MIDDLE EAR Fluid and HIGH FREQUENCY HEARING
The Impact on listening and learning

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ABSTRACT
This theoretical and applied monograph outlines a study area of human auditory perception that is often misunderstood. The authors review a wide range of literature surveying developmental, anatomical, experimental and remedial findings related to hearing beyond 2,000 Hertz. They conclude that hearing in the higher frequencies is universally vital to all oral human communication. The reader is alerted to the additional risks which youth and age present to loss of high frequency hearing. The authors believe a solid professional case is presented that fluctuation in hearing levels during language acquisition years, caused mainly by Middle Ear Fluid can have a long term effect on speech language, learning and listening skills, which is some cases are similar to attention deficit disorder patterns.

High Frequency Hearing

INTRODUCTION

By writing this monograph we intend to capture our current thoughts regarding the significance of higher frequencies of sound for human perception and communications.

Our curiosity in this area has grown greater and greater over the years along with our clinical experience with hearing impairment, learning disabilities and communication disorders. Two recurring questions about high frequency sound continue to arise that seem to be inextricably bound with our work: 1) why does the human species have functional hearing beyond the ranges of the human voice? And; 2) what relevant information might be held in the higher frequencies of speech itself?

Although there is a considerable amount of speculation on the topic of high frequency sound, it is scattered in an unrelated fashion throughout the literature of several disciplines. To date, the information has never been gathered together in any systematic or potentially useful manner. In this brief volume, we attempt to bring together the information from various sources to create a tentative blueprint which will begin to describe the value which high frequency hearing has for humans at both the conscious and preconscious levels.

HIGH FREQUENCY SOUND: A HISTORICAL PERSPECTIVE

Research into the value of high frequency sound for human communication has been hampered in the past by two inter-related issues:

1) Firstly, testing equipment prior to the early 1970's had not sensitive enough to accurately assess hearing in the higher ranges. The data produced was often unreliable and, therefore, did not provide any solid base for further investigation.

2) Secondly, this lack of viable data led to a general dismissal of high frequency sound as an issue of relevance.

Recent advancements in the technology of testing equipment, and improved assessment procedures for the perception of high frequency sound have reawakened interest in the field. Moreover, contemporary investigations regarding the physiology of human hearing are leading to a reevaluation of the practical purposes of higher frequency sounds.

The immediate result has been a new infusion of interest into this area, as both practitioners and researchers have begun to explore high frequency sound in a more rigorous fashion. Yet, despite this revitalization, any generic area of research, which might be called “High Frequency Hearing”, has been slow to develop.

Each month, serious audiophiles publish volumes on the esoteric and practical enjoyment that can be derived from the reproduction of broadband sound recordings. Meanwhile, the telecommunications industry has been busy analyzing the behavior of high frequency sounds to develop advanced systems for data transfer and weapons-guidance. Concurrently, scientists in psychoacoustics, audiological, speech/language and medical laboratories have started to examine higher frequency sound reception in humans, models of human hearing, non-human machine analogs, and in hearing in other animals.

As in the past, these contemporary investigations into high frequency hearing have maintained a generally uncoordinated and un-integrated approach. There continues to be very little that serves to unify the scattered data that is being generated independently by various professional groups.

Despite all of this parallel activity, confusion and contradiction reigns, as differing terminologies, diverse tools, and diverging purposes, have all been engaged in the exploration of communication. Ironically, the result has been near non-communication about communication.

Through this monograph, we hope to examine some basic issues concerning high frequency hearing and we have attempted to pull together some of the stronger data-threads in order to weave a credible tapestry that will begin to explain the how's and why's of high frequency sound as it applies to human hearing. Hopefully, we will also provide some preliminary insight into the reasons that humans throughout the world continue to possess the ability to perceive high frequency sound. We have chosen to forego annotation in the text in order to communicate more clearly. The reference section contains a bibliography arranged by topics and concepts as they appear in discussion. Although we have tried to keep free of professional jargon in order to reach a more general audience, that task has been more difficult.

SOUND

We begin our investigation into high frequency hearing with an introduction to some of the properties of sound. In the context of human perception, we will review sound as it relates to its source, the immediate environment, and its interaction with the human head and ears.

WHAT IS A WAVE LENGTH?

Sound travels in the form of waves. Each sound wave is made up of a specific pattern of peaks and troughs, and the length of a sound wave is determined by scanning it from one peak to the next.
High frequency sounds are multi-rippled with many short peaks and troughs, while low frequency sounds have relatively few, but deep peaks and troughs. The higher the frequency, the shorter the wavelength the greater the number of peaks and troughs..

HOW FAST DOES SOUND TRAVEL?

