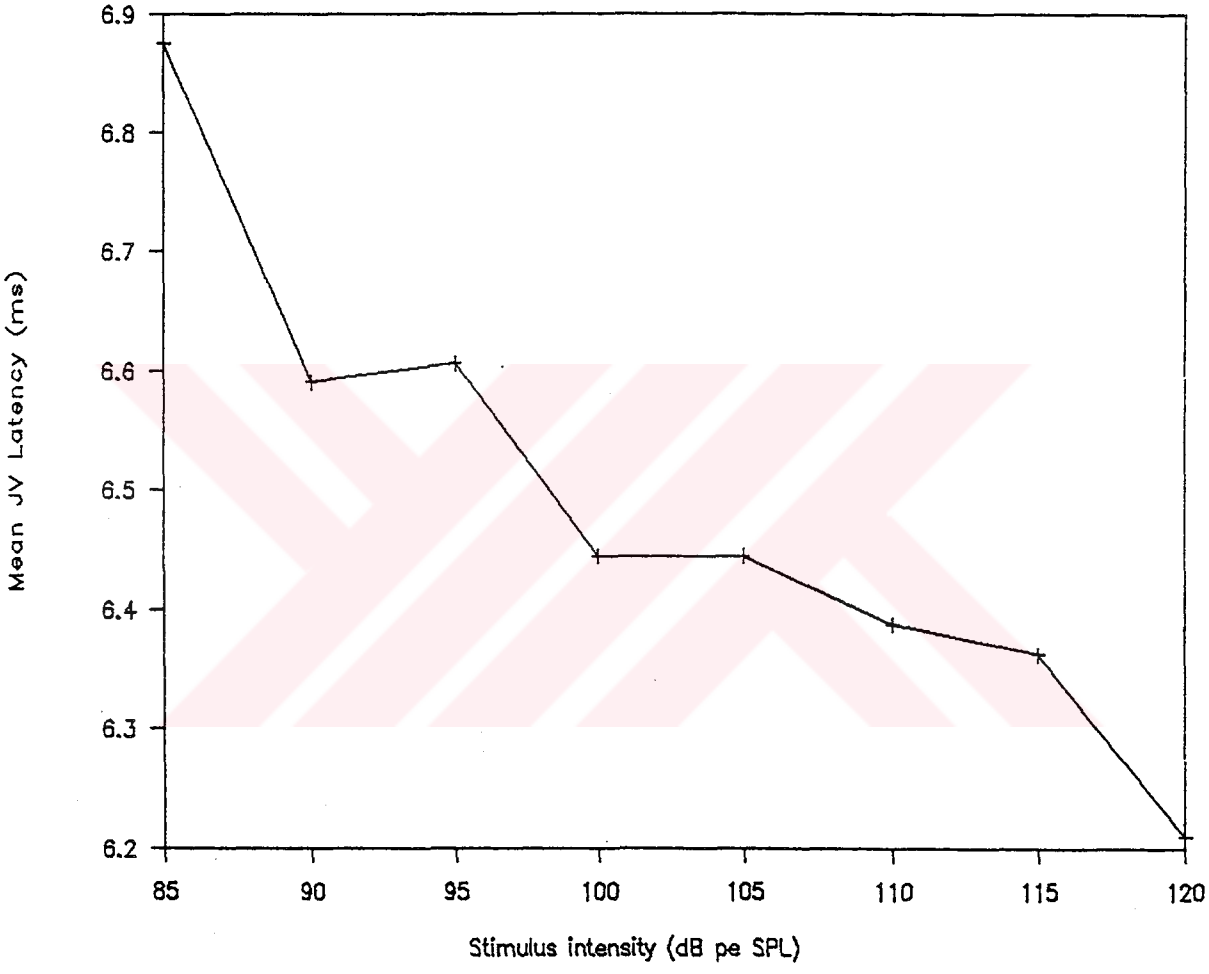

Figure 5.2 The relationship of the mean JV latency and stimulus level (intensity in dB p.e. SPL).

5.2.5 The statistical distribution of the data

As regards the statistical analysis, the basic question to be answered was related to the distribution of all the data obtained in this experiment. If the data are distributed normally, or approximately normally, then parametric tests can be used. However, if the distributions differ significantly from normal, in that case non-parametric tests will have to be applied or appropriate transformation carried out to normalise the data (Thornton, 1975). Therefore, the distributions of all the JV latency values were tested for normality (e.g. the results of all JV latency measurements, mean values of JV latency, JV latency differences at the intensities of 5 dB apart from each other).

In two ABR studies (Thornton, 1975; Parker, 1977), however, the JV latency values had normal distributions, their standard deviation was related to the magnitude of the mean JV latency. Hence, in their study, it was decided that logarithmically transforming the data would yield more valid parametric statistical analyses. In the present study, a trend towards a decrease in the in the mean and standard deviation of the JV latency with increasing stimulus intensity level was noted (table 5.2). As the present study was not designed to compare the effects of low and high intensity levels on the ABR parameters, the samples of the groups which presented in the tables 5.1, 5.2, and 5.3 were different from each other (especially, LDL-40 group with very high standard deviation was very small, n=9). All the individual JV latency values across their associated standard deviations were plotted on a graph. From this graph, it was concluded that there was no "visible" relationship between the individual JV latency values and their standard deviations.

In the present study, the Kolmogorov-Smirnov one-sample test (Siegel, 1956) was used to test the distributions of the data for any significant departure from the normal. The distribution test results of all JV latencies were not significantly different from normal.

The test of normality (Kolmogorov-Smirnov test) was also carried out for the slope of the JV latency-intensity function (JV latency differences resulting from changing the intensities in 5 dB steps). By using the same Kolmogorov-Smirnov one sample test, all the slope values were within normal distribution. Appendix 7 summarizes all the normality test results.

As was mentioned in the statistical methodology section, testing the data for normality would clarify the way of the statistical analysis. Since all the data had a normal distribution, parametric tests would be carried out.

5.2.6 Effect of changing stimulus levels on the JV latency measurements

As stated in the section 4.3, the main purpose of this experiment was to find a stimulus level (or levels) that would have an effect on the changing JV latency which will differ significantly from the others. To test the significant effects of changing stimulus on to the JV latency data, repeated measures analysis of variance was used. In carrying out tests of statistical significance, null hypothesis should be stated.

