

Introduction

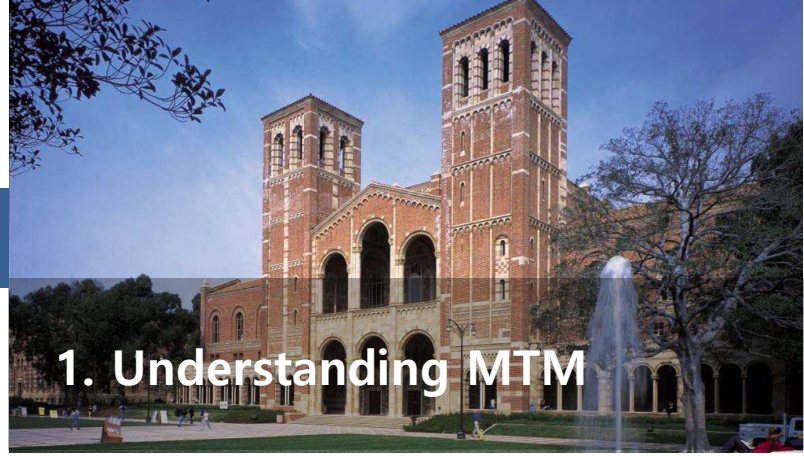
This book is an academic textbook for professionals who study the phenomenon of tinnitus. "Diagnosis and Treatment of Tinnitus with MTM" is divided into two volumes. Volume 1 introduces MTM, a new technology in the field of tinnitus diagnosis and treatment, and provides a detailed dissection of MTM technology and the results of MTM clinical trials. Volume 2 is an interactive discussion and debate between a group of clinicians who led the clinical trials and a group of developers who designed the MTM system to create a universal manual for the diagnosis and treatment of tinnitus. The various clinical cases cited in Volumes 1 and 2 were subjected to objective statistical tests of the clinical effectiveness of the MTM tinnitus diagnostic and treatment techniques and used as evidence to support the Gaussian function theory.

For about two months in October and November 2018, a multicenter clinical trial for the diagnosis and treatment of tinnitus was conducted with the support of the Seoul Global Biomedical Fund. A total of 17 medical centers located in major cities in Korea, including Seoul, Busan, Incheon, Daejeon, Ulsan, Gwangju, Changwon, Jeonju, Bucheon, Andong, Gumi, Jeju, Wonju, and Chungju, participated in the trial. Clinical subjects were recruited mainly from patients visiting the 17 medical centers, and a total of 258 voluntary subjects participated in the MTM trial. Of the 258 subjects, a total of 195 subjects completed the entire clinical trial.

In Volume 1 of MTM Diagnosis and Treatment of Tinnitus, a comprehensive macro-level analysis was conducted on the micro-hearing structures of all 195 participants. Statistical validation of changes in tinnitus symptoms was attempted using various sample groups. By implementing the RCPTA automated hearing test method, which controls an algorithm to finely divide the test frequency range into 67 bands, participants' hearing conditions were precisely examined at high resolution. Through MTM clinical trials, the Gaussian function theory regarding the correlation between tinnitus and hearing was demonstrated, followed by statistical considerations and interpretations.



Research and development of MTM's underlying technologies, the RCPTA and TSC algorithms, began in September, 2000 with the support of the Cora Black Scholarship from the State of California, USA.



1. Understanding MTM

MTM has two meanings: Modulated Tinnitus Masking and Masked Threshold Management. To better understand the concept of MTM, let's look at both definitions.

Modulation Tinnitus Masking: "Frequency modulation, amplitude modulation, and modulated sound signal intensity"

Modulated tinnitus masking refers to a masking technique using modulated sounds for tinnitus. The general unmodulated masking method is the traditional tinnitus masking method that most experts in this field know. Modulated tinnitus masking, or MTM, is a modulated version of the traditional tinnitus masking method. In MTM, modulation is divided into two types: frequency modulation and amplitude modulation. The frequency-modulated signal must be an acoustic signal within the audible frequency band to be properly masked from tinnitus symptoms. The frequency-modulated acoustic signal is assigned an appropriate modulation amplitude and modulation period so that it can sequentially and evenly stimulate groups of auditory cells and auditory neurons within a unit auditory filter, i.e., a single critical band. Frequency modulated signals within the audible frequency band are more effective as stimuli to elicit auditory biological responses when combined with amplitude modulation. This is because three-dimensional auditory information that combines not only frequency information but also intensity information can be transmitted simultaneously to the auditory center.

When masking tinnitus symptoms in the audible frequency band, the strength of the masking should be at a descending threshold. The descending threshold is the point at which the signal first becomes inaudible when the volume of the modulated sound signal is gradually reduced from audible to inaudible. The difference between traditional tinnitus masking and MTM is not only the difference in the auditory characteristics of the masked signal, but also the intensity at which the masking occurs. In traditional tinnitus masking, the volume of the masking stimulus is adjusted to a level of intensity that sufficiently masks the tinnitus or is equivalent to the tinnitus. Most conventional tinnitus treatments that use white noise or band noise are based on tinnitus masking, where the intensity of the masking stimulus is higher than or equal to the volume level of the tinnitus. In contrast, MTM targets the intensity of the modulated sound signal not at the point where the tinnitus is blocked, but at the descending threshold where the modulated sound signal itself is "completely blocked" by the tinnitus. The intensity of the modulated acoustic signal as a masking stimulus must be lower than the volume level of the tinnitus, as well as completely drowned out by the tinnitus. Conceptually, MTM is often referred to as "modulated tinnitus masking," but a more accurate description of what it means is as

follows.

'A tinnitus treatment method in which a frequency-amplitude-modulated sound signal with a certain modulation width and modulation period is adjusted to the descending threshold value, which is the intensity level at which the tinnitus sound is completely masked, and then listened to for 30 minutes twice a day for about 2 weeks to 3 months to achieve tinnitus suppression effect.'

Based on the above definition, let's look at another definition of MTM: masked threshold management.

Masked threshold management: "Mask the modulated sound signal with your own tinnitus"

"Masked threshold management" is more precisely "masked threshold management." "Masked threshold" refers to the real-time situation of the auditory threshold that is masked and interfered with by something. The "something" is tinnitus. The concept of tinnitus masking the threshold may sound unfamiliar, but if you look at it from the subject's point of view, it can be understood as a situation where the modulated acoustic signal located at the threshold is inaudible due to the subject's tinnitus.

The purpose of blocking the modulated acoustic signal at the descending threshold in tinnitus is to alleviate or eliminate the symptoms of tinnitus without causing further hearing loss. In conventional tinnitus treatments, the intensity of the masking signal is often greater than the intensity of the tinnitus. This often results in an increase in hearing threshold. Repeatedly listening to an auditory stimulus that exceeds the intensity of the threshold over a period of time results in an increase in threshold, either temporarily or permanently. Paradoxically, an increase in threshold often results in relief of tinnitus symptoms. The reasons for this are discussed in detail in Chapter 13, Gaussian Effects in Tinnitus.

It is important not to misinterpret the concept of "increased threshold" as "improved hearing". Otolaryngologists and audiologists who are familiar with the ISO8253 series of standard audiograms (i.e., "audiogram coordinates with the 0 and 100 values on the y-axis reversed") from the past 70 years often understand "elevated threshold" as "improved hearing." In the ISO226 audiogram, the foundational standard of ISO8253, an 'increase in threshold' means a 'loss of hearing.' MTM prohibits masking tinnitus by matching the intensity of the modulated sound signal to the intensity of the tinnitus or by making it stronger than the tinnitus. This is because the intensity of the modulated sound signal may be equal to or greater than the intensity of the tinnitus, which may result in an increase in hearing threshold. This is not desirable, even if the increase in threshold results in relief of tinnitus symptoms. Inducing artificial threshold elevation to alleviate tinnitus is no different from a 'burning the bridge to kill the rats' approach, comparable to performing a labyrinthectomy or auditory nerve section for tinnitus elimination. It is difficult to ethically justify the practice of intentionally raising hearing thresholds to alleviate tinnitus symptoms. In the name of 'adaptation', we

should not compromise fine hearing in order to control tinnitus.