Although sound waves vary in length, the actual wavelength of a specific sound peak/trough/peak) does not effect the speed that the sound will travel. All sound waves, regardless of length, travel at the same speed in any given medium. For example, sound in air moves at about 750 miles/hour or 1207 km/hour on a comfortable day. Since all sound waves travel at the same speed, knowing the actual speed of sound does not provide us with much information about the characteristics of the sound. Therefore, it is more common to measure the relative speed of sound by counting the number of peaks in a sound wave that pass a point in one second. This measure of sound is called "frequency" and is measured in "Hertz".

WHAT IS A DECIBEL?

In addition to wavelength, speed and frequency, sound also has dynamic force or energy at all frequencies. This force, which is generally referred to as "loudness", is measured in "decibels".
Decibels are subjectively determined, equal sound-energy units. The decibel scale was developed by using a normal group of adult listeners to judge the relative loudness of pure, single tones at pre-selected frequencies. The results of the consensus reports were then plotted, published and endorsed as standard measurement norms. Such graphs and their occasional revisions are now widely in use as international norms to test individual hearing levels.
There is evidence to indicate that for many reasons, such as age or city/rural living, the standards are less than accurate. However, because they have become so entrenched as policy, the 'pure-tone standard' is difficult to bypass in clinical decisions, even when it bears only minimal relationship to an individual's real-life ability to understand speech. Hearing graphs of pure tones have revealed that for normal human hearing, 20 - 20,000 Hertz), perceived loudness may vary from minimum detection at -10 decibels to an intensity causing physical pain at 120 decibels.

SUBJECTIVE SOUND

Up to now, we have been talking primarily about pure tone sound. However, the sounds that we normally hear are the result of the complex interactions of various frequencies, and intensities, which interweave in intricate ways to produce differing subjective effects. In order to share these everyday analogs of pitch/intensity effects, with vibration and a few more dimensions added, it might prove useful to look at the following sound-painting of some' frequency and force interactions. Low frequency/low energy sound, for example, can be imagined as a collage of lapping waves on a quiet peaceful lake at dusk (20 decibels). On the other hand, low frequency/high energy sound might be pictured as a pulsing (100 Hertz) diesel locomotive at a siding. We can literally feel its 90 decibels of slow sound waves push against our bodies.

A high frequency/low energy scene may be heard as a mother's unvoiced 3,500 Hertz whisper to her baby in the quiet nursery, the force of a whisper being but 20 decibels. In ear splitting contrast we can easily imagine the high frequency/high energy sound of a jet plane headed off any runway screaming out 4,000 Hertz at 120 decibels - a whisper gone out of control.

The wavelength of low frequency sounds are long, - really long. For example, the 100 Hertz pulsing of the locomotive averages a peak-to-peak wavelength of over eleven feet. The wavelength of higher frequency sounds, in contrast are short. In real terms the sound of a 10,000 Hertz midnight leaf rustles is only 1.1 inches long.

Not only are low frequency waves lengthy, but they usually have more energy, allowing them to easily bend, bubble and weave around objects like the human head. Such broadly sweeping bass sounds, often perceived as a low, non-locatable rumble, tend to arrive at both sides of the head almost simultaneously, confusing our ears. The result in a subway station, for example, is that it is exceedingly difficult to determine from which tunnel your train will emerge just from the sound of the approaching vehicle. 0n the other hand, the shorter and weaker high frequency sounds are easily soaked up in their surroundings. These sounds in the non-vowel, speech-consonant range are less than two inches in length and do not bend easily. High frequency sounds, therefore, can serve as excellent directional beacons. If they hit one side of our head they stay there providing the clues that our brain uses to localize sources of sound in space. These weaker, higher frequency sounds are easily absorbed even in the air. This is the reason that, the sound of distant lightning and thunder has a low deep roll, while close thunder has a very definite hiss and crack. The air absorbs over distance, the energy of the higher frequencies. The hiss and crackle never gets to arrive. In addition, the powerful waves of low frequency sounds also have a tendency to cancel out the more fragile, shorter waves of the higher frequencies. As a result, speech is more difficult to understand in a noisy situation. In a lecture hall one may "hear" a speaker, yet sometimes miss understanding the words. This happens because the high frequency, mini-second stops around the spoken vowels are soaked up into the normal low frequency ambient noise created by the audience as they shift and mumble.

HIGH FREQUENCY SOUND & HEARING

The frequency range of sound available for human speech is limited by very practical considerations. The physical structures of the lungs, larynx, throat, mouth and lips restrict speech production for most people to a span which extends between 100 to 10,000 Hertz. However, as noted previously, the combination of inadequate technology and associated conceptual limitations have made accurate measurement difficult until recently. As a result, early audiological theory placed the fundamental limits for speech sounds in a much narrower band, falling between 250 and 6,500 Hertz.

Furthermore, as a direct consequence of standardized testing procedures, which assessed the hearing of adults under the least likely conditions of earphones in a sound-proof room, a formidable inaccuracy was introduced into the system that narrowed the range for meaningful speech to a span falling between 300 and 3,000 Hertz. Part of definition of the meaningful speech range was introduced by research in the needs of telephone companies.