The values of JV latency and their shifts by changing the stimulus level, were tested by using the repeated measures analysis of variance (MANOVA), with the following null hypothesis (H_o):

$$H_o = \mu_1 = \mu_2 \ldots\ldots \mu_n = \mu \quad (\mu\text{=the population mean})$$

where significance level (α) is 0.05. The MANOVA relies on certain assumptions, such as testing only the completed set of data. But this experiment was not designed to record ABR at the same time and consistent intensity levels for all subjects. While testing the JV latency values and shifts in JV latency according to LDLs of the subjects with the MANOVA, 6 out of 22 cases, were rejected because of "missing data". When using the MANOVA for the data which was organized with reference to either sensation level of the subjects or peak equivalent SPL, more cases were rejected.

An analysis of variance regarding the JV latency and shift in JV latency under the condition of changing the intensity (in dB p.e. SPL) in 5 dB steps relative to LDL value, yielded no significant difference between the cases. Results of the MANOVA showed that the neither the JV latency nor the shifts in JV latency varied significantly as a function of level. Another MANOVA designed to investigate the effect of LDL values of the subjects and the differences in the JV latency resulting from changing the intensities (in dB p.e. SPL) in 5 dB apart showed similar results. Results of MANOVA with the shifts in JV latency with decreasing the intensity are summarised in table 5.4.

Source of Variation	Sum of squares	Degree of freedom	Mean squares	F	Sign. of F
Within cells	3.20	30	0.11	ND	ND
LDL (*)	0.17	2	0.09	0.82	0.452

Table 5.4 MANOVA of the difference in the JV latency measurements.

(*) : JV latency differences resulting from LDL relative intensities.

Explanation of the data used in the MANOVA is as follows: the intensity levels used to calculate the JV latency differences was in the range of LDL-5 dB to LDL-20 dB of each subject. The change of intensity was in 5 dB steps.

Calculation of differences in the JV latency resulting from the intensity levels (in dB p.e. SPL) relative to LDL is listed :

Diff1:JV latency at LDL-10 dB minus JV latency at LDL-5 dB

Diff2:JV latency at LDL-15 dB minus JV latency at LDL-10 dB

Diff3:JV latency at LDL-20 dB minus JV latency at LDL-15 dB

As explained in section 4.3, a justification of the outcomes was made by conducting the homogeneity tests of variance. Their results confirmed the results of the MANOVA.

The last step of the statistical analysis was based on the shifts in JV latency resulting from the intensity changes in dB sensation Level. In this case, JV latency values were grouped according to the LDLs of the subjects but in terms of dB SL. To

be able to make comparisons also within the groups, the minimum subject number within each group had to be 2. Thus, the subjects were seperated into 5 groups according to their LDL. These groups and number of subjects within the groups are as follows:

Group 1. consisted of 2 subjects with LDL=105 SL,

Group 2. consisted of 8 subjects with LDL=100 SL,

Group 3. consisted of 3 subjects with LDL=95 SL,

Group 4. consisted of 5 subjects with LDL=90 SL,

Group 5. consisted of 2 subjects with LDL=85 SL.

For calculating the shifts in JV latency resulting from changing the intensity in 5 dB steps, the same principle was applied, as was described above for the table 5.5. This is summarized below:

Diff 1: JV lat.change at LDL-10 dB SL minus JV lat. change at LDL-5 dB SL,

Diff 2: JV lat.change at LDL-15 dB SL minus JV lat. change at LDL-10 dB SL,

Diff 3: JV lat.change at LDL-20 dB SL minus JV lat. change at LDL-15 dB SL...

etc.

The two way analysis of variance was applied to the data. In this analysis there were two variables. The first variable was shift in JV latency (Diff 1/2/3/4) and the second was the group of the same LDLs (Group 1/2/3/4/5).

The results of the analysis of variance did not show any statistically significant difference between the shifts either within the groups or between the groups, at the

significance level of 0.05. But only one design of analysis, which is summarized in the table 5.5, showed borderline significance at the level of 0.05.

Source of variation	Degree of freedom	Sum of squares	Mean squares	F ratio	F prob
Btw. groups	1	0.0887	0.0087	4.669	0.0536
Within group	12	0.2976	0.0190	ND	ND

Table 5.5 The result of one design of the analysis of variance of JV latency. It is the analysis of 2 groups of with LDL=105 and LDL=100 dB SL.

In the table 5.5, the first variable was Diff3 and the second variable was Group 1/2. Diff 3 is equal to JV latency difference resulting from changing the intensity from LDL-20 dB SL to LDL-15 dB SL. Group 1 was the group of the subjects with LDL=105 dB SL and the group 2 was the group of the subjects with LDL=100 dB SL.

5.3 Summary of the statistical analysis

On the whole, JV latency as a function of intensity, and the slope of the latency-intensity function have been analysed. The obtained data had normal distribution. Since the experiment consisted of repeated measurements, data was tested by MANOVA. The results of MANOVA demonstrated that the shifts in JV latency by increasing the intensity yielded no significant difference between the different LDL relative intensity levels.

CHAPTER 6

DISCUSSION AND CONCLUSION

CHAPTER 6

DISCUSSION AND CONCLUSION

The latency-intensity function of the ABR to 2 kHz tone pips at high stimulus intensities has seldom been the focus of attention in the literature. In particular, combining the 2 kHz tone pip with high-pass masking noise as a stimulus has rarely been the topic of investigation. This is surprising given the widely held belief that the tone pip is a much more promising stimulus to elicit a response with useful frequency-specific threshold information (Suzuki & Horiuchi, 1981). However, frequency-specificity is not good for tone pips alone at suprathreshold, and therefore, it requires the addition of high-pass masking noise (see section 2.3). Thus, there are some difficulties in comparing the results of this study with those of others.

The first purpose of the present study was to establish normative data on the JV latency-intensity function and the slope of the JV latency-intensity function of the frequency-specific ABR. The second purpose was to predict the LDLs of the same subjects based on this normative data. The results of these investigations will now be discussed.

As indicated in previous studies (Hayes & Jerger, 1982; Picton et al., 1981), mean JV latency in this study decreases as the signal intensity increases. This relationship was valid even after converting the stimulus into different parameters (i.e. sensation level and dB p.e. SPL). But when the individual JV latency-

intensity functions were analysed in detail, it was difficult to establish this relationship for all individual responses.

