ULTRASONICS IN CLINICAL AUDIOMETRY

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Several investigators (Wegal 1932) Wever and Lawrence (1954); Deetherage *et al*, (1954), Corso and Oda (1961), Haaff and Knox (1963) have reported on human auditory responses to sounds of frequencies even above 10,000 HZ and upto 100,000 HZ. Corso (1965) while studying the phenomenon of high frequency and ultrasonic hearing obtained DLS for pitch and loudness at various frequencies both by air and bone conduction. Even as evidences of cochlear function at high and ultrasonic frequencies are being obtained clinicians have started speculating about the possible uses of hearing in these frequencies as a diagnostic tool. The purpose of this article is to discuss (1) the problems involved in the production, transmission and calibration of sonic and ultrasonic sounds (2) some of the studies made on the pitch and loudness discrimination functions of cochlear at high and ultrasonic frequencies and finally (3) some of the possible uses of these frequencies in the diagnosis of auditory impairments.

Broadly speaking, all frequencies above 20,000 HZ could be considered as ultrasonic. However, a few consider frequencies above 10,000 HZ also to be ultrasonic.

Ultrasonic waves can be produced by electrically exciting a piezoelectric crystal. Such a crystal changes its dimensions under the influence of an electric field and will radiate energy in the form of sound waves. The opposite effect can also occur; when the dimensions of the crystal are changed by a sound beam striking the crystal, a voltage is developed across the crystal. Thus the same crystal can be used to generate a sound field and also to detect one.

It is possible to design a transducet of the electromagnetic type which will have a fair efficiency at frequencies as high as 20,000 HZ to 30,000 HZ and is therefore capable of operating in what might be called near ultrasonic region. But above 30,000 HZ the output falls off rapidly. For frequencies upto about 60,000 HZ the magnetostriction generator is the most effective radiator. A transducer constructed from a barium titanate crystal loaded at each end by a piece of machined alluminium responds from 1000 to 100,000 HZ satisfactorily.

Corso (1965) used the following method for generating ultrasonic frequencies. A bank of oscillators generate the required frequency in the ultrasonic region. The signals are then fed to a power amplifier whose frequency response covers the ultrasonic region up to 100,000 HZ. The amplified signals are then applied across the face of the crystal transducer which generates sound waves in the ultrasonic region.

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In the case of bone conduction the machined alluminium tip attached to the face of the crystal is brought into contact with the mastoid or forehead with a force of 200 to 400 grams. It is essential to make sure that the subject is comfortably seated and also to see that he is discouraged from even the slightest movements of the head and body, for they produce a change in the hearing sensitivity. Corso (1965) has suggested a method by which even a few degrees of movement of the observers head would close a relay and the signal would be cut off until a correct position is assumed by him. The other studies do not seem to have controlled the problem of observer's movement.

In the case of air conduction, signals from oscillator after passing through the power amplifier are fed to the leads of a triple or dual type dynamic speaker. To cover the frequency range satisfactorily from low frequencies to 25,000 HZ, it is necessary to have a coupling transducer with two or three loud-speaker units.

The acoustical components are calibrated using a condensor microphone. Due to the extreme directionality of tones of high frequency, it is necessary to monitor the level of sound pressure at the meatus during all experimental tests. To accomplish this, a probe tube is used which would measure the sound field without significantly disturbing it.

The success of high frequency audiometry lies in avoiding one of the persistent problems—the formation of standing wave patterns in the earphone eardrum coupling. High frequencies have very small wavelengths and would easily give rise to standing waves. No sound will be heard when standing wave formation takes place. This problem can be overcome by adjusting the distance of the transducer from the ear. To obtain pure tones in the H.F. region by air conduction (upto 18,000 HZ) at least one commercial instrument is available.

This field of sonic and ultrasonics is still in the exploratory stages and as such no audiometric zero or standard exists for frequencies above 8000 HZ. Before proceeding with the diagnostic use of high frequencies it is essential to obtain normative data and standardizing calibration techniques.