Indeed, as we now know, while this range may be adequate for simple adult communication over a telephone line, more recent research tends to indicate that a much wider frequency spectrum is necessary for the normal development of speech and language, particularly in a child's early years. Normal speech acquisition appears to require accurate and uninterrupted reception of the full sound spectrum that is available from the human speech apparatus.

THE PURE TONE. STANDARD

Traditionally, human hearing has been assessed by providing generated pure tone sound between 125 Hertz and 8,000 Hertz at one octave intervals through earphones in a sound proofed room. An individual is asked to indicate when a sound is heard, and the responses are recorded in a graph format. Generally, this custom of applying pure tones was promoted by a need to derive an efficient system with available 1950's technology, which was neither accurate nor reliable. With the information thus derived, it became common in Audiology to equate the reception of pure tones to an individual's ability to process speech. Data from early research with adults, under highly controlled but unrealistic conditions, suggested that the arithmetic average of the pure tones generated at 500, 1,000 and 2,000 Hertz could be used to predict accurate speech reception. The use of these three tones, labeled as the "pure tone average" by Audiology texts, has since become enshrined as a cornerstone of clinical Audiology.

As we shall discuss in a later section, there are significant problems posed by the acceptance of this formula, not the least of which is the failure to recognize that the "pure tone standard" of children differs from that of adults. Nonetheless, if one is to follow the guidelines established by the current state of clinical practice, which relies in part upon pure tone averaging, "high frequency hearing" can be considered as hearing, which occurs beyond 2,000 Hertz.

THE IMPORTANCE 0F HIGH FREQUENCY SOUND

An unfortunate corollary that has resulted from the equation of pure tone reception to speech processing, has been that speech frequencies which fall above 2,000 Hertz have often been undervalued as sound without practical purpose for communication. While in the days of cave dwellers, a high frequency rustle of leaves may have been a useful signal of danger, the skill seems to be out of place in our modern life. Much like the human appendix, high frequency hearing is considered by some to be a remnant of earlier times, without modern day relevancy. Yet, despite the general acceptance of the "below 2,000" maxim, evidence has begun to mount regarding the value of high frequency sound for speech acquisition and meaning. It is beginning to become apparent that upper frequency hearing is not a quaint relic. In fact it appears to be essential in at least five major human categories. In the following sections we will draw together information toward this revised view from the areas of human development, anatomy, and pathology, as well as evidence from the experimental laboratory and from the remedial classroom.

Anatomy

Hearing was ancestrally formed in the waters of the sea, and sound in the ocean depths was conveyed through liquid. Those essential conditions for hearing remain today, simulated in miniature within our heads. For normal hearing to take place, sound in air must be changed to sound in fluid in order for us to hear.

The ear is primarily a receiving device that converts sound wave energy first into liquid wave energy, and then into electrical impulses. This is accomplished in three interconnected stages. Sound waves in the air are first collected by our outer ears and funneled along tubular ear canals where they press against the ear drums. The drum then sets a series of three tiny bones into rapid motion to transfer the energy to the fluid containing cochlea. Inside the cochlea are the tiny hair cells that convert the fluid wave into electrical impulses for the trip along the auditory nerve to the brain where it is interpreted as sound.

As an overview, the material presented above is, of course, vastly simplified. To proceed, we shall present more detailed information on both the anatomy of hearing, and the manner in which each linked segment of the hearing apparatus is designed to favor higher frequency sounds.

Sound reception in humans begins at the external ears, or auricles. The size and shape of the auricles tend to favor the reception of high frequency sounds, while acting as baffles for other frequencies. This is so, simply because the shorter wavelengths of higher frequencies, especially those from 3000 to 5000 Hertz which are between 2-1I2 and 3-3/4 inches in length, are embraced by the auricle structure, while the longer, low frequency sounds tend to bypass the "receiver dish"

. This selective action is well demonstrated experimentally, when all spectrum "white noise" is presented in a room. Inevitably, the adult human ear selects and amplifies any sounds between 3000 and b000 Hertz. Lower frequencies will tend to roll past.

The auricle shapes and redirects sound into the ear canal, whose physical dimensions work to produce a double peaking resonance at approximately 3,500 Hertz, and 8000 Hertz. The result is an amplification of the volume for sounds in those ranges while other ranges remain virtually unchanged.

At the far end of the ear canal is the eardrum or tympanum, against which the incoming sound waves bump and tap. The eardrum is a one millimeter thick, three part membrane, which responds to various sound frequencies in specific patterns. At low frequencies, the tympanic membrane vibrates as a single elastic unit. For sounds above 2,700 Hertz, however, the membrane responds with a complex, multi- sectioned rhythm.