The intensity level of the modulated tones in MTM should be sufficiently lower than the intensity of the tinnitus. MTM treatment can be safely performed by finding the descending threshold where the modulated tones are masked by the tinnitus and the presence of the modulated tones is not perceived. By precisely maintaining a volume where the tinnitus is sufficiently masking the modulated sound signal at the descending threshold, the MTM technique is able to calm the unstable hearing condition in the tinnitus frequency band and restore a healthy hearing threshold in that frequency band.



The first modulated acoustic signal for MTM was created at the Cognitive Acoustics Laboratory on the UCLA campus in California, USA.

Modulated Sound Signals: "Characteristics of the modulated acoustic signal should be masked by tinnitus."

There are many different types of modulated acoustic signals that are masked in MTM, depending on the type of tinnitus. However, the modulated acoustic signal in the MTM clinical trial introduced in this book is a frequency-amplitude modulated acoustic signal within the audible frequency band, which is a combination of frequency modulation and amplitude modulation with a constant modulation width and modulation period.

For tinnitus to mask the modulated sound signal, the frequency and intensity characteristics of the tinnitus and the modulated sound signal must be well matched. It is not possible to perfectly match subjective tinnitus to objective modulated sound signals. All types of psychoacoustic tinnitus, including pure tone or noise tinnitus, complex tinnitus with multiple pure tones, noise tinnitus with multiple noises, and mixed tinnitus with various tinnitus components co-occurring simultaneously, are subjective tinnitus, which is an electrophysiological auditory phenomenon that is difficult to objectively measure externally. Therefore, it is not reasonable to assume that the true nature of subjective tinnitus can be accurately determined based on the results of behavioral response tests such as tinnitus frequency matching tests or minimum masking level (MML) tests.

However, there is a relatively objective way to determine the nature of subjective tinnitus that takes the judgment of the sufferer or healthcare professional out of the equation. One such method is the RCPTA test, which is designed to track the burst firing of auditory cells and the neural synchronization of groups of auditory neurons that accompany tinnitus

episodes. The RCPTA test is discussed in detail in several chapters of this book.



Thankful Tinnitus

Everyone has probably heard a "peep" or "tweet" in their ears when they are tired. Suppose you hear this sound for the first time and then, about two weeks later, you are tired again and hear the sound in your ears again. One interesting fact is that the probability that the sound you hear this time is the same frequency as the sound you heard before is very high. There are 15,000 auditory cells in the cochlea, and various frequencies ranging from 20 to 20,000 Hz are processed. How can the frequency of the sound heard briefly and the current sound be the same?

It is not easy to remember exactly when you first experienced tinnitus. The 'beep' sound that people often hear when they are tired is also tinnitus, even if it is heard for a moment and then disappears. Do you remember the first time you were tired? Do you remember if you heard any sounds in your ears or head at that time, and when exactly was that? If people could remember this day and know exactly what frequency components of the early-stage tinnitus they heard on that day, and if they could immediately turn off the tinnitus alarm by properly stimulating the auditory cells, then perhaps we could have a world where tinnitus patients are hard to find. It is not difficult to find the frequency of tinnitus at the onset of tinnitus and try to eliminate it. This is one of the best ways to detect hearing loss early and prevent further hearing loss.

Tinnitus is a warning sign of auditory nerve damage. Tinnitus is an

alarm signal that alerts your brain to the fact that you are currently experiencing hearing loss in a particular frequency band, and helps you protect your ears to prevent further hearing loss. The central auditory nerve and peripheral auditory cells are systematically networked together in a frequency relationship, and if there is even a slight disruption in the auditory network that processes a particular frequency, tinnitus can occur at that frequency location. In this sense, tinnitus is a kind of "real-time report card of malfunctioning frequencies in the body" that immediately reports when hearing in a particular frequency band is even slightly compromised. Early-stage tinnitus is neither something to ignore nor something to fear, but something to listen for. You need to listen, memorize, and find the frequency values. Then you can stop it immediately. Early-stage tinnitus is a thankful task that provides valuable information for managing your hearing health.

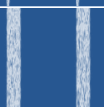
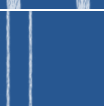
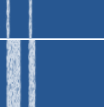
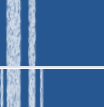
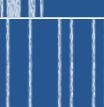
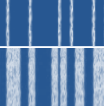
Classification of Tinnitus

Acoustics, a branch of physics, categorizes the properties of sound into two broad categories: tone and noise. Tones are further categorized into two types: pure tones, which have only one frequency component, and complex tones, which are composed of two or more pure tones. Tinnitus can be categorized into 'tone tinnitus' and 'noise tinnitus' based on the acoustic characteristics of the tinnitus, as it is a 'sound' perceived by the brain. Tinnitus is further divided into 'pure tone tinnitus' and 'complex tone tinnitus'.

Tinnitus can also be categorized by the number of frequency components. Tinnitus consisting of only one frequency component is called 'simple tinnitus'. When two or more simple tinnitus components occur simultaneously, it's called complex tinnitus. Simple tinnitus or complex tinnitus can occur in only one ear, or it can occur in both ears simultaneously. To summarize, tinnitus is divided into pure tone tinnitus, complex tone, and noise tinnitus according to whether the component frequency characteristics are tone or noise. It is also divided into simple tinnitus and complex tinnitus according to the number of component frequencies. Accordingly, a total of 10 types of tinnitus can be classified as shown in the following page <Tinnitus Classification> Table.

<Tinnitus Classification Method>

Critical band: The critical band is the unit of human auditory filtering and is a key concept in psychoacoustics that is applied to the placement of electrodes in cochlear implants and the design of filters in hearing aids. The frequency range of a critical band is approximately 1 millimeter across the cochlea, which corresponds to an interval of 1/3 to 1/6 of an octave (major second to major

Tinnitus Types		Definition	Characteristics	Spectrum
Unilateral Simple Tinnitus	Unilateral pure-tone simple tinnitus	A single pure tone occurring in a critical band of one unilateral ear	Beep~ / Frequency matching possible	
	Unilateral noise simple tinnitus	A single narrowband noise occurring in a critical band of one unilateral ear	Si~ Shi~ Shu~ / Frequency matching possible	
Bilateral Simple Tinnitus	Bilateral pure-tone simple tinnitus	The same pure tone occurring simultaneously in a critical band of both ears	Beep~ Doo~ Wing~ Woong~ / Frequency matching not possible	
	Bilateral noise simple tinnitus	he same narrowband noise occurring simultaneously in a critical band of both ears	Si~ Shi~ Shu~ Swa~ Chi~ / Frequency matching not possible	
Unilateral Complex Tinnitus	Unilateral complex-tone complex tinnitus	Two or more pure tones occurring simultaneously or alternately in at least one critical band of one unilateral ear	Beep~ Doo~ Wing~ Woong~ / Frequency matching not possible	
	Unilateral noise complex tinnitus	Two or more noise components occurring simultaneously or alternately in at least one critical band of one unilateral ear	Si~ Shi~ Shu~ Swa~ Chi~ / Frequency matching not possible	
	Unilateral mixed-tone complex tinnitus	Two or more pure tones or noise components occurring simultaneously or alternately in at least one critical band of one unilateral ear	Shu~ Swa~ Chi~ Soe~ Jjaeng~ Kkaeng~ Kking~ Gwaeng~ / Frequency matching not possible	
Bilateral Complex Tinnitus	Bilateral complex-tone complex tinnitus	Two or more pure tones occurring simultaneously or alternately in at least one critical band of both ears	Beep~ Doo~ Wing~ Woong~ / Frequency matching not possible	
	Bilateral noise complex tinnitus	Two or more noise components occurring simultaneously or alternately in at least one critical band of both ears	Si~ Shi~ Shu~ Swa~ Chi~ / Frequency matching not possible	
	Bilateral mixed-tone complex tinnitus	Two or more pure tones or noise components occurring simultaneously or alternately in at least one critical band of both ears	Shu~ Swa~ Chi~ Soe~ Jjaeng~ Kkaeng~ Kking~ Gwaeng~ / Frequency matching not possible	

third) on the musical scale.