In the present study, using the 2 kHz tone pip stimulus in 2900 Hz high-pass masking noise, the latency-intensity function of wave V (JV) did not give a reliable indication of the LDL of the subjects. Contrary to the results of Picton et al. (1981), the latency-intensity function of the 2 kHz tone pip response did not produce a linear relationship. In fact, in order to rely on the latency-intensity function of this stimulus combination (2 kHz tone pip in high-pass masking noise), it is necessary to establish the normative criteria for the particular equipment (that is Nicolet Pathfinder II). Most laboratories establish their own normative data for the latency-intensity function of JV latency (Stockard & Stockard, 1983). But there is no established normative data of the latency-intensity function of this stimulus combination (2 kHz tone pip in high-pass masking noise) for the Nicolet Pathfinder II.

This experiment additionally evaluated the slope of the latency-intensity function of the JV. The slope of the latency-intensity function of the 2 kHz tone pip varied among the intensity ranges. In the present study, in order to demonstrate the slope of the latency-intensity function, the ABR was recorded at various stimulus levels relative to LDL. As explained in chapter 5, analysis of variance showed that there is statistically no significant difference between the shifts in the JV latency resulting from LDL relative intensity changes. When the stimulus was converted into dB Sensation Level, the results of the analysis of variance were similar : there was no statistically significant difference between the shifts in the JV latency due to changing the intensity

(in dB SL) relative to LDL. But there was a "borderline" significance of the shifts in JV latency resulting from changing the intensity from LDL-20 dB SL to LDL-15 dB SL. The borderline significant difference of the "intermediate" levels of this experiment was analysed according to the results summarized in the appendix 8. The shifts in JV latency resulting from changing the intensity from LDL-15 to LDL-20 dB SL, were slightly smaller than the higher or lower intensity levels.

As far as JV latency values of the 2 kHz tone pip are concerned, the results of the present study show that they are in the range of 5.26 msec (minimum) to 8.06 msec (maximum)(see appendix 5). The two highest JV latency measurements belong to the recordings from the same subject listed in the appendix 5 as 6/R and 6/L.

JV latency data obtained in the present study showed high variability. This variability of the JV latency at changing intensity levels, was more than expected. The standard deviation of the JV latency value (see tables 5.1, 5.2 and 5.3) was at least three times bigger than the standard deviation of the JV latency to click stimuli (Parker, 1981). Possible reasons of this variability of the data are dealt with below.

Because of the use of high intensity levels, the early portion of the ABR was contaminated by the electro-magnetic artifact. By further increasing the intensity, the electro-magnetic artifact partly obscured the evoked potential waveform and caused a slight difficulty in the identification of JV.

Apart from the electro-magnetic artifact, there were additional problems, which were degrading the response. One of the identifiable problem was biological noise. Especially at high intensity levels, such as 115 to 120 dB p.e. SPL, in the averaged waveform there was a high level of biological noise (eye movements, other muscle movements etc.), since with a loud sound in the ears, subjects had difficulty in keeping still. A widely recognized measure to reduce the electro-magnetic artifact is to use a shielded transducer (Cooper & Parker, 1981). At high intensity levels, however, the transducer, fitted with a screened cable, did not reduce the artifact effectively. These factors combined at high intensity levels and increased the variability of the JV latency.

In the present study, the stimulus level of the ABR has been presented according to the subjective decisions of the subjects (i.e. according to their LDLs). In other words, the results of the present study depend on obtaining consistent LDL measurements from the subjects. As explained in section 2.4, the LDL is affected by numerous variables which can not be easily controlled. Indeed, even when simple and clear instructions were used to obtain the LDL of the subjects, it was observed that each subject was using a different "scale" to indicate the relative magnitude of the sensation of the increasing stimulus. ABR stimulus levels used in the present study were highly dependent on the subjective LDL measurements, which are difficult to control. This may have increased levels of the variability in the ABR measurements.

The shift in JV latency as a function of frequency was also investigated by several authors. One of the relevant studies was carried out by Picton et al., (1979).

In their study, they used notched-noise to mask the frequency spread of acoustic energy in the brief tone pips that are used to elicit the ABR. By employing different frequencies of tone pips in notched-noise, they evaluated the frequency-specificity of this technique. Their result supported the view that the ABR to tone pips in notched-noise produces more frequency-specific information than the ABR to tone pips alone. In their study, Picton et al. analysed the mean JV latency as a function of intensity (changing in 10 dB nHL steps) of the ABR to 2 kHz tone pip. The intensity was in the range of 0 to 80 dB nHL. They found that the latency-intensity function for the response to tone pips in notched-noise was approximately linear and was roughly parallel between frequencies. Among the tone pip frequencies of 0.5, 1, 2, and 4 kHz, the measurements of the latency-intensity function of the 4 kHz stimulus was less variable than the others.

There is a study in which filtered clicks were used as well as broad-band clicks (Klein & Teas, 1978). In their study, an attention was on the effect of different frequency signals on the evoked response. In an attempt to describe the evoked response to the different frequency of filtered clicks, it has been focused on the JV latency shifts. Filtered clicks with center frequencies of 0.5, 1, 2, 4, and 8 kHz were used to elicit the ABR. The JV latency shifts were evaluated as function of both frequency and intensity of stimulus. Contrary to the results of Picton et al. (in which latency-intensity function curves of 4 different frequencies of tone pips were parallel), the latency-intensity function curves of 5 different frequency filtered clicks were not parallel. That is, the lower the frequency of the filtered click, the steeper the curve becomes. Two of the curves, which belong to 4 and 8 kHz filtered

clicks, behave in a similar way (both of their slopes are lower if compared with lower frequencies). Comparison of the results of these studies may contribute to the discussion on the frequency-specific latency-intensity function. Low-frequency stimulus at low levels initiates a travelling wave nearer to its nominal frequency, but at high intensity levels, it will evoke a response which may have originated from the high-frequency fibres. Probably this is the reason for the steeper slope of latency-intensity function at low-frequency filtered clicks. But a frequency-specific stimulus will produce a well ordered linear latency-intensity function (therefore, in terms of frequency-specific information, the results of Picton et al. are much more valuable). Since Klein and Teas did not use any measure to control for recruitment of high frequency fibres with increasing intensity (such as employing high-pass masking noise), they were unable to gather frequency-specific information. Additionally, Klein and Teas commented on the amount of decrease in JV latency due to increases in stimulus intensity by changing the stimulus frequency. The decrease in JV latency due to increases in stimulus intensity was greatest for low frequencies and least for high frequencies. The results of their study support the view that each frequency has its own latency-intensity function. This study raised the question of comparing the latency-intensity function of one stimulus with the others.