On the inner side of the eardrum, the vibrations of the tympanic membrane are transferred to the three tiny bones of the ossicular chain, which act to amplify the sound wave energy another 15 decibels by mechanical leverage.

when sound below 2000 Hertz is present, the Stapedial Reflex, which can occur as frequently as 100 times per second, is activated. The effect of the Stapedial Reflex, which acts directly on the ossicles, is to stiffen the eardrum and thus protect it against the excessive movement and potential damage that can occur from the uncontrolled presence of very powerful, low frequency sound waves.

Interestingly, the Stapedial Reflex is also activated immediately as one speaks. Perhaps the damping effect that is produced allows us to focus on our own higher, and presumably more meaningful syllable- binding frequencies of speech.

The last bone in the ossicular chain transmits sound energy to the snail-shaped, liquid filled cochlea of the inner ear through the membrane of the oval window.

Immersed c0mpletely in the fluid of the cochlea lies the "Organ of Corti", aptly named for its role, both in the biological and musical sense. The "keys" of the organ exist as hair-like cells, which are played by the movement of currents and countercurrents produced by the sound energy that is transferred from the oval window to the fluid of these hair-like cells; sound is converted to electrical energy necessary for transmission to the brain and subsequent interpretation.

High frequency sounds are processed in the area of the cochlea nearest the oval window, with sounds around 4,000 Hertz being handled in the very first turn of the spiral. It would appear that in the process of evolutionary adaptation, anatomical preference has been given to high frequency sounds, since they are processed first in time as the waves move from front to rear of the cochlea.

In the cochlea, sound vibrations are converted by the hair cells from mechanical energy to electrical energy for transmission to the brain. The electrical energy is transferred to the eighth cranial nerve, the bulk of whose fibers are responsive to sounds above 1,000 Hertz. The greater ratio of nerve fibers responsive to higher frequencies is consistent with the mechanical properties of the ear, which are also high frequency biased. 0nce again it would appear that evolutionary adaptation has provided conditions in which the weaker, high frequency waves can compete equally with the lower frequencies.

0nce beyond the cochlea, ninety percent of the fibers from the auditory nerve bundle of the right ear service the left brain temporal lobe, while the converse is true for the left ear.

It is of further interest to note that in addition to the eighth auditory nerve bundle, each ear is also serviced neurologically by the fifth, seventh and tenth nerve bundles as well. Complete integration exists between sensory and motor routes. For example, the Trigeminal nerve, which controls the front of the tongue, also has a motor route to the skin of the outer ear, and to the ear canal. Clearly, there is an intricate weaving of hearing and speech pathways. This leads to a view that demands the appreciation of hearing as an active and reaching process that occurs in complete unison with speech production.

DEVELOPMENT

The small size of a baby's head and the relative dimensions of its ears predispose human babies to favor high frequency speech. In fact, not only do newborn infants prefer human speech to other environmental sounds, but they also naturally orient more readily to the higher frequencies of female voices.

SOUND RECEPTION & HEAD SIZE

An infant's head is approximately half the size and mass of an adult's. Therefore, in a practical sense, it simply blocks less sound that is sent its way.
Furthermore, since the space separating one ear from the other is about three inches, any sound with frequency less than 2,000 Hertz (which has a wavelength about six inches long~ is likely to reach both ears simultaneously, and with equal force.
However, as we will discuss later, the time lag between a sound's arrival to one ear and then the other is one very important piece of information which humans use to locate sources of sound. The physics associated with the smaller head of a baby insist that, in order to gain a sound map of their world, babies rely heavily on the force of medium sounds only in conjunction with high frequencies.

SOUND RECEPTION AND EAR SIZE

The ears of babies are small too. Generally, the external ear (auricle~ acts as a sound dish on the side of the head. The auricle selects out specific frequency ranges, and amplifies the sounds in those ranges by as much as ten decibels.
As noted previously, the external ear of an adult will collect more sounds in the 3,000 to 6,000 Hertz range than in ranges above and below it, because of its size. Anatomically smaller, a baby's auricles will be much more likely to collect its frequency menu in the range between 8,000 to 10,000 Hertz. Wavelengths of sound in these frequencies are about 1-3/4 to 1-1/4 inches long.
To confuse the issue slightly, the shorter ear canal of a baby under two years of age also tends to set up energizing vibration patterns called resonance, which amplify frequencies in the 6,000 Hertz range. The consequence of this resonance effect is to double the power of sound in the b000 Hertz range. The general effect with babies is to mechanically step up the very high frequencies only.
Given the above information, it is not surprising that when pure tones are presented to infants, adult-like response patterns are obtained for tones above 4,000 Hertz, while no consistent responses occur below that frequency.

HIGH FREQUENCY SOUND & SPEECH

From the developmental perspective, it is extremely intriguing to note that, while all of the inner and middle ear structures are close to full size at birth and capable of full sound spectrum processing, the sound shaping equipment of skull, auricle and ear canal is biased toward higher frequencies.