<Tinnitus Classification> is cited from Earlogic's 『Tinnitus Taxonomy』

Tonotopy

The reason why the audible frequency components of the natural world can be represented as sounds in the human brain is due to the principle of 'tonotopy,' which is a representative sound processing mechanism of the auditory nervous system. Tonotopy is a neural network structure that governs the frequency processing of the auditory nervous system, and is a kind of 'frequency map' organized in a grid-like manner within the auditory cortex. The number of the most basic unit combinations of auditory neurons that form the frequency map is at least 100,000, and the number of cases of neuronal lattice responses among all unit combinations in the entire frequency map reaches at least several trillion. This is the total number of random sounds that are passively perceived in the human auditory system, either accidentally or unconsciously.

Sound stimuli from outside are always subject to the tonotopy principle in the human brain. In the case of sounds with physically distinct frequency characteristics, such as pure tones or complex tones, the tonotopic operation of the auditory nervous system is performed immediately, and specific auditory neurons actively respond at specific frequency locations in the auditory cortex. And that sound is manifested as a distinct psychological phenomenon called pitch. When the sound has a frequency characteristic that is not physically clear, such as narrowband or broadband noise, the tonotopy operation does not occur immediately, and only the auditory neurons in a certain frequency band position in the auditory cortex collectively respond passively. And that sound is represented only by the random electrical reactions between auditory neurons in the auditory cortex without any distinct pitch.

Tinnitus as an Electrical Phenomenon in Tonotopic Reorganization

The central auditory neurons that process sound and the peripheral auditory cells involved in sound amplification are paired with cells and neurons that process the same frequency. However, when auditory cells are damaged, this pairing structure breaks down, leading to disruptions in tonotopy. In the case of healthy hearing, there is a unique mechanism in which the central auditory nerve in the brain suppresses the peripheral healthy auditory cells to an appropriate level. This is called efferent inhibition. If an A frequency processing peripheral auditory cell "A cell" is damaged, the corresponding central auditory neuron "A neuron", which is responsible for processing the A frequency, lifts its inhibition on the damaged A cell and undergoes reorganization by forming new pairings with other healthy cells, such as B cells. As a result of this reorganization, the damaged A peripheral auditory cell becomes excluded from the efferent inhibition of the A neuron, losing its normal function of sound amplification or attenuation. Additionally, deprived of efferent inhibition from the A neuron, the damaged A peripheral auditory cell begins to generate spontaneous sound in the absence of external stimuli, leading to tinnitus.

Schematic Understanding of the Occurrence of Tinnitus

Let's take a closer look at the auditory nervous system principle that causes tinnitus using Sam Kwak's tinnitus diagram. The diagram below shows a comparison between a normal auditory nervous system and an abnormal auditory nervous system in which tinnitus is currently occurring.

<Normal auditory system and the auditory system with tinnitus>

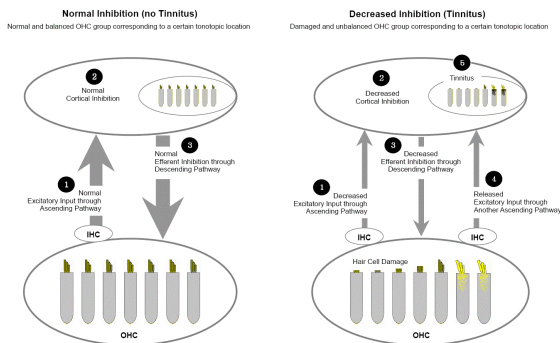
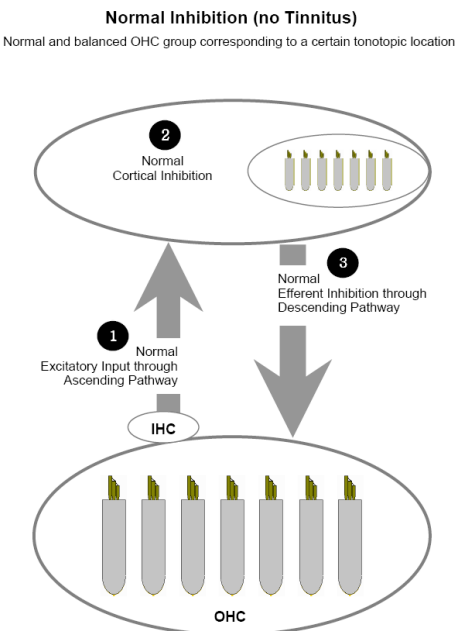


Figure 1 below shows the principle of operation of a normal auditory nervous system in which tinnitus does not occur.

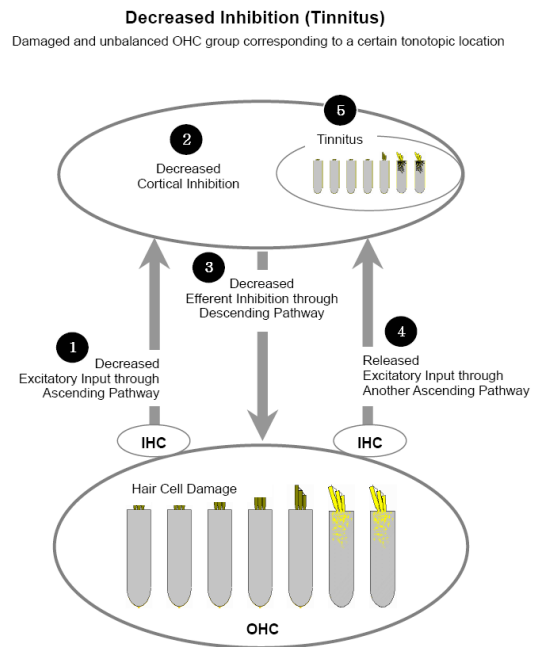
Figure 1. Normal auditory nervous system



Outer hair cells (OHCs) that respond to specific frequencies are essentially motile cells with dynamic properties. When all of these outer hair cells are in their normal state, the electrical signals from the spontaneous movement of the outer hair cells are not perceived as sound even when they are transmitted to the central nervous system through the inner hair cells (IHCs) and the afferent auditory pathway. This is because the cerebellum receives such a strong inhibition. The inhibitory control from the brain to outer hair cells (OHCs) is constantly transmitted via the efferent auditory pathway, regardless of the presence of external sound, and properly regulates their motility.

Meanwhile, Figure 2 below shows the working principle of the auditory nervous system in which tinnitus is occurring.

Figure 2. Auditory nervous system with tinnitus



When some of the outer hair cell groups that respond to a particular frequency are impaired, the electrical signals that are transmitted to the center through the inner hair cells carry somewhat less energy to the brain than they would normally. The brain receives the reduced energy and lowers the inhibitory strength for the entire group of outer hair cells in that frequency band. The reduced inhibitory energy fails to sufficiently suppress the spontaneous responses of the remaining intact outer hair cells in the affected frequency band. These partially inhibited spontaneous electrical signals result in tinnitus, a neurological phenomenon in which sound is perceived in the absence of external stimuli.

For modern individuals, who live surrounded by various types of sounds, such as speech, music, road noise, traffic, environmental noise, etc. Tinnitus is like forewarned ecological revolt of auditory cells. It is an ecological side effect of overexposure to highly disordered acoustic

stimuli, where the human ear is accustomed to moderate volumes of speech and music.

Neuroscience of Tinnitus

<From the ear or the brain?>

If tinnitus, which is perceived as sound even in the absence of external stimuli, is a visible presence, is it located in the ear (peripheral organ) or is it nesting in the brain (central organ)?

Based on the expressions of tinnitus patients, such as "the tinnitus is heard only in one ear" or "it is heard in both ears," it was initially assumed that all phenomena related to tinnitus occur in the cochlea, i.e. the peripheral auditory organ.

However, in the early 1980s, it was discovered that a significant number of patients still perceived tinnitus as a result of the eighth cranial nerve resection performed as part of the surgical treatment of tinnitus. In 1992, among patients who had their eighth cranial nerve severed in the process of treating acoustic neuroma, it was found that a significant number of patients still perceived tinnitus. After the results were announced that 34% of people had newly started to hear tinnitus, the theory that tinnitus exists in the central auditory organ was proposed and gained great support based on the results of various animal experiments.