Thornton et al. (1987) did a similar study to the present study to predict the LDL by ABR parameters. They concluded that at higher intensities of click each individual's JV latency did tend to stabilise around a fairly constant value. Their conclusion was based on the JV latency shifts at intensities 10 dB apart. Even if there might be smaller JV latency shifts at high intensities of broad-band click stimulus

(which correlates with the other studies such as Klein & Teas, 1978), there are some difficulties in using this information in the LDL predictions ("shift of JV latency becomes less than 0.1 msec by increasing intensity 10 dB, after reaching the level of LDL-15 dB of the individual" Thornton et al., 1987).

In fact, in the view of the literature related to the slope of the JV latency-intensity function, there are some remarkable conclusions about the slope of the latency-intensity function. First of all, on its own, the slope of the latency-intensity function is found to be an unreliable measure of cochlear pathologies. Non-linearity of the latency-intensity function makes the slope of latency-intensity function an unreliable measure (Stockard & Stockard, 1983). Different studies have failed to produce similar normative data on the slope of latency-intensity function (Stockard & Stockard, 1983; Galambos & Hecox, 1978). This discrepancy is explained by the fact that the slope of the latency-intensity function at lower intensities may not correlate with the slope at higher intensities. Hence, when slope norms are compared, they must be specific for the intensity range tested (Stockard & Stockard, 1983). This conclusion does not support the LDL prediction studies using ABR. LDL prediction studies assume that the slope of the latency-intensity function may also be established by changing the intensity relative to LDL. If the slope of the latency-intensity function is only specific for the intensity range tested, this slope may be valid only for the specified range, but not for the range relevant to LDLs.

It is necessary to establish a LDL measurement technique which can be applicable for very young children. The ABR waveform is affected by the

myelination of the auditory nerve fibres during the first 1 to 2 years (Mason, 1988). In this period, the slope of the JV latency shows age dependent changes. As a result of this maturation process of the ABR waveform, age factor would additionally have to be taken into account.

It is claimed that LDL predictions for cochlear hearing-impaired persons would be valid as well (Thornton et al., 1987). The logic of using latency-intensity function in estimating the LDL relies on studies done on recruiting ears. In this case, it would be much more difficult to generalise the results due to the nature of the individual cochlear pathologies. Partly due to complex interaction between stimulus intensity and excitation patterns, the latency-intensity function is found to be unreliable for detecting the cochlear hearing loss (Abramovich, 1990).

6.1 Summary of the conclusion

The correlation between the LDL and ABR parameters has not been established yet. It is difficult to perform reliable LDL measurements. There are numerous variables that can affect the LDL results. Additionally there is no standard technique for testing the LDL. These factors make any correlations between LDL and ABR parameters fairly difficult.

One of the ABR parameters which is claimed to provide an estimate of LDL, is the slope of the latency-function of JV latency of the click response. The normative studies about the slope of the function are however not in agreement.

As a conclusion of the present study, predicting LDL using frequency-specific ABR parameters did not seem to be very promising. Use of the stimulus in high intensity levels is one of the reasons which limits the frequency-specific information in the ABR. Using masker in order to obtain more frequency-specific information may change the excitation patterns in the cochlea and may create another variable in the ABR studies. ABR studies employing high intensities may end up with high variability in the ABR parameters. In order to deal with this variability, the ABR study design should take this into account. Using effective shielding techniques and recording the ABR in an insulated room (electrical and sound insulation) might give JV latency measurements with less variability. Additionally, decreasing the biological noise as much as possible might help to deal with this problem.

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APPENDICES

APPENDIX 1

ADULT HEARING QUESTIONNAIRE

Name: Date of Birth:
Occupation: Date of Questioning:

EAR

R / L DETAILS

1) Have you any problem with hearing? O O
2) Have you any ringing, roaring, or buzzing in your ears? O O
3) Have you had any fullness or pressure in your ears? O O
4) Have you any pain or itching in your ears? O O
5) Have you had any discharge or drainage from your ears? O O

NO / YES DETAILS

6) Have you had any dizzy spells, loss of balance or lightheadedness before? O O
7) Have you had any ear operations at all? O O
8) Are you taking any medication? O O
9) Have you ever taken large doses of Aspirin, Anacin, Bufferin, Empirin, or quinine? O O
10) Have you been exposed to loud noises (machinery, gunfire, rock music)? O O
11) Is there a history of hearing difficulties in your immediate family who has a hearing loss now with the onset of five years old? O O
12) Have you ever received antibiotic injections such as Streptomycin, Kanamycin or Gentamycin? O O
13) Do you think that you can easily feel discomfort when you are in a noisy environment such as discotheque or a noisy factory? O O
14) Any other complain related with ears or hearing? O

APPENDIX 2

LIST OF PURE TONE THRESHOLDS OF THE FIRST 8 SUBJECTS

(in dB HL)

Subject No/Ear	Age	Frequency (kHz)					
		0.250	0.5	1	2	4	8
1/R	28	10	10	10	10	0	0
1/L	28	15	10	10	15	10	0
2/R	34	15	10	5	5	5	15
2/L	34	10	5	5	5	5	10
3/R	31	10	10	5	0	5	10
3/L	31	10	5	5	5	10	10
4/R	34	15	15	10	15	10	5
4/L	34	15	10	10	5	10	10
5/R	28	15	15	5	5	15	0
5/L	28	15	10	10	10	10	5
6/R	33	15	15	5	0	5	15
6/L	33	0	5	10	0	15	15
7/R	33	15	5	10	10	10	0
7/L	33	10	10	10	5	5	10
8/R	29	10	10	0	0	0	10

APPENDIX 2

LIST OF PURE TONE THRESHOLDS OF THE OTHER 8 SUBJECTS

(in dB HL)

Subject No/Ear	Age	Frequency (kHz)					
		0.250	0.5	1	2	4	8
8/L	29	10	5	0	10	0	10
9/R	35	15	10	0	0	0	0
9/L	35	15	10	5	0	5	5
10/R	34	10	15	10	0	0	0
10/L	34	5	10	15	10	15	10
11/R	27	0	0	-5	0	-5	-5
11/L	27	0	0	-10	-5	-5	0
12/R	29	10	5	0	0	0	0
12/L	29	10	0	5	0	5	10
13/R	28	5	5	5	0	5	10
13/L	28	10	10	10	0	15	10
14/R	28	10	10	5	0	0	0
14/L	28	10	0	0	-5	10	10
15/R	28	0	0	5	5	5	10
15/L	28	0	0	5	5	5	10
16/R	32	10	5	0	5	5	5
16/L	29	5	0	0	5	5	5