Babies are predisposed to gather information from the higher frequencies. It would seem that perhaps there is something very valuable for speech development in the higher frequencies that is found primarily within this spectrum. The answer seems to lie in an analysis of speech and its structural dependence upon higher frequencies for meaning, while the infant's favored building brick of language seems to be the syllable, it is the consonants within the syllable, which provide distinctive word information. Indeed, at least 80% of word information is in the higher frequencies found in speech consonants, rather than in the vowels. At birth al1 babies seem to be programmed, hard-wired as it were, to instinctively, aut0matically, and extremely rapidly segregate speech into syllable categories. 4ver time in any given culture, a word hierarchy is formed that is unique to the child and its communicative milieu. Every syllable has its own specific sound structure or envelope. This envelope is quite uneven, consisting of a pattern of millisecond pauses between sounds. The pauses are, for the most part, bound by consonants. Look at the word "sat" for a moment. This single syllable word is bound by the high frequency consonants, "s" and "t". An alteration of consonants at either end instantly changes the word meaning, (e.g. "hat" or "sad"). Unbounded, the low frequency vowel "a" conveys very little information by itself. The presence of a clear consonant signal would thus appear to be a significant element in the correct imprinting of a culture's speech pattern. However, consonants generally appear in frequency ranges beyond 2,000 Hertz, with "s" and "th" sounds extending well into the 3000 to 10,000 Hertz range. And, like all high frequency sounds, consonants tend to exhibit a low energy level. often consonants seem to be added to words in conversation as momentary afterthoughts despite their importance for comprehension.

It is highly probable that the design of an infant's small head, tiny auricles and short ear canals not only influence the child speech-hunger for high frequency sound but actually assist the child to obtain the very basic and distinctive high frequency information necessary for the development of speech itself.

SPEECH AND EAR INFECTIONS

As noted above, the high frequency sounds produced by consonants are generally also low energy sounds. As such, they are also much more susceptible to poor transmission within the auditory system if the process of amplification is impeded by a mechanical malfunction in the system.

The most frequent malfunction in childhood hearing is created by infections of the middle ear. The fluid build up that inevitably results from such infections tends to restrict the movement of the ear drum, thus clipping off the high frequency components of words. As a result a muffled sound pattern is received by the brain, which can then be recorded into the child's permanent memory trace. In other words, during critical periods of speech development, the distortion may imprint an incorrect speech pattern in the brain that will be used for future speech reference.

This might be compared to a broken tape recorder, recording sound on a good quality tape. The broken mechanism will certainly introduce distortion into the recording. Even if the tape machine is then repaired to factory mint condition, the master tape, when replayed, will faithfully reproduce the original recorded errors.

HEARING & THE BRAIN

When sound leaves the Cochlea, where does it go? "Where is this speech reception, analyzing, categorizing and storage section of the brain?" you might ask. For all intents and purposes the "main frame" area responsible for these tasks seems to be in the left temporal brain lobe which appears to be uniquely equipped to extract high frequency consonant information, in order to construct meaningful language from raw speech sounds.

The process have been carefully investigated by a number of researchers. In 1969, Doctors Studdent-Kennedy & Shankweiler at Haskin's Laboratories in New Haven Connecticut attempted to determine the precise qualities of "sounds" that determine whether the brain will perceive them as speech, and the location in the brain at which the interpretation occurs. The basic approach was to present a number of simple consonant-vowel combinations to see which of the combinations was easiest for the brain to interpret. The syllable samples were fed to both ears simultaneously. Brain reaction was closely monitored to determine the locations at which various 'speech pieces' were processed.

The researchers concluded that in the left temporal lobe of the brain there is a special device that is unique in its ability to identify and interpret fundamental stop consonants and final stop consonants as being speech relevant. The device appears to be lacking from the right brain, which is unable to make linguistic decisions based on consonant boundary information.

In the plain English language, vowels are bound together for meaning by low energy, high frequency consonants, which often become confused in children's hearing. Since sound boundary data is exactly what the left brain requires to engineer speech it is then, not too surprising that a baby's hearing is tuned toward a higher pitch because that is where most of the speech information exists and where instantaneous speech decisions need to be made.