As early as 1932, Wegel reliably showed auditory response to frequencies upto 24,000 HZ by air-conduction. Pumphry (1950) conducted experiments on the upper limit of frequency for human hearing and reported hearing upto 16,000 HZ by air-conduction and 100,000 HZ by bone-conduction. Further more recent studies [Wever and Lawrence (1954); Deetherage *et al,* (1954); Corso and Oda (1961); Haaff and Knox (1963) etc] have shown that the upper limit of audibility for bone conduction extends to 100,000 HZ, while that for air-conduction terminates in the range of 25,000 HZ.

Corso (1965) while studying the phenomena of high frequency and ultrasonic hearing has obtained DLs for pitch at various frequencies both by air and bone conduction. Table 1 shows the results obtained by various investigators with respect to the limits of hearing and pitch perception by both air and bone conduction. It is of interest to note that a majority of studies have made use of subjects with musical training. However, the number of subjects used in these studies is small with the exception of the study made by Corso.

TABLE 1

Limits of hearing and pitch perception by air and bone-conduction

Author	Upper limit frequency heard	Pitch discrimination	Remarks
Air Conduction			
Pumphrey (19S0)	upto 16,000 HZ	Discrimination begins to fail above 12,000 HZ	N = 3
Wever (1954)	upto 25,000 HZ	•••	• ••
Ward	• ••	Pitch discrimination disappears at about 5,000 HZ	Subjects were musically trained
Corso (1965)	upto 25,000 HZ	Begins to fail about 16,000 HZ	N=37 (musically trained) A well controlled study
Bone Conduction			
Pumphrey (1950)	upto 100,000 HZ	Pitch ceased to be discriminated at about 16,000 HZ	N = 3 Sensory elements at the basal end of cochlea are competent to respond to sounds upto 100,000 HZ
Deatherage Jeffers, Blodgett (1954)	• ••	Pitch discrimination was not found in the ultrasonic region. The pitch of an ultrasonic tone is comparable to the highest tone an individual can hear	....
Corso and Oda (1961)	upto 100,000 HZ	...	. ..
Haaff and Knox (1963)	upto 108,000 HZ	. ..	. ..
Corso (1965)		Tones of 57,000,64,000 and 94,000 HZ are matched in pitch to a tone approximately 17,000 HZ	At 2000 HZ the DLs for pitch are approximately equal for air and bone conduction but from 4000 HZ to 14,000HZtheDLsare significantly smaller for bone conduction N=37 musically trained persons

In another study by Corso and Levine (1965) equal loudness contours were established for both air and bone-conduction at 0, 10 and 20 phon loudness levels. The frequencies used for air conduction in this study range from 2000 to 16,000 HZ and for bone conduction 2000 to 94,000 HZ. The results indicated that the curves for the two modes of transmission are essentially similar up to 14,000

HZ approximately; however, the extrapolated Ac curves appear to converge .at 17,000 HZ, while the bone conduction curves converge at 85,000 HZ. It is concluded that the loudness function for human hearing extends considerably higher in frequency than previously believed.

These studies of loudness function and pitch discrimination when considered in conjunction indicate that the auditor}' system is capable of processing loudness discrimination information, but not pitch discrimination information for bone conducted tones in the ultrasonic region from 2000 HZ to at least 85,000 HZ. Pitch discrimination seems to fail near the (conventional) 'UPPER LIMIT OF HEARING' by air-conduction, but equal loudness judgements may be made reliably for at least another four octaves. This suggests that the limit for pitch discrimination for both air and bone conduction is imposed by the neuroanatomical structure of the cochlea where as the limit for loudness discrimination in air-conduction is imposed by some peripheral structure of the auditory system, such as the ossicular chain.

The available data indicate that the auditory mechanism mediating pitch and loudness discrimination do not fail at the same upper frequency limit. When the limiting factor of the air conduction system is bypassed by resorting to bone conduction, the range of frequencies over which the ear can respond in loudness is considerably greater than previously believed. Throughout their ultrasonic range when the subject is presented with a given frequency, he hears the tone whose pitch is equated to that of a bone conducted sound at approximately 16,000 or 17,000 HZ.