APPENDIX 3

LIST OF PSYCHO-ACOUSTIC THRESHOLD AND LDL FOR 2 kHz TONE PIP STIMULUS

(in dB p.e. SPL)

Subject No/Ear	Age	Psycho-acoustic thr. for 2 kHz TP	LDL for 2 kHz TP
1/R	28	30	115
1/L	28	30	115
2/R	28	30	130
2/L	33	25	125
3/R	29	30	125
3/L	33	25	120
4/R	34	30	120
4/L	34	35	120
5/R	31	30	130
5/L	31	30	130
6/R	35	35	125
6/L	35	30	125
7/L	33	25	130
8/R	29	30	130
9/L	35	25	120
10/R	34	30	120
11/R	27	25	125
12/R	29	25	125
13/R	28	30	125
14/L	28	25	125
15/R	34	35	125
16/R	22	30	120

APPENDIX 4

LIST OF LDLS FOR PURE TONES

AND FOR THE 2 kHz TONE PIP STIMULUS

Subject No/Ear	LDL for 1 kHz PT (in dB HL)	LDL for 2 kHz PT (in dB HL)	LDL for 2 kHz TP (in dB pe SPL)
1/R	105	105	115
1/L	100	105	115
2/R	105	105	130
2/L	105	110	125
3/R	105	105	125
3/L	105	100	120
4/R	95	100	120
4/L	100	105	120
5/R	105	110	130
5/L	105	110	130
6/R	105	105	125
6/L	105	105	125
7/L	105	100	130
8/R	90	85	130
9/L	100	100	120
10/R	105	105	120
11/R	115	115	125
12/R	95	95	125
13/R	110	100	125
14/L	105	120	125
15/R	80	80	125
16/R	100	95	

APPENDIX 5

LIST OF JV LATENCY VALUES OF SUBJECTS

(in mcsec)

Sub. No. & Ear R/L	LDL dB pe SPL	Int. Rel. Lev. to of LDL of 2kHz tone pip Ind. -5	-10	-15	-20	-25	-30	-35	-40
1/R	115	6.50	6.28	6.34	6.40	6.58	ND	ND	ND
1/L	115	6.47	6.38	6.46	6.65	6.74	7.02	6.48	ND
2/R	130	6.18	6.20	5.97	6.01	5.89	5.94	6.08	6.08
2/L	130	6.42	6.28	6.12	5.48	5.46	5.70	5.98	5.96
3/R	125	6.02	5.96	5.82	5.80	5.98	6.16	6.56	6.84
3/L	125	6.02	6.02	5.96	6.14	6.36	6.54	6.60	ND
4/R	120	6.62	6.52	6.52	6.34	6.46	6.50	6.66	ND
4/L	120	6.52	6.78	6.72	6.58	6.56	6.66	6.60	ND
5/R	130	6.38	6.48	7.02	7.08	7.16	ND	ND	ND
5/L	130	6.38	6.90	6.56	6.34	6.28	6.48	6.60	6.70
6/R	125	6.31	6.34	6.54	7.60	7.62	7.92	7.70	8.06
6/L	125	6.10	6.46	6.64	7.08	7.20	7.46	7.58	7.82
7/L	130	6.48	6.50	6.60	6.34	6.62	6.80	7.06	ND
8/R	130	6.66	6.72	6.86	6.96	7.04	7.04	7.32	ND
9/L	120	6.58	6.66	6.58	6.70	7.14	ND	ND	ND
10/R	120	6.12	6.12	6.02	6.00	6.00	6.20	6.02	6.46
11/R	125	5.50	5.76	6.16	6.14	6.24	6.38	6.28	ND
12/R	125	5.26	5.96	6.28	6.24	6.18	6.38	6.44	6.62
13/R	125	6.34	6.40	6.24	6.00	6.04	6.08	6.04	5.96
14/L	125	5.34	5.90	6.38	6.46	6.58	6.48	ND	ND
15/R	125	6.37	6.58	6.60	6.36	6.40	6.64	6.68	ND
16/R	120	6.90	6.64	6.42	6.38	6.44	6.74	ND	ND

APPENDIX 6

LIST OF JV LATENCY SHIFT/5 dB LDL RELATIVE INTENSITY CHANGE

(in msec)

Sub.&	Int.	Diff.	in	dB	re	LDL	(*)
Ear	Diff1	Diff2	Diff3	Diff4	Diff5	Diff6	Diff7
1/R	-0.22	0.06	0.06	0.18	ND	ND	ND
1/L	-0.08	0.08	0.19	0.09	0.28	-0.54	ND
2/R	0.02	-0.23	0.04	-0.12	0.05	0.14	0
2/L	-0.16	-0.16	-0.64	-0.02	0.24	0.28	-0.02
3/R	-0.06	-0.14	-0.02	0.18	0.18	0.40	0.28
3/L	0	0.06	0.18	0.22	0.18	0.06	ND
4/R	-0.10	0	-0.18	0.12	0.06	0.16	ND
4/L	0.26	-0.06	-0.14	-0.02	0.10	-0.06	ND
5/R	0.10	0.54	0.06	0.08	ND	ND	ND
5/L	0.52	-0.34	-0.22	-0.06	0.20	0.12	0.10
6/R	0.03	0.20	1.06	0.02	0.30	-0.22	0.36
6/L	0.36	0.18	0.34	0.12	0.26	0.12	0.24
7/L	0.02	0.10	-0.26	0.28	0.18	0.26	ND
8/R	0.06	0.14	0.10	0.08	0	0.28	ND
9/L	0.08	-0.08	0.12	0.44	ND	ND	ND
10/R	0	-0.10	-0.02	0	0.20	-0.18	0.44
11/R	0.26	0.40	-0.02	0.10	0.14	-0.10	ND
12/R	0.70	0.32	-0.04	-0.06	0.20	0.06	0.18
13/R	0.06	-0.16	-0.24	0.04	0.04	-0.04	-0.08
14/L	0.56	0.48	0.08	0.12	-0.10	ND	ND
15/R	0.21	0.02	-0.24	0.04	0.24	0.04	ND
16/R	-0.26	-0.22	-0.04	0.06	0.30	ND	ND
(*)	Int.	in	dB	p.e.	SPL	rel.	to LDL