PATHOLOGY AND HIGH FREQUENCIES OTITIS MEDIA

The air chamber of the middle ear, which contains the three tiny ossicular bones is extremely susceptible to infection and/or fluid collection, especially in children. This condition, called Otitis Media, may occur intermittent or it may be a long-standing complaint. However, because it can occur without a pronounced redness of the eardrum, pain or any other visual signs that can be observed even with manual Otoscope. The Otoscope is what most physicians rely on to determine the presence or absence of fluid in the ear. 0titis Media may go unnoticed, even in the presence of the significant but temporary hearing loss that can result. A fluctuating mild ear loss is more often attributed to behavior changes than hearing loss. The child is in its own world, they have selective hearing or the just “don’t” listen to their parents. Parents may not always perceive that their children's behavior problems are related to hearing difficulties. Often they will explain a child's lack of cooperation or enthusiasm as self-centeredness or inattention. Annoyingly loud television, yelling when talking, or complaints about earaches may also be accepted as a normal, if difficult part of childhood adjustment. When a child does not respond the parents often form a habit of simply raising their voice or being to ignore the child. Frequently it is not until children go to school that their teacher, school nurse or hearing screening programs may detect the loss. Some childhood changes that can be caused by fluid in the ear but are not often thought about are: Unusual irritability, Difficulty sleeping, Tugging or pulling at one or both ears, Red or hot ears, Fever, Loss of balance, Ear(s) popping, over reaction to loud sounds, change in speech patterns, change to aggressive behavior more noticeable in males, withdrawal, poor reading and spelling, TV loud and inattention to most adult conversations. The above conditions represent only the more common physical and behavioral changes often associated with recurrent fluid and any of the above changes can be due to other causes.

The presence of fluid in the middle ear, which is usually air filled, interferes with the free movement of the ossicles. As a result, hearing is damped in all frequencies. However, because liquid is more efficient at absorbing the shorter, weaker wavelengths of high frequency sounds, the higher frequencies lose relatively more energy than do sounds in the lower frequencies. Estimates of the incidence of Otitis Media have suggested an occurrence as high as high as 70% for children under two years of age. Yet it is precisely during these Otitis bouts that language programming, which is dependent on the high frequency consonants for meaningful information, will be most at risk.

Unfortunately, once a temporary bout of 0titis Media has seemed to clear, residual high frequency loss may continue to linger for months or even years as a result of the negative middle ear pressure which pulls on the eardrum, giving it a "stiffness tilt" and making it less responsive. Stiffness can also occur because of poor articulation between the joints of the three bones of hearing, much like arthritis. If the disease is recurrent, there will also be a tendency toward a thickening and scarring of the eardrum. These long term effects can go un-noticed when the ear drum is examined because of the wide variability in how ear drums appear with a manual Otoscope. As a result, the eardrum may be less able to process high frequency sounds because it can no longer perform its three part vibrational "flutter" above 2,700 Hertz. In recent years, a significant amount of information has become available linking 0titis Media to learning disabilities. Assessment of high frequency hearing appears to indicate that one possible result of the disease is a general deterioration for hearing above 4,000 Hertz. This reduction in high frequency hearing capacity, it has been noted, is usually present well after the obvious signs of the disease have cleared. High frequency loss may, then, be a signature of previous ear infections or non-infected fluid formation which is no longer in existence. This often accounts for parents and teachers “noticing” a hearing loss while the physician or audiologist says the ear and tests are “normal”. The end organ of hearing is normal, while the results of old ear problems are what the parents and teacher are “noticing”.

The incidence of middle ear problems seems to be on the rise. Nonetheless, others who have not examined its long-term consequences have sometimes criticized those who have aggressively approached the infection in order to reduce its impact. Perhaps, the full significance of high frequency hearing loss is not recognized because remedial medical costs are not usually credited to educational budgets. However, it is clear that the educational costs alone are significant enough to warrant early intervention and prevention strategies. A recent publication in the Journal of Otolaryngology by two Canadian Researchers; Lisa Elden MD & Peter Coyte PhD, reported: "More prescriptions are written for Otitis Media (middle ear fluid) than for any other condition". Estimated costs for Otitis Media in the U.S.A. is *3 to 4 billion dollars a year and in Canada 600 million plus.* These costs do not include the family's cost of travel, lost work time, uninsured use of antibiotics and uninsured costs to the family, related to repeated treatment or surgical intervention.

THE EFFECTS OF LOUD NOISE

High Frequency Degeneration infection is not the only risk factor for high frequency hearing. Due to the physical structure of the Cochlea, hearing in the range of 4,000 Hertz is especially susceptible to degeneration by loud noise. The progressive loss of hearing from 4,000 Hertz upward, known as "the 4000 hertz dip", is a common industrial hazard and is well recognized in medicine and audiology. Noise exposure and its effect on high frequency hearing is regulated by almost every industrialized country in the world and second only to backs in the number of claims filed by works for disability.

AGING

It can also be argued credibly, that one of the primary victims of aging is high frequency hearing, especially for men. The condition, called Presbycusis, produces a progressive hearing loss in many people that proceeds downward from 8000 Hertz at age 45, to 2000 Hertz or lower by age 65. Age-bound Presbycusis is a very common and handicapping ailment, whose effect may be compounded by a number of factors, including exposure to industrial noise, non-prescription drugs and medications, life style choices (e.g. Smoking, weight, blood pressure). The synergistic effects of smoking, high blood pressure and industrial noise has long been recognized to cause greater hearing problems when combined than any one by itself. Synergistic effects have risen to prominence in recent medical research and the popular press regarding accidental hospital deaths. We are just looking at the tip of a very large iceberg.