However, classifying tinnitus as a brain disease can lead to misunderstandings. Tinnitus is not a symptom of a brain disease such as "mental illness" or "hysteria." Although tonotopic reorganization can occur in the central auditory cortex, it is also a scientific fact that damage to the peripheral auditory system is a major cause of tinnitus, as many studies have shown. Therefore, it is advisable to approach the treatment of tinnitus by considering that all auditory organs involved in sound perception

may be involved in the occurrence and progression of tinnitus, rather than focusing all attention on the central auditory organs.

<Peripheral Auditory organs and Tinnitus>

Most researchers agree that tinnitus is caused by abnormal conditions within the cochlea. Let's take a closer look at the current theories on how the peripheral auditory system may be involved in tinnitus.

a. Structural changes: The outer hair cells are more easily damaged than the inner hair cells. Eventually, there are areas in the cochlea where the inner hair cells are normal but the outer hair cells are damaged. This can lead to a situation where the tectorial membrane, which has lost contact with the outer hair cells, comes into contact with the inner hair cells. This situation makes it easier for depolarization of the inner hair cells to occur, which can induce a state of increased spontaneous response of the nerve than normal and eventually lead to tinnitus.

b. Efferent nerve damage: Damage to the auditory cells can progress to efferent nerve damage around those cells. In this case, the function of the efferent nerves that inhibit the cochlea is disrupted, causing an imbalance

between excitation and inhibition, which can ultimately increase the spontaneous firing of the auditory nerve.

c. Loss of motility of outer hair cells: The decreased motility of outer hair cells can conversely increase the sensitivity of inner hair cells, which in turn can increase the amount of spontaneous firing. Some studies have shown that impaired outer hair cell function increases the amount of glutamate, a neurotransmitter in inner hair cells.

<Central Auditory Organs and Tinnitus>

It is well-established that when the cochlea is damaged due to noise or ototoxic drugs, the damage is not confined to the cochlea alone but results in structural, neurochemical, and physiological changes throughout the entire auditory system. This phenomenon is influenced by neuroplasticity the important characteristic of the nervous system that allows its structure and responses to be flexible and adaptable to the environment. Many of the phenomena that explain the relationship between the central auditory system and tinnitus are also the result of neuroplasticity.

a. Changes in spontaneous firing rate: It has been experimentally observed how the spontaneous firing rate of each nerve changes at different levels of the central auditory system after inducing tinnitus with drugs or traumatic noise.

b. Burst firing and neural synchronization: The spontaneous firing of auditory nerves is supposed to be randomized, but in animals in which tinnitus is induced by drugs and noise exposure, burst firing, which is a clustering of spontaneous firing, and neural synchronization, which is a simultaneous response, have been observed.

c. Reorganization of the tonotopic frequency map: The auditory system has tonotopic features that separate areas that respond to different frequencies of sound. These features are present in each neurotransmission pathway from the cochlea, or peripheral auditory organ, to the auditory cortex in the brain. After damage to the cochlea by noise or ototoxicity, reorganization of the tonotopy map has been observed at different stages of the auditory pathway, as well as in the cerebral auditory cortex.

<How Tinnitus Occurs>

Several theories have been proposed as to how tinnitus occurs based on the observations that have been made.

a. An imbalance between excitatory and inhibitory neural responses: The transmission of sound signal and information from the ear to the brain is a process that involves numerous combinations of neuronal excitatory and inhibitory responses. The interaction between excitatory and inhibitory responses is called peripheral hearing. They are known to be present at almost every level from the peripheral auditory system to the cerebral auditory cortex, and when the auditory system is normal, the balance between excitatory and inhibitory responses is well maintained.

However, when auditory cells are damaged by ototoxicity or noise and fail to function properly, the flow of information from the hair cells in the damaged area to the auditory nerve in that area is reduced. In turn, this impairs the role of the nerves responsible for inhibitory responses, leading abnormal neuroexcitatory responses with weakened inhibitory responses, changes in spontaneous firing rates, rapid firing, and synchronized responses.

b. Cerebral auditory cortex reorganization: Schematic of auditory cortex reorganization. Although it can be said to be caused by a situation where the balance between excitatory and inhibitory nerves is disturbed, the reorganization of the auditory cortex's tonotopic map can affect neural responses in the opposite direction, so the reorganization of the auditory cortex can be both a consequence and a cause of tinnitus.

c. Synaptic plasticity: As explained earlier, damage caused by ototoxicity, noise, etc. is not limited to auditory cells, but leads to damage to the auditory nerve. However, when a nerve is damaged, the body automatically initiates a nerve repair process that includes the creation of new axons, nerve endings, etc. Although the body tries to restore the original state, the process is not always perfect and new synapses are created, a phenomenon known as synaptic plasticity. Two things can happen during this process of nerve repair and new growth. First, excitatory nerve responses that are repaired in the absence of inhibitory nerves can send a cascade of signals to the brain. Next, nerve signals that are not related to hearing can be mixed with auditory signals, which can lead to tinnitus.

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3. Understanding Hearing



The hearing and all-or-nothing law

There is an important neurophysiological principle that is often discussed in electrophysiology is the all-or-nothing law. This law refers to the phenomenon where a single muscle fiber or nerve fiber will not respond to stimuli below a threshold, but will respond to stimuli above the threshold with a response that is constant in magnitude regardless of stimulus intensity. Over the past few decades, while conducting research on hearing and tinnitus, the authors have always had a question: "Why do modern otology claim that sensorineural hearing loss cannot be restored? Could it be because they are viewing the issue solely from the perspective of the 'all-or-nothing' practicality law, which applies to individual nerve fibers?" The following is a statement by a professor from the Department of Otolaryngology at a hospital, as quoted in a major daily newspaper.

"Exposure to loud sounds for prolonged periods increases the risk of damage, much like taking multiple jabs and eventually getting knocked out - it's a cumulative effect. In acute cases, medication may be used, but once the nerve is damaged, it cannot be reversed, and prevention is the best approach."

Most otologist and audiologists believe that once hearing is damaged, it can never be reversed. There is also a widespread social myth that hearing loss is an incurable disease. However, this is a myth that has not been scientifically validated because it is based on a one-to-one correspondence between a single auditory cell and a single auditory neuron. The analogy of the auditory nerve taking multiple jabs before

finally being knocked out implies that hearing is governed by all-or-nothing rule, reaching an irreversible stage at some point. This view overlooks the nature of hearing as 'more than the sum of its parts' and the neurological mechanisms of hearing formation. It is also a view of human hearing at the single-cell (single nerve fiber) level. The following two facts demonstrate that hearing loss due to auditory nerve damage does not follow the all-or-nothing rule.

First, in hearing, multiple auditory nerves work together in a bundle to process specific frequencies, rather than a single auditory nerve. For example, the auditory nerve processing a 1,000 Hz frequency is not a "single" nerve fiber, but rather a "bundle" of several dozen or even several hundred individual nerve fibers. Therefore, the loss of a single auditory cell or auditory nerve fiber does not mean the inability to hear that frequency. Second, hearing has a tendency to involve a synchronized response from nerves at harmonic frequency multiples. The origin of this characteristic lies in the brain's harmonic template. For instance, if the hearing threshold for a 1,000 Hz frequency is 50 dB, it is often observed that stimulating the 2,000 Hz auditory nerve (the second harmonic of 1,000 Hz) can also alter the threshold for 1,000 Hz.

The all-or-nothing law is a principle that applies only at the level of a single nerve fiber. The auditory neural response to sound, or "hearing," which involves the complex interaction of bundled nerve fibers and harmonic related neural responses, is essentially a simultaneous, parallel network response that encompasses peripheral hearing, central hearing, afferent hearing, efferent hearing and passive and active hearing. There is no 'all or nothing' approach in the way specific sounds are processed. Hearing does not follow the all-or-nothing law.