Having come to the conclusions that human hearing (1) by air conduction extends upto 25,000 HZ even though the pitch discrimination would stop approximately about 16,000 HZ and (2) by bone conduction extends upto 100,000 HZ though the pitch discrimination would stop at about 17,000 HZ, audiologists have thought of using these high frequencies in predicting and diagnosing auditory impairments. However, these studies are limited to air conduction only. Studies have yet to be made in the use of bone conduction in high frequency and ultrasonics as a diagnostic tool. Though the pitch perception by the two modes of transmission namely air and bone conduction ceases after about 17,000 HZ, by making use of the loudness differential function the frequencies upto 25,000 HZ in the case of air conduction and upto 100,000 HZ in the case of bone conduction could be made use of to arrive at specific frequency characteristics of auditory impairments.

Clinical Applications

In a study of presbycusis, Rosen *et al,* (1964) extended the range of test frequencies on the Mabaan subjects (people who are living in a relatively calm area of Africa) and compared them with urban populations in New York, Diisseldorf and Cairo. Test frequencies ranged from 12,000 to 24,000 HZ and showed the Mabaans, to have better hearing acuity at the high frequencies with ageing. This was attributed not only to the lack of noise, but among other factors to diet and the lack of stress and strain in their lives.

It is observed that it is in the very high frequencies that the hearing acuity changes in the initial stages. Obtaining audiological data in the high frequency range in the initial stages itself, will make it possible to diagnose and to stop further deterioration of hearing. Sataloff *et ah,* (1968) speculated that if high frequency thresholds were affected by urban living, then daily exposure to industrial noise might impair further acuity for high frequencies. Test frequencies in their study were 10,000; 12,000 and 14,000 HZ. It was shown that their subjects who were papermill employees and had characteristic audiometric dips at 4000 HZ and 6000 HZ also had reduced hearing for the three higher test frequencies. Compared to subjects not exposed to noise, the difference was approximately 10 dB at each frequency.

Downs has found indications that high frequency audiometry shows up the beginning effects of kanamycin sulphate toxicity earlier than standard audiometry. These studies suggest a growing importance of the use of high frequency audiometry.

In a study of high frequency hearing followingmeningitis by Fletcher *et al.,* (1965) it was shown that patients seriously ill with meningitis can suffer significant sensory neural losses that would be undetectable by usual audiometric testing methods. One of the most serious effects of meningitis is profound sensory-neural hearing loss. In the literature only severe hearing losses are described. Fletcher after conducting high frequency audiometry through 18,000 HZ concluded that high frequency loss need not be severe and also that the hearing loss depends upon the severity of the illness.

Harris and Ward (1967) used high frequency audiometry in normal children of ages 10 to 12 years. The purpose of their study was to determine the feasibility of performing audiometry through 20,000 HZ using equipment which differs as little as possible from the clinical procedures now used and to provide some data upon which tentative norms may be established. The extremely good acuity of a substantial number of young ears at the highest frequencies is of interest. The above mentioned studies have been made using air conduction. Audiometry using bone-conduction in the sonic and ultrasonic region has to be explored still and it may not be long before this technique becomes a part of the diagnostic audiometry.

It would seem that the testing of high frequency hearing might prove useful in many areas such as meningitis, noise induced hearing loss, ototoxicity etc. Perhaps high frequency losses could be detected in patients under drug therapy which may be ototoxic, therapy preventing losses in the lower, more serious, frequency region. The logic of this approach parallels that suggested to persons exposed to industrial noise in which high frequency audiometric losses would precede losses at lower comparable frequencies, thereby enabling management, to predict and avoid such losses. Certainly research in this area should prove worthwhile. Investigations are being conducted now to explore the feasibility of high frequency audiometry as part of the routine audiometric examination **and** to standardize the techniques.

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