DRUG EFFECTS

Finally, there is the rather unique finding that hearing sensitivity to frequencies beyond 8,000 Hertz may be reduced following exposure to certain drugs. This reaction, known as a drug ototoxic effect has definite implications regarding the degeneration of high frequency hearing. However, at this time, the area requires more extensive study based on large clinical trails. Large clinical trials on drugs and hearing have not been carried out because of the high cost of repeated testing. This will change with the introduced of advanced hearing technologies that can be done over the Internet and ability to save information is global databases of information. Physicians and Audiologists are still trained primarily to treat one patient at a time and only with many years of experience learn to recognize unusual patterns of problems within their specialty. The collecting of databases of information was primarily the responsibility of the researchers which was reported in publications and in many cases were crippled by poor funding because of cost cuts to research and outcomes assessments. It is clear that the educational costs alone are significant enough to warrant early intervention and prevention strategies, while the effects on family incomes, social development, and other long term costs to society are far likely much greater.

THE EFFECTS OF LOUD NOISE

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AGING It can also be argued credibly, that one of the primary victims of aging is high frequency hearing, especially for men. The condition, is often confused with Presbycusis, as both condition produce a progressive hearing loss in many people that proceeds downward from 8000 Hertz at age 45, to 2000 Hertz or lower by age 65. Age-bound Presbycusis is a very common and handicapping ailment, whose effect may be compounded by a number of factors, including exposure to industrial noise, drugs, high blood pressure, recreational noise, life style choices, hereditary factors and new synergistic effects being discovered.

EXPERIMENTAL FINDINGS

Why does the human ear function beyond 10,000 Hertz, if human speech is not produced past that range? What happens to the actual information in the 10,000 to 20,000 Hertz range at the level of brain processing. Furthermore, why does there seem to exist a cross purpose between the ear's natural tuning to high frequencies and the degenerative processes that attack high frequency hearing. These remarkably simple questions are not fully addressed in modern professional work.

If we deal with the highest frequencies first (10,000 to 20,000 Hertz), we might reason that they help us to unconsciously localize the source of sounds. Since many animals rely up0n short, high-pitched sounds to locate objects in space, and some navigate using very short, high frequency noise bursts; it is possible that we may similarly use high frequency as localizing information.

Such speculation would not be in disagreement with well known sound localization theories. It seems that for high frequencies, the intensity of the sound at the ear closest to the source is a distinguishing contributor to direction awareness. In contrast, longer waves tend to bend and diffuse around the head in an action known as the "head shadow effect". Therefore, with lower frequency waves, a time comparison factor between the arrival of sound at the two ears operates to assist orientation.

We might speculate that there is at least one other purpose for the frequencies between 10,000 and 20,000 Hertz, and that is to modulate sensory arousal levels. The rational for such a hypothesis comes from the clinical observation of poor arousal control in many language disordered children. These children fidget constantly. Coincidentally, many of these children have difficulties with phonetics, which would indicate internal speech timing and memory dysfunctions. Often the most common thread that links these children is early, recurrent bouts of otitis Media.

Recent research upon single cells in the auditory systems of animals along with psychophysical work with humans would seem to suggest that the auditory system regularly tunes itself. Furthermore, the research indicates that tuning accuracy increases as the frequency scale is ascended. This opens up the distinct likelihood that higher frequencies may serve as an automatic self-tuning standard for the lower sound boundaries.

In fact, the cochlea itself appears to be a very proactive organ. Recordings from adult ear canals demonstrate that it continually produces high pitch sounds of up to 20 dB. A self-tuning hypothesis such as this one conforms quite nicely with what has been noted about language development in children who suffer from Otitis Media. As noted previously, a high frequency speech preference in babies seems to be essential to form the basics of speech. However, if speech reception is improperly tuned because of high frequency sound distortion during a long-term bout of disease, it is very probable that the speech of these children will lack normal synchronization. It is also likely that appropriate fine-tuning to speech sounds will be inaccurate. This may result in the confusion of sound boundaries so often seen with language disorders. Perhaps one day this will be tested directly.

In our opinion Physicians and Audiologists must not only repeat hearing testing to form plans for remedial hearing care, they must gather the clinical history of ear blockage and infection. It is important to ultimately determine how many blockages during the language acquisition years a child can have without affecting listening skills. Some of this work has begun demographically. Professional consideration might also include listening skill problems that can result from temporary hearing losses which have subsequently cleared. Previously stored, distorted reference patterns for speech and language can and do produce behavioral responses similar to mild to moderate high frequency losses.

REMEDIAL STRATEGIES

Individuals with high frequency impairment naturally tend to gravitate toward quieter areas. 0nce there, they usually prefer face-to-face conversation so that they can lipread as a backup to their poor auditory speech perception. Interestingly, the lipreading is frequently developed as a subconscious rather than conscious method of compensation.