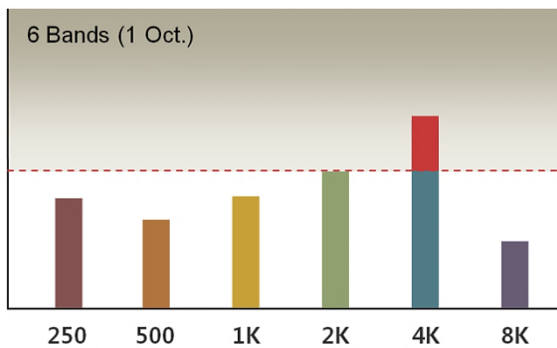
Hearing Tests

Audiometry is the act of finding the value of the dependent variable Y according to the independent variable X to define the hearing status at time Z. Z is the point in time at which the Y value is determined, X is the frequency, and Y is the threshold. The numerical range for X is 20 to 20,000 and the range for Y is -10 to 120. Since the frequency sequence of the cochlea follows an isoelectric sequence, a hearing test focuses on the main frequency band, approximately 250 to 12,000 Hz. (The relationship between 1,000 and 2,000 in audible frequencies is the same as the relationship between 10,000 and 20,000).

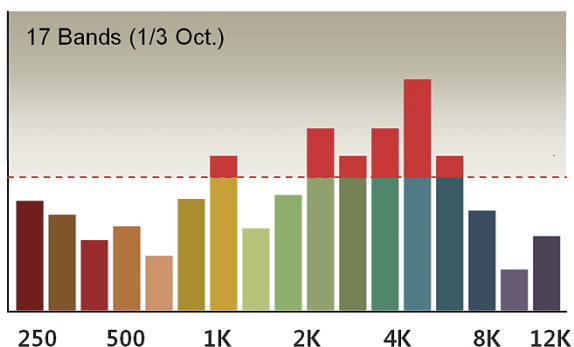
An individual's hearing is never uniform across the 20~20,000 Hz audible frequency band, so to perform an accurate audiogram, you need to measure the individual hearing thresholds at each frequency individually. Since audiometry is about defining the Y-value at each X coordinate, the resolution of the X coordinate determines the accuracy of the audiogram.



The figure below shows the results of an audiogram at 6-8 band frequency resolution. International standard pure tone audiometry, represented by ISO8253, typically has 6-8 X values and determines the Y value of hearing at each X coordinate.

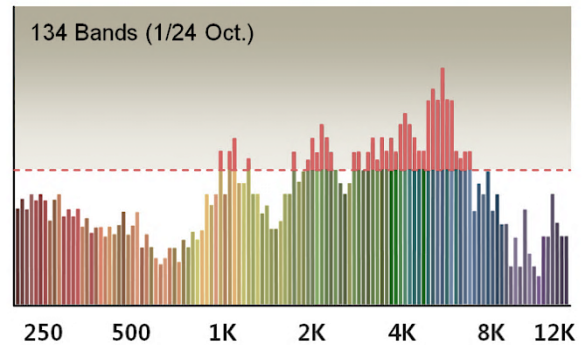


The figure below shows the results of an audiogram with 17 band frequency resolution. The 17 frequency bands are set on the x-axis to better define each individual hearing level. The 250 to 12,000 Hz frequency range is divided into 17 frequency bands by dividing it into 1/3 octave intervals. A third of an octave is the average frequency width of the critical band, the unit of the human auditory filter.



This figure shows the results of a 134-band frequency resolution audiogram. High resolution audiometry, such as 134 band, allows for repeated measurements within a single critical band, allowing for three-dimensional hearing results along the time axis. It is also possible to observe threshold fluctuations, a common phenomenon in the

reorganization process of hearing.



Critical Bands

To understand the microstructure of hearing, let's take a closer look at the concept of critical bands. The term critical band refers to the human auditory filter, and we briefly defined it in <Chapter 2, Understanding Tinnitus> when we described the classification of tinnitus.

The critical band is the unit of human auditory filtering and is a key concept in psychoacoustics that is applied to the placement of electrodes in cochlear implants and the design of filters in hearing aids. The frequency range of a critical band is approximately 1 millimeter across the cochlea, which corresponds to an interval of 1/3 to 1/6 of an octave (major second to major third) on the musical scale.

Let's take a closer look at the research that led to this simple definition of critical band.

<Origins of the Critical Band Concept>

The critical band is a psychoacoustic concept derived from several types of loudness perception experiments. Recent findings on critical bands recognize the important contributions of the concept in explaining how signals are processed between the auditory center and periphery, and in identifying the mechanisms of tinnitus. First introduced in 1940 by Fletcher, an American physicist and first generation psychoacoustician, the critical band concept provides information about the oscillatory behavior of the cochlear basilar membrane and primary nerve responses up to and including the cochlear nucleus. An example of the first generation of psychoacousticians who systematically cited the critical band concept is the work of Dutch physicist Plomp. In his book <Aspects of Tone Sensation (1976)>, Plomp discusses the similar concepts of dissonance and roughness. The frequency difference between two arbitrary pure tones f1 and f2 determines the degree of dissonance that occurs in their combination. In terms of what frequency difference between two pure tones f1 and f2 is most dissonant in different pitches, Plomp uses the concept of critical bands to explain the following.

"The point at which the dissonance of any two pure tones f_1 , f_2 is maximized has a systematic relationship with the results of critical band measurements obtained from loudness perception experiments. In most pitches, except for relatively low pitches, the f_1 , f_2 frequency interval at the point where the dissonance of any two f_1 , f_2 tones is maximized is approximately equal to 25% of the critical band frequency width."

When Plomp explains the concept of critical bands and the sensation of dissonance or roughness, he makes an analogy to the basement membrane vibration pattern. Most contemporary literature examining the relationship between the concept of the critical band and the basilar membrane's vibration region considers there to be a systematic correlation between the critical band and the pattern of basilar membrane vibration. Some of the most commonly used terms in this regard are "overlap" and "interference". The implications of these terms are clear. The stimuli used to measure the critical band were mostly two pure tone stimuli with close frequencies, and it is easy to predict that two points in close proximity on the basilar membrane will interfere with each other. According to some scholars, the degree of interference is directly related to the concept of critical bands. The "overlapping area" of the basilar membrane and the "degree of interference" between the highly organized auditory cells on top of the basilar membrane are still the only physiological clues to the concept of critical band. Plomp, who also derived the physiological clue to the dissonance sensation from the critical band concept, agrees that the degree of interference between auditory cells within the overlapping region of the basilar membrane may be the direct cause of the dissonance sensation.

Critical Band Measurement Experiment

Zwicker, a first generation German psychoacoustician, used three types of loudness perception experiments to measure the critical band frequency width in the human body with normal cognitive function.

a. Masking threshold measurement experiment: There are two pure tones f_1 , f_2 of 50 dB. The center frequency of these two pure tones was 570 Hz. While the subject pressed the button, the frequency interval of f_1 and f_2 decreased at a constant rate, and when the subject released the button, the frequency intervals increased. Now, these two pure tones were supposed to mask a narrowband noise with a 30 Hz bandwidth, with a center frequency of 570 Hz and a frequency component evenly spaced between 555 and 585 Hz. The results of the experiment showed that while the subject steadily widened the frequency spacing between f_1 and f_2 , the masking bandwidth of the narrowband noise remained constant at about 36 Hz until the frequency spacing reached about 130 Hz. In other words, when the two pure tones f_1 , f_2 of 50 dB intensity with a center frequency of 570 Hz were within 130 Hz of each other, the 36 dB of narrowband noise was completely masked by the two pure tones f_1 , f_2 and was inaudible. However, when the frequency separation was beyond 130 Hz, the 36 dB of narrowband noise became audible. Based on the center frequency of 570 Hz, the masking of the narrowband noise was constant until the frequency interval of 130 Hz, but the masking was

different after that.

"If the frequency interval between any two pure tones is within a certain value, there is no change in the sum of their loudness. However, if they are outside a certain value, the sum of the two pure tones changes. In the masking threshold measurement experiment using the combination of two pure tones f_1 and f_2 with a center frequency of 570 Hz, the figure of 130 Hz is the width of the critical band based on the frequency of 570Hz."

b. Loudness perception of variable band noise: This experiment was conducted to investigate the effect on loudness when the frequency bandwidth of a certain noise with a center frequency of 1,000 Hz is expanded symmetrically both above and below. Even without conducting the experiment, we can easily predict that the loudness of the noise will be perceived as increasing as the frequency bandwidth of the noise expands. The results of the experiment showed that there was no perceived increase in loudness up to a frequency bandwidth of 160 Hz relative to 1,000 Hz, but after that, a steady increase in loudness was perceived up to a certain level. In this experiment, 160 Hz represents the critical bandwidth for the center frequency of 1,000 Hz.