Explanation of the values in the appendix 6

Diff1:JV lat. at LDL-10 dB minus JV lats. at LDL-5 dB
Diff2:JV lat. at LDL-15 dB minus JV lat. at LDL-10 dB
Diff3:JV lat. at LDL-20 dB minus JV lat. at LDL-15 dB
Diff4:JV lat. at LDL-25 dB minus JV lat. at LDL-20 dB
Diff5:JV lat. at LDL-30 dB minus JV lat. at LDL-25 dB
Diff6:JV lat. at LDL-35 dB minus JV lat. at LDL-30 dB
Diff7:JV lat. at LDL-40 dB minus JV lat. at LDL-35 dB

APPENDIX 7

THE RESULTS OF KOLMOGOROV-SMIRNOV GOODNESS OF FIT TEST

Level of sti.	No.of cases	K-S Z value	2-tailed P
LDL-5 dB	21	1.033	0.236
LDL-10 dB	22	0.422	0.994
LDL-15 dB	22	0.499	0.965
LDL-20 dB	22	0.690	0.728
LDL-25 dB	22	0.623	0.833
LDL-30 dB	19	0.567	0.965
LDL-35 dB	18	1.598	0.012
LDL-40 dB	9	0.649	0.79

Diff. in (*) Stim.level	Number of cases	K-S Z value	2 tailed P
Diff 1	21	0.868	0.438
Diff 2	22	0.706	0.701
Diff 3	22	0.574	0.897
Diff 4	19	0.615	0.844
Diff 5	18	0.781	0.687
Diff 6	9	0.733	0.656

Explanation about the appendix 7

(*)

Diff 1: JV lat at intensity of LDL-10 dB pe SPL minus JV lat of at intensity of LDL-5 dB pe SPL

Diff 2: JV lat at intensity of LDL-15 dB pe SPL minus JV lat of at intensity of LDL-10 dB pe SPL

Diff 3: JV lat at intensity of LDL-20 dB pe SPL minus JV lat of at intensity of LDL-15 dB pe SPL

Diff 4: JV lat at intensity of LDL-20 dB pe SPL minus JV lat of at intensity of LDL-25 dB pe SPL

Diff 5: JV lat at intensity of LDL-30 dB pe SPL minus JV lat of at intensity of LDL-25 dB pe SPL

Diff 6: JV lat at intensity of LDL-35 dB pe SPL minus JV lat of at intensity of LDL-30 dB pe SPL

APPENDIX 8

LIST OF JV LATENCY VALUES WITHIN GROUPS

LIST OF JV LATENCY OF GROUP 1 (SUBJECTS WITH LDL=105 dB SL)

Sub.	LDL	-5	-10	-15	-20	-25	-30	-35
7/L	105	6.48	6.50	6.60	6.34	6.62	6.80	7.06
2/L	105	6.42	6.28	6.12	5.48	5.46	5.70	5.98

LIST OF JV LATENCY OF GROUP 2 (SUBJECTS WITH LDL=100 dB SL)

Sub.	LDL	-5	-10	-15	-20	-25	-30	-35
5/R	100	6.38	6.48	7.02	7.08	7.16	ND	ND
8/R	100	6.66	6.72	6.86	6.96	7.04	7.32	ND
2/R	100	6.18	6.20	5.97	6.01	5.89	5.94	6.08
11/R	100	5.50	5.76	6.16	6.14	6.24	6.38	6.28
12/R	100	5.26	5.96	6.28	6.24	6.18	6.38	6.44
13/R	100	6.34	6.40	6.24	6.00	6.04	6.08	6.04
5/L	100	6.38	6.90	6.56	6.34	6.28	6.48	6.60
3/L	100	6.02	6.02	5.96	6.14	6.36	6.54	6.60

LIST OF JV LATENCY OF GROUP 3 (SUBJECTS WITH LDL=95 dB SL)

Sub.	LDL	-5	-10	-15	-20	-25	-30	-35
9/L	95	6.58	6.66	6.58	6.70	7.14	ND	ND
3/R	95	6.02	5.96	5.82	5.80	5.98	6.16	6.56
6/R	95	6.31	6.34	6.54	7.60	7.62	7.92	7.70

APPENDIX 8

LIST OF JV LATENCY OF GROUP 4 (SUBJECTS WITH LDL=90 SL)