The emotional effect of lipreading upon the message sender in conversation tends to be highly favorable since it appears that the hearing impaired listener is gazing deeply into their eyes with rapt attention. The focus of the listener is, of course, rather on the speaker's mouth and its movement. Having developed the need for this compensating technique, the individual may eventually withdraw from any social situation in which face-to-face information is difficult to obtain.
0ne alternative strategy to remediate weak hearing reception has been to artificially bolster a primary speech signal over competing background noise. This can be accomplished by good quality loudspeakers, personalized FM systems, or with low gain, automatic output limiting, high frequency emphasis hearing aids. Early testing with analog devices proved successful in many cases and with the introduction of digital hearing aids the added control of the acoustical settings within the hearing aid require this approach to be revisited.
Each of these techniques have been effectively tried experimentally with learning disabled, high-frequency-poor children. Early analog results indicate an individualized high- frequency-emphasis hearing aid for classroom use on a temporary bases can be of use when other remedial help is not available, slow or not working. However, more comparative studies must be carried out to determine the most effective unit for various settings, length of use, long term effects hearing effects, specific impacts on education and social adjustment. This approach requires study but early results under carefully controlled conditions have proven useful is many cases.
The other strong effect noted by high frequency impairment is, of course, the hindrance of precise speech acquisition. It has been known for a long time that many reading disabled and distractible children miss phoneme categories in words. They miss the sound boundary categories and have poor pronunciation. Many of their histories, as discussed previously, have had recurrent Otitis Media as a common element.
Physical medicine has acted to treat Otitis with antibiotics and antihistamines. However, perhaps the most effective medical method of correction has been the use of a venting technique that inserts tubes through incisions in the eardrum. New procedures using modern laser technology are gaining recognition in the literature. The laser technique relies on establishing a temporary hole in the ear drum which heals in several days and is reported to done without a general anesthetic. The placing of the tubes in the ear permits the suctioning of fluid from the ear while the child is under a short anesthetic and the placement of a ventilation tube so that middle ear pressure is equalized. An aggressive medical approach, venting of the middle ear through the ear drum has had the most promising results to date. In spite of vigorous intervention by specialists understanding the potential long term effects of repeated otitis, some children still surrender their high frequency reception to infection. In many cases it is difficult to determine if the high frequency changes is in the middle or inner ear. At the present time, it is likely that if the loss is mild or even moderate and only in the high frequencies, it will be identified and dismissed as trivial and insignificant educationally especially at the primary medical care level. This is due in part to the lack of general information regarding the effects of high frequency changes

during language acquisition years. In many youngsters at best, if speech pronunciation is poor and a high frequency dip is present, traditional non-medical treatment has involved a special class placement, speech correction, psychological or medication approach without consideration for the basic causal effects. The various speech techniques rely upon the ear becoming sensitized to missed sounds by way of motor feedback and practice. Such intervention is labor-intensive and involves careful identification of weak speech categories. A set of hierarchical goals is set for each individual, and then the individual is drawn through the specialized programs. More recently an alternate non-medical intervention strategy has been introduced. Accepting the well established fact that "input precedes output, and that clear speech is unlikely to develop from either an unclear signal or previously stored distorted one, some researchers have tried fitting children with a high frequency auditory trainer with emphasis on the consonant range of speech. When fitted to the speech-favoring right ear, the result of a clearer signal in several cases shown a significant speech correction. The capacity of the children to hear rapidly changing phoneme markers in words given a consonant "kick" seems to spontaneously improve. The high frequency emphasis strategy seems to be phoneme-blending specific however. It does not appear to assist short-term auditory memory, as required for example in oral spelling. Improvement in behavior and listen habits are usually reported but empirical evidence for this is difficult to establish. Separating “hope” for improvement is difficult to separate from actual improvement in hearing behavior related work because of its complexity.

THE FUTURE OF HIGH FREQUENCY HEARING

Doors of exploration in this subject area, closed for many years, are now beginning to open. Advances in computer and database technology, the Internet and digital testing equipment are serving as a major impetus into the investigation of high frequency hearing. The territory is very fertile, and long overdue for careful and unbiased exploration. High frequency hearing basics have yet to be established and in a society which is vastly advanced in other fields of human study.

It is surely more than happenstance, or a mere quirk of advanced human evolution that we continue to maintain hearing in the ranges of 10,000 to 20,000 Hertz. That hearing band is doing something, however, what? The discoveries are awaiting our systematic investigation.

As we learn more about the wonder of hearing it is likely that new remedial technology will develop. The strongest probability is that the emerging technology will join hands with more traditional approaches to remediation and compliment current practices in education, audiology, medicine, psychology and speech language pathology. Such knowledge can only enrich, strengthen and support what we already know, and what we already do. The significant question is, "what yet waits to be discovered?"

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