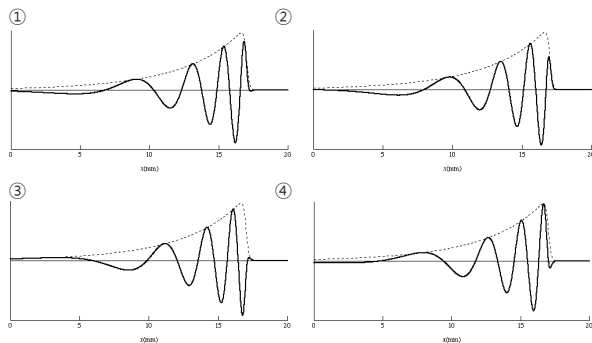
c. Loudness Sum Perception Experiment: When two pure tones were equally spaced apart in frequency with respect to the center frequency of the two tones, the loudness sum of the two pure tones was found to increase starting at a certain point. When the center frequency was 500 Hz, the increase in loudness sum started at approximately 100 Hz of the frequency separation. When the center frequency was 1000 Hz, the increase in loudness summation was perceived starting at the 160 Hz frequency interval, and when the center frequency was 2000 Hz, the increase in loudness summation was perceived starting at the 300 Hz frequency interval. Here, 100, 160, and 300 Hz are the respective threshold bands for center frequencies of 500, 1,000, and 2,000 Hz, respectively. Additionally, Zwicker measured the threshold bandwidth for one center frequency of 1000 Hz at various intensities, and found that the threshold bandwidth in this case was also constant at 160 Hz regardless of stimulus intensity.

Basilar membrane traveling waves and standing waves

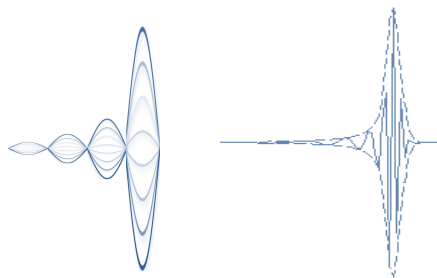
When an audible frequency sound signal vibrates the fluid in the cochlea, causing the basilar membrane to move, the auditory cells arranged on the basilar membrane convert their kinetic energy from the basilar membrane vibration into electrical energy in the corresponding frequency band. There are two distinct principles of basilar membrane motion involved in the energy conversion process in auditory cells: the basilar membrane traveling wave and basilar membrane standing wave.

Traveling waves are a principle of basilar membrane oscillations discovered by Nobel Prize winner in physiology, Bekesy, in 1961. They are

typically observed in the frequency range above 1,000 Hz, and are clearly observed in the passive hearing system. Figures 1 through 4 below show examples of basilar traveling waves in chronological order.



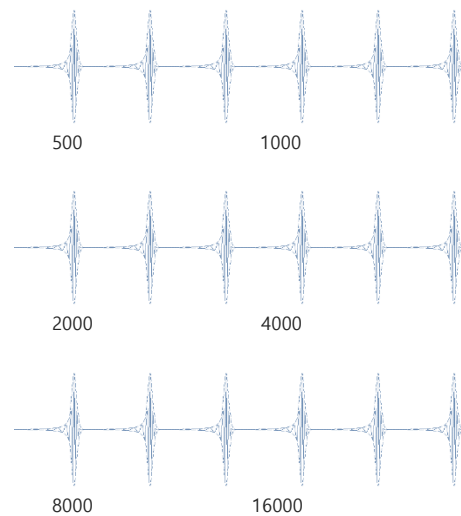
Although standing waves are most commonly observed in basilar membrane vibrations below 1,000 Hz, they are thought to occur over virtually the entire band of audible frequencies in the active hearing system. Standing waves always occur simultaneously with traveling waves and are considered the dominant basilar membrane vibration principle in living humans with normal cognitive function.



Displacement and Critical Bandwidth of Basilar Membrane Oscillations

Traveling waves in the basilar membrane of the cochlea are a basilar membrane oscillation principle observed primarily in non-human animal hearing, or passive auditory systems. In humans, there are some studies of basilar membrane traveling waves in sleep or models of basilar membrane traveling waves under anesthesia, but there are few studies of real-time observations of basilar membrane oscillations in the active auditory system, i.e., real-time hearing in humans with normal cognitive function. For the past 70 years, observational studies of basilar membrane oscillations in humans have been primarily behavioral response experiments based on psychoacoustic theory. The various findings derived from psychoacoustic experiments have a relatively high level of scientific confidence due to the sophistication of the experimental design.

In the active auditory system, the unit displacement of a traveling wave or series of standing wave oscillations of the basilar membrane evoked by moderate intensity ranges from about 0.9 mm to 1.2 mm in length. Given that the total length of the cochlea is approximately 28 mm, there are approximately 24 to 31 basilar membrane oscillation stationary displacements, assuming that the unit displacements of the basilar membrane oscillations are lined up in a row. In reality, the basilar membrane does not always have the following fixed displacements. The example below is only a rough schematic to understand the concept of critical band, which is equivalent to the unit displacement of basement membrane vibration.



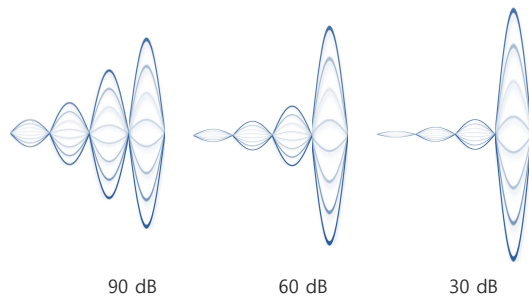
In the active auditory system, the unit displacement of a basilar membrane traveling wave or a series of standing wave oscillations roughly corresponds to the critical bandwidth. The critical bandwidth is approximately 1 mm in the cochlea. It is beyond the scope of this text to explain the biological reasons for the formation of a single, 1 mm wide critical band. Critical bands are a neurophysiological phenomenon that only occurs in the active auditory system of the human body during normal cognitive functioning; passive auditory system does not have a critical band, or if it does, it is different from that of the active auditory system.

In the passive auditory system, as the intensity of the sound increases, the range of a single oscillation of the basilar membrane traveling wave, or "unit displacement," becomes wider and wider. In an active auditory system, on the other hand, the unit displacement of the basilar membrane traveling wave oscillations does not widen as the sound intensity increases unless the intensity exceeds a certain level. What is unique about active auditory systems is that within a certain range of sound intensities, as the intensity of the sound decreases, the basilar membrane traveling wave characteristics become more prominent than the standing wave oscillation characteristics. In addition, the phase of the standing wave amplitude of the basilar membrane singularity that

processes that frequency tends to be inversely proportional to the stimulus intensity of the acoustic signal.

The term active hearing system refers to the real-time hearing (or hearing acuity) of a hearing person with normal auditory cognitive function, which is the hearing response system of a hearing person to an auditory signal at an appropriate volume.

<Basilar membrane standing waves in the active auditory system>



Fluctuations in Hearing Thresholds

When conducting a micro-audiometry based on a 67-band RCPTA, transient threshold fluctuation phenomena are frequently observed. In the active auditory system, when subtle hearing loss is progressing or additional hearing damage is suspected in a particular frequency range, a sudden threshold fluctuation phenomenon may occur. Before examining various types of threshold fluctuation cases reflected in the 67-band micro-audiogram, let's first look at the example of the fluctuating phenomenon of the "harmonic template," the fundamental auditory neural network that controls the tonotopic organization of the brain. According to Sam Kwak's harmonic template theory, the harmonic template is a system that controls the phase-locking function, which is the core principle of the brain that simplifies the complex patterns of auditory evoked potential signals. It refers to the fundamental auditory neural network of the tonotopic organization. In the active auditory system, the harmonic template is responsible for frequency operations when processing simultaneous audible frequency information and simplifies the complex spectrum of sounds into a single fundamental frequency component for decoding. Recent animal experiments on the harmonic template show evidence of its existence even in the passive auditory system. However, compared to humans, the harmonic templates in animals are quite rudimentary in terms of their functionality.