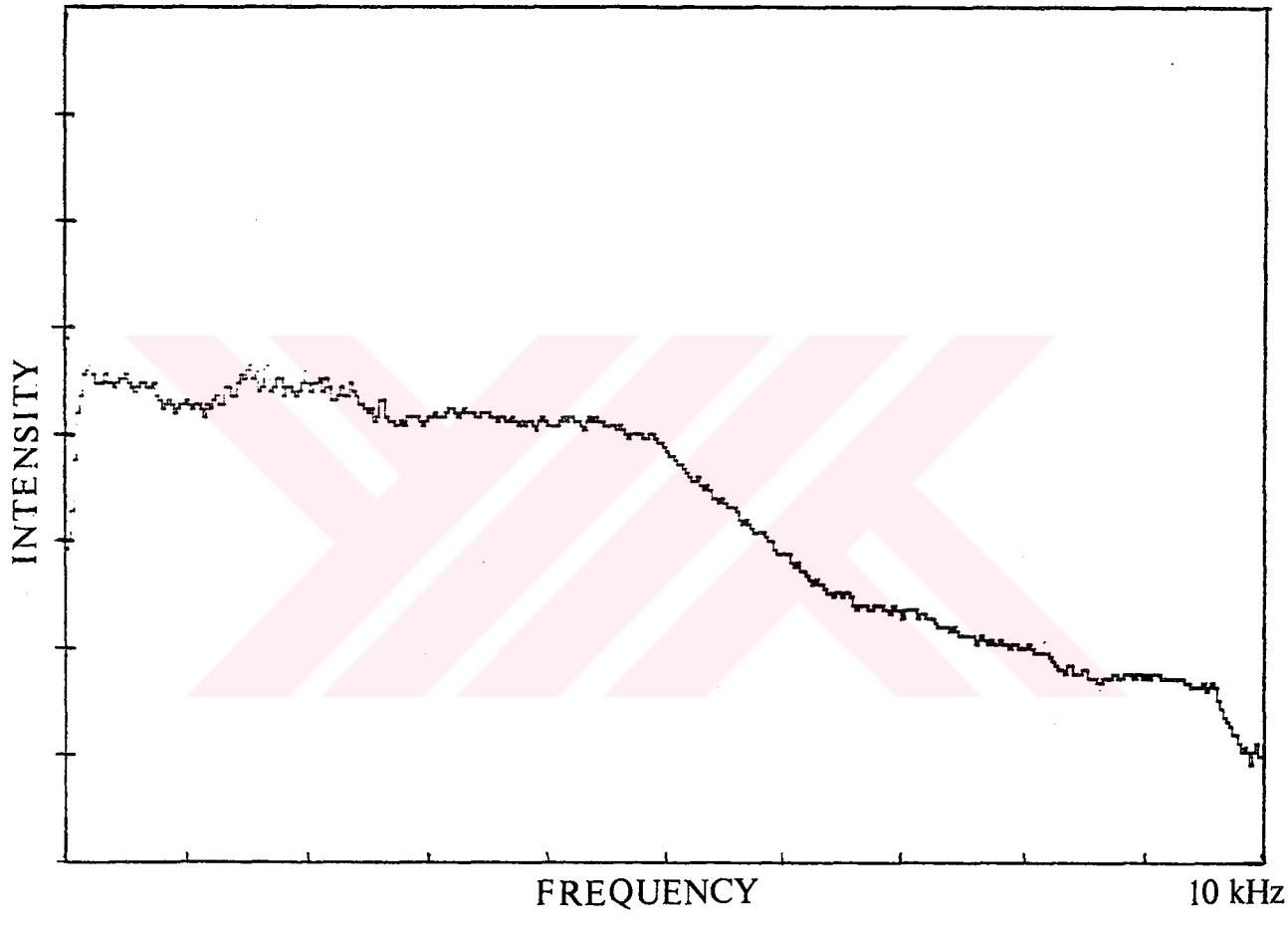
SUB.	LDL	-5	-10	-15	-20	-25	-30	-35
10/R	90	6.12	6.12	6.02	6.00	6.00	6.20	6.02
4/R	90	6.62	6.52	6.52	6.34	6.46	6.50	6.66
15/R	90	6.37	6.58	6.60	6.36	6.40	6.64	6.68
6/L	90	6.10	6.46	6.64	7.08	7.20	7.46	7.58
16/R	90	6.90	6.64	6.42	6.38	6.44	6.74	ND

LIST OF JV LATENCY OF GROUP 5 (SUBJECTS WITH LDL=85 SL)

SUB.	LDL	-5	-10	-15	-20	-25	-30	-35
1/R	85	6.50	6.28	6.34	6.40	6.58	ND	ND
1/L	85	6.47	6.38	6.46	6.65	6.74	7.02	6.48

APPENDIX 9

BROAD-BAND ACOUSTIC SPECTRUM



Acoustic spectrum of the broad-band noise used in the experiment.

(Spectrum measured with 6 cc. artificial ear. Frequency range was set 0 to 10 kHz. Intensity scale arbitrary and in 10 dB steps. Intensity output was 70 dB dial reading of the Amplaid ECochG/ERA stimulus generator.)

FREKANSA ÖZGÜ BEYİN SAPI İŞİTSEL YANITLARI KULLANARAK RAHATSIZ EDİCİ SES YÜKSEKLİĞİ BELİRLENMESİ

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Uzmanlık Tezi Özeti

TEZİN AMACI:

Rahatsız edici ses yüksekliği, kooperasyon kurulabilen hastalarda kolaylıkla saptanabildiği halde, küçük çocuklarda ve kooperasyon kurulması mümkün olmayan hastalarda zorlukla tayin edilebilmektedir. Böylesi durumlarda uygulanacak bir yöntem arayışı doğmuştur. Bu çalışmada işitsel beyin sapı potansiyelleri kullanılarak rahatsız edici ses yüksekliğinin belirlenme olasılığı araştırılmıştır.

LİTERATÜR TARAMASININ ÖZETİ:

İşitme cihazlarının maksimum ses çıkışının ayarlanması, protezlenecek hastanın rahatsız edici ses yüksekliğinin belirlenmesiyle mümkün olmaktadır. Rahatsız edici ses yüksekliği, subjektif yanıt vermesi mümkün olmayan hastalarda ve küçük çocuklarda belirlenememektedir.Beyin sapı işitsel yanıt parametrelerine dayanılarak ve klik uyaranı kullanılarak rahatsız edici ses yüksekliği belirlenebilirse de (Thornton ve arkadaşları, 1978), bu şekilde yapılan bir ölçüm frekansa özgü yanıtı ortaya çıkarmaktan uzaktır. Maskelenmemiş klik uyaranı, kokleada geniş frekans bandını uyarması nedeniyle bu amaca uygun bir uyaran sayılmaz. Değişik frekanslarda kısa süreli ton uyaranları da yüksek şiddet düzeylerinde kullanılacak olursa, klik uyarana benzer sonuçlar doğurmaktadır. Bu durumda önerilebilecek bir yöntem ise, kısa süreli ton uyaranı ile birlikte aynı kulaktan maskeleme sesinin verilmesidir. Ancak işitme cihazı kullanacak hastaların rahatsız edici ses yüksekliği değişik frekanslarda belirlenebildiği takdirde, bu frekanslarda işitme cihazlarının maksimum ses çıkışı ayrı ayrı ayarlanabilecektir.

MATERYAL

Bu çalışmada test edilen deneklerin beyin sapı işitsel yanıtlarının kaydedilmesinde Nicolet Pathfinder II sistemi kullanılmıştır. Bu sistem şu bölümlerden oluşmaktadır:

NIC 1280 Merkezi İşlem Birimi

NIC SM-100 Uyarı Denetleyicisi

NIC SM-200 Fizyolojik Yükseltici

NIC SM-700 İşitsel Uyarıcı

2 kHz ton pip uyaranla birlikte aynı kulaktan uygulanacak maskeleme sesi Kemo VBF/24 ikili kanal filtresi yoluyla süzüldü. Karşı kulağın yanıt vermesinin önlenmesi amacıyla Amplaid ERA/ECOChG Stimulus Generator cihazı çıkışlı genişband gürültüsü kullanıldı. Kayıt sırasında gümüş/gümüş klorid elektrotlar kullanıldı. Aktif elektrod mastoid üzerinde pasif elektrot verteks üzerinde ve toprak elektrodu ise alın üzerinde uygulandı. Beyin sapı işitsel yanıtın kayıt geçiş bandı 30-3000 Hz olarak seçildi. Yükselticinin duyarlılığı 50 microvolt, herbir kayıt için averajlanan yanıt sayısı 2048 ve averajlama zamanı 20 msn. idi. Uyaranın tekrarlama oranı saniyede 11.1 ton pip sesi, polaritesi ise alternan olarak sunuldu. Ton pip uyaranın süresi 2.57 msn. idi.

METOT

Denekler: Bu çalışmada yaşları 27-35 yaş arasında normal işitenler test edildi. İşitmenin normalliği pür ton odiyometri ve timpanometrik ölçümlere dayanılarak belirlendi. Ayrıca bu kişilerin geçmişte kulakla ilgili şikayetlerinin olup olmadığı da soruşturuldu.

Deneysel metodoloji: Bu çalışmadan amaçlanan beyin sapı işitsel yanıtındaki V. dalganın latansı ile rahatsız edici ses yüksekliği arasında bir ilişkinin olup olmadığının araştırılmasıdır. Bu nedenle önce subjektif olarak 2 kHz ton pip uyaranının rahatsız edici ses yüksekliği saptandı. Daha sonra aynı deneklerin 2 kHz ton pip uyaranı ve maskeleme sesi verilerek beyin sapı işitsel yanıtları kaydedildi. Geniş band gürültünün 2900 Hz üzerinin filtre edilmesiyle elde edilen ve test edilecek kulağa uygulanacak maskeleme sesi, 2 kHz ton pip uyaranın frekansa özgü yanıtı ortaya çıkarmasını sağlamak amacıyla kullanıldı.

Uyaran ses şiddeti-latans fonksiyonunun elde edilmesi için, şiddeti 5 dB aralıklı olarak değişen uyaranlarla, minimum olarak 5 şiddet düzeyinde beyin sapı işitsel yanıtları kaydedildi. En yüksek uyaran şiddeti, herbir deneğin aynı uyaranla beliren rahatsız edici ses yüksekliğinden 5 dB altında tutuldu.

16 deneğe ait toplam 22 kulak üzerinde yapılan beyin sapı kayıtları tamamlanarak analiz edildi. Absolüt V. dalga latansları ölçüme tabi tutuldu. Alınan sonuçlara göre, ortalama V. dalga pik latans değerlerinin, uyaran şiddetin düşmesine bağlı olarak artış gözlendi(Bkz. Tablo 1). Bağlı değişken olan V. dalga latanslarının normal dağılım göstermesi nedeniyle istatistiksel yorum için parametrik istatistiksel testler kullanıldı. Bu nedenle, uyaran şiddetinin değişmesinin V. dalga latansı üzerine olan etkisinin test edilmesi amacıyla seri ölçümlere dayalı varyans analizi anlamında MANOVA (Multiple Analysis of Variance) testi kullanıldı(Bkz. Tablo 2).

BULGULAR:

UYARAN ŞİDDETİ DÜZEYİ(*)	ORTALAMA V. DALGA LATANSI (msn)	STANDART DEVİASYON
- 5 dB	6.299	0.375
- 10 dB	6.356	0.308
- 15 dB	6.400	0.306
- 20 dB	6.413	0.474
-. 25 dB	6.499	0.508
- 30 dB	6.585	0.523
- 35 dB	6.628	0.521
- 40 dB	6.722	0.793

Tablo 1. Rahatsız edici ses düzeyine bağlı olarak belirlenen uyaran şiddetlerinde kaydedilen beyin sapı işitsel yanıtların V. dalga latanslarının ortalaması ve standart deviasyonu.

(*). Uyaran şiddeti için deneklerin rahatsız edici ses yükseklikleri referans olarak alınmıştır.

ETKİ	KARELER TOPLAMI	SERBESTLİK ÖLÇÜSÜ	KARELERİN ORTALAMASI	F SAYISI	F SAYISININ ANLAMLILIĞI
Denek etkisi	3.20	30	0.11	-	-
Rahatsız edici ses yüksekliği etkisi (+)	0.17	2	0.09	0.82	0.452

Tablo 2. Uyaran şiddetinin 5 dB değişmesine bağlı olarak V. dalga latans değerlerinde beliren farklılıkların istatistiksel yorumunu yapmada kullanılan MANOVA testinin sonuçları

(+). Uyaran şiddetinin tayininde rahatsız edici ses yüksekliği referans olarak alındığından bu değişken uyaran şiddeti değil, rahatsız edici ses yüksekliği olarak ifade edilmiştir.

TARTIŞMA VE SONUÇ:

Kısaca sonuç olarak, 2 kHz ton pip uyaranıyla kaydedilen beyin sapı işitsel yanıtların V. dalga latans değerleriyle aynı uyaranla saptanan rahatsız edici ses yüksekliği arasındaki ilişki istatistiksel incelemeye tabi tutulduğunda aralarında istatistiksel olarak anlamlı bir ilişkinin bulunmadığı belirlendi(Bkz. Tablo 2).

Bu çalışmanın sonuçlarını etkileyebileceği düşünülen, hastaya ve yönteme ilişkin birtakım faktörlerin varlığı belirlenmiştir. Rahatsız edici ses yüksekliğinin ölçümü subjektif kriterlere dayandığından deneklerin tümünün aynı kriterlere sadık olarak bunu belirleyebildiklerini varsaymak zor olacaktır. Yüksek ses şiddetine bağlı olarak kulaklıklardan yayılan elektro-magnetik artifakt, beyin sapı işitsel yanıtlarının erken bölümlerinde fazla miktarda gürültülü kayıtlara yol açmıştır. Bu durumun dalga latanslarının ölçülmesine olumsuz etkisi olmuştur. Ayrıca yüksek şiddette işitsel uyaran kullanılması sonucunda oluşan ek biyolojik gürültü V. dalga latanslarında değişkenliğin artmasına neden olmuştur. Bu sayılan faktörlerin tek başına latans ölçümlerinin değişkenliğini artırmaya etkisi olamayacağı halde, bunların bir araya gelmesi halında değişkenlik üzerinde olumsuz etkilerinin olabileceğini düşünmekteyiz.