Fluctuations in the Harmonic Template

In a traditional pure tone audiogram based on ISO8253, the frequency values of all test tones sequentially stimulate a single harmonic template in the central auditory nervous system during the hearing test. The hearing test standards derived from ISO 8253, almost without exception,

set the basic frequencies for hearing tests at 250, 500, 1,000, 2,000, 4,000, and 8,000 Hz. When these frequencies reach the brain, they are all processed by the same single harmonic template. In other words, an international standard pure tone audiometry can be considered an auditory performance test for a single harmonic template in the brain that extracts the fundamental frequency components, such as 500 Hz or 1,000 Hz (in the harmonic template, 250 Hz is classified as a submultiple (1/2) frequency of 500 Hz).

In hearing tests, the frequency composition of the test tones is randomized to avoid continuously stimulating a single harmonic template, which is the basis of the randomized controlled pure tone audiometry (RCPTA) for micro-audiometry. In this method, the 67 test tone frequencies randomly stimulate harmonic templates from different series at random points and in random order. If an "artificial" threshold fluctuation pattern appears in the random arrangement of hearing thresholds obtained through RCPTA-based testing, it can be considered as evidence of the harmonic template fluctuation phenomenon in the auditory nervous system. The "artificial pattern" of the fluctuation phenomenon must appear as an accidental pattern at random points within the random sample. In traditional manually operated pure tone audiometry, where the audiologist consciously supervises the procedure and the hearing results are artificially determined based on the audiologist's judgment, there can be no "artificial" threshold fluctuation phenomenon. The "artificial" fluctuation phenomenon in hearing thresholds is an accidental and sudden auditory response pattern that can only be observed in the RCPTA test environment, where the frequency presentation is randomized by a computer algorithm without bias. If such a pattern appeared in a manipulated sample, it would be difficult to provide a systematic interpretation. However, if an artificial pattern is found within a random sample, it carries scientifically significant implications.

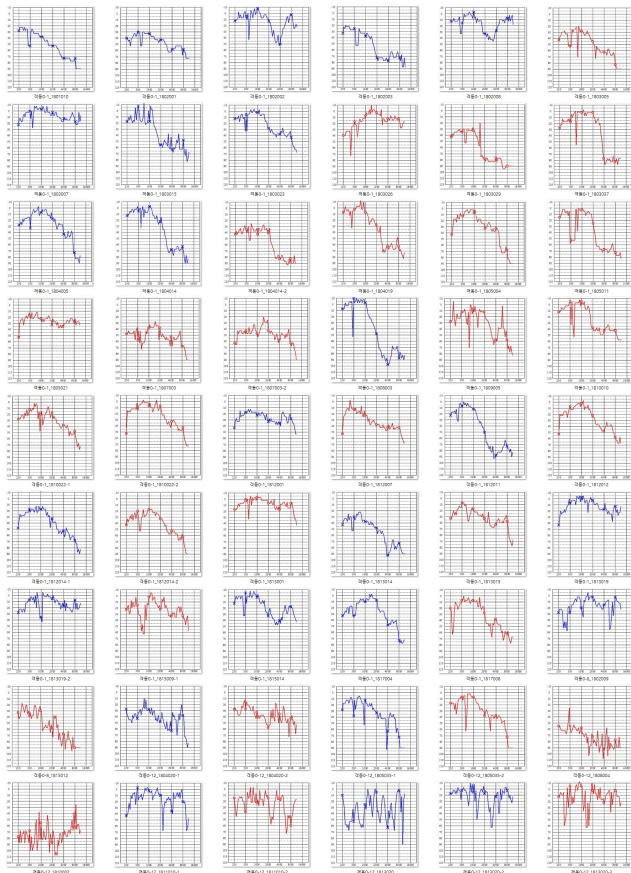
The reason why threshold fluctuation phenomena in hearing manifest as artificially structured patterns within the time series of randomly obtained hearing thresholds is due to the activation of burst firing or neural synchronization in approximately 15,000 auditory cells or the central auditory neural networks connected to them. This phenomenon can also occur when reorganization is taking place within the auditory neural networks of the brain. Since sudden threshold fluctuation in hearing contains valuable information about the patient's past, present, and future auditory state, it requires careful observation and attention.

Threshold fluctuations occurring in frequency bands below 1,000 Hz are interpreted as resulting from abnormalities in the harmonic template of the central auditory nervous system rather than damage to peripheral auditory cells. When the cerebral harmonic template is unstable or has issues with frequency processing, threshold fluctuations can appear unpredictably in frequency ranges below 1,000 Hz. In contrast, threshold fluctuations in frequency bands above 1,000 Hz may be directly caused by damage to specific peripheral auditory cells within the particular frequency range of each harmonic template. Once again, it is important to note that threshold fluctuations below 1,000 Hz may not necessarily originate from damage to the auditory cells corresponding to those

frequencies.

In the MTM clinical trial, conducted as a multicenter study over two months in October and November 2018 at 17 medical centers in Korea, 36 out of 42 cases observed in 585 micro-audiometry from 195 participants showed clear evidence of harmonic template fluctuations in the central auditory system. During the three micro-audiometry conducted over the span of one month, 30 subjects experienced harmonic template fluctuations once on either side, while 6 individuals experienced the phenomenon more than once. All 36 subjects displayed distinct threshold fluctuation patterns in the frequency range below 1,000 Hz. When considering the left and right hearing results of the 36 individuals independently, the total number of harmonic template fluctuation cases was calculated to be over 50.

<Harmonic Template Fluctuation: Cases of Fluctuation Below 1,000 Hz>



To understand why 1,000 Hz is used as the reference point, let's explore the concept of the absolute refractory period, one of the key principles in electrophysiology that is comparable the all-or-nothing law, as well as the periodicity theory, one of the three main theories of frequency information processing. The absolute refractory period refers to a brief time span of approximately 0.001 seconds during which a new action potential cannot be generated, regardless of the stimulus intensity. According to this principle, the periodicity theory of frequency processing

cannot be applied to frequency ranges above 1,000 Hz. In these higher frequency ranges, frequency information processing occurs solely based on the place cues of the basilar membrane, and only the place theory can be applied. The volley theory, another frequency information processing theory, deals with the processing of complex sounds rather than pure tones, and since this textbook focuses only on the hearing of pure tones, we will not discuss it. The periodicity theory, which is a frequency processing theory under the place theory, applies only to frequencies below 1,000 Hz and aligns with the understanding of the absolute refractory period. The periodicity theory states that for a 300 Hz frequency, 300 neural firings occur, and for a 400 Hz frequency, 400 neural firings happen. The lower the frequency, the greater the explanatory power of periodicity theory.

It would not be correct to infer that a 1,001 Hz frequency is processed by the basilar membrane's place cues, while a 999 Hz frequency signal is processed by periodicity (or phase) cues, just because the absolute refractory period of the cells involved in auditory information processing is 0.001 seconds. It is generally understood that the frequency range between approximately 500 Hz and 1,000 Hz involves both periodic and place cues in processing frequency information. Additionally, even for frequencies below 500 Hz, there may still be partial involvement of place cues. Nevertheless, it is reasonable to explain that the occurrence of hearing threshold fluctuations below and above 1,000 Hz originates from different mechanisms within the context of the absolute refractory period law and the periodicity theory.

4. Threshold Fluctuation Phenomenon

Randomized Hearing Threshold Time Series

In conventional international standard pure tone audiometry (PTA) determines the hearing threshold results for each frequency based on the audiologist's deliberate judgment. Therefore, the threshold fluctuation phenomenon, which only appears in a randomized hearing threshold time series, cannot be observed using traditional manual audiometry techniques. A randomized hearing threshold time series refers to a sequence of hearing thresholds rearranged chronologically, determined at random intervals by the random presentation of frequencies. It is nearly impossible for a human to consciously determine 134 left and right hearing thresholds at 134 different random intervals, with 67 frequencies presented in random order for each ear. Even if possible, this process would require changing the frequency and intensity values randomly with each stimulus and relying on handwritten records, pushing the limits of human memory capacity. Such a hearing test would take at least 6-7

hours. Even if the audiologist's determination makes it possible to conduct this test, there would be almost no participants available for tests lasting more than 6-7 hours. If 268 hearing thresholds must be determined at 268 random intervals from a sequence of 134 frequencies in random order, this would take at least 12-14 hours. With traditional manual audiometry, which requires the audiologist's direct involvement, it is difficult to observe accidental and sudden threshold fluctuation phenomena.

<Mr. J's Left and Right Thresholds Measured by RCPTA 134 Text Results>

VER : 10 ID : 1802007 Name : Age : 75 Gender : m Date : 10:11 15/10/2018 ElapsedTime : 1012					
Left Ear			Right Ear		
262	17.5	1010	262	22.5	376
277	22.5	851	277	22.5	407
294	17.5	605	294	22.5	438
311	17.5	815	311	22.5	576
330	17.5	754	330	27.5	719
349	22.5	696	349	27.5	257
370	17.5	534	370	22.5	544
392	12.5	902	392	32.5	855
415	22.5	812	415	22.5	557
440	12.5	195	440	12.5	699
466	12.5	629	466	17.5	724
494	12.5	747	494	22.5	789
523	2.5	923	523	22.5	741
554	12.5	252	554	17.5	850
587	12.5	750	587	17.5	624
622	17.5	486	622	22.5	449
659	22.5	430	659	27.5	319
698	17.5	458	698	27.5	835
740	27.5	580	740	27.5	661
784	27.5	939	784	32.5	765
831	27.5	667	831	37.5	934
880	27.5	597	880	27.5	303
932	30	834	932	40	509
988	35	589	988	40	405
1047	37.5	925	1047	32.5	875
1109	37.5	775	1109	40	927
1175	42.5	329	1175	40	1012
1245	42.5	466	1245	47.5	1003
1319	42.5	742	1319	52.5	993
1397	42.5	837	1397	50	866
1480	37.5	375	1480	50	483
1568	37.5	584	1568	40	344
1661	22.5	793	1661	37.5	352
1760	22.5	844	1760	37.5	571
1865	22.5	434	1865	37.5	745
1976	20	553	1976	37.5	249
2093	27.5	409	2093	32.5	515
2217	35	877	2217	37.5	342
2349	30	262	2349	42.5	337
2489	35	427	2489	47.5	481
2637	40	894	2637	60	816
2794	50	968	2794	70	598
2960	52.5	858	2960	72.5	848
3136	57.5	960	3136	82.5	856
3322	72.5	727	3322	72.5	439
3520	72.5	561	3520	92.5	978
3729	67.5	575	3729	92.5	987
3951	92.5	980	3951	82.5	555
4186	87.5	942	4186	72.5	651
4435	87.5	997	4435	87.5	1001
4699	82.5	787	4699	72.5	681
4978	77.5	969	4978	72.5	600
5274	77.5	886	5274	82.5	878
5588	82.5	735	5588	87.5	979
5920	72.5	399	5920	92.5	965
6272	87.5	963	6272	92.5	1006
6645	95	952	6645	92.5	1004
7040	72.5	272	7040	67.5	548
7459	92.5	957	7459	92.5	721
7902	87.5	703	7902	67.5	780
8372	67.5	393	8372	87.5	996
8870	67.5	550	8870	67.5	757
9397	67.5	607	9397	90	825
9956	77.5	737	9956	72.5	558
10548	90	914	10548	90	973
11175	90	989	11175	67.5	339
11840	82.5	974	11840	90	985

<Example of Importing Mr. J's Text Results>

	Left Ear			Right Ear	
262	17.5	1010	262	22.5	376
277	22.5	851	277	22.5	407
294	17.5	605	294	22.5	438
311	17.5	815	311	22.5	576
330	17.5	754	330	27.5	719
349	22.5	696	349	27.5	257
370	17.5	534	370	22.5	544
392	12.5	902	392	32.5	855
415	22.5	812	415	22.5	557
440	12.5	195	440	12.5	699
466	12.5	629	466	17.5	724
494	12.5	747	494	22.5	789
523	2.5	923	523	22.5	741
554	12.5	252	554	17.5	850
587	12.5	750	587	17.5	624
622	17.5	486	622	22.5	449
659	22.5	430	659	27.5	319
698	17.5	458	698	27.5	835
740	27.5	580	740	27.5	661
784	27.5	939	784	32.5	765
831	27.5	667	831	37.5	934
880	27.5	597	880	27.5	303
932	30	834	932	40	509
988	35	589	988	40	405
1047	37.5	925	1047	32.5	875
1109	37.5	775	1109	40	927
1175	42.5	329	1175	40	1012
1245	42.5	466	1245	47.5	1003
1319	42.5	742	1319	52.5	993
1397	42.5	837	1397	50	866
1480	37.5	375	1480	50	483
1568	37.5	584	1568	40	344
1661	22.5	793	1661	37.5	352
1760	22.5	844	1760	37.5	571
1865	22.5	434	1865	37.5	745
1976	20	553	1976	37.5	249
2093	27.5	409	2093	32.5	515
2217	35	877	2217	37.5	342
2349	30	262	2349	42.5	337
2489	35	427	2489	47.5	481
2637	40	894	2637	60	816
2794	50	968	2794	70	598
2960	52.5	858	2960	72.5	848
3136	57.5	960	3136	82.5	856
3322	72.5	727	3322	72.5	439
3520	72.5	561	3520	92.5	978
3729	67.5	575	3729	92.5	987
3951	92.5	980	3951	82.5	555
4186	87.5	942	4186	72.5	651
4435	87.5	997	4435	87.5	1001
4699	82.5	787	4699	72.5	681
4978	77.5	969	4978	72.5	600
5274	77.5	886	5274	82.5	878
5588	82.5	735	5588	87.5	979
5920	72.5	399	5920	92.5	965
6272	87.5	963	6272	92.5	1006
6645	95	952	6645	92.5	1004
7040	72.5	272	7040	67.5	548
7459	92.5	957	7459	92.5	721
7902	87.5	703	7902	67.5	780
8372	67.5	393	8372	87.5	996
8870	67.5	550	8870	67.5	757
9397	67.5	607	9397	90	825
9956	77.5	737	9956	72.5	558
10548	90	914	10548	90	973
11175	90	989	11175	67.5	339
11840	82.5	974	11840	90	985

**<Rearrange Mr. J's Left-Right Thresholds by
Frequency in Order of Threshold Determination Time>**

195	440	12.5	576	311	22.5	848	2960	72.5
249	1976	37.5	580	740	27.5	850	554	17.5
252	554	12.5	584	1568	37.5	851	277	22.5
257	349	27.5	589	988	35	855	392	32.5
262	2349	30	597	880	27.5	856	3136	82.5
272	7040	72.5	598	2794	70	858	2960	52.5
303	880	27.5	600	4978	72.5	866	1397	50
319	659	27.5	605	294	17.5	875	1047	32.5
329	1175	42.5	607	9397	67.5	877	2217	35
337	2349	42.5	624	587	17.5	878	5274	82.5
339	11175	67.5	629	466	12.5	886	5274	77.5
342	2217	37.5	651	4186	72.5	894	2637	40
344	1568	40	661	740	27.5	902	392	12.5
352	1661	37.5	667	831	27.5	914	10548	90
375	1480	37.5	681	4699	72.5	923	523	2.5
376	262	22.5	696	349	22.5	925	1047	37.5
393	8372	67.5	699	440	12.5	927	1109	40
399	5920	72.5	703	7902	87.5	934	831	37.5
405	988	40	719	330	27.5	939	784	27.5
407	277	22.5	721	7459	92.5	942	4186	87.5
409	2093	27.5	724	466	17.5	952	6645	95
427	2489	35	727	3322	72.5	957	7459	92.5
430	659	22.5	735	5588	82.5	960	3136	57.5
434	1865	22.5	737	9956	77.5	963	6272	87.5
438	294	22.5	741	523	22.5	965	5920	92.5
439	3322	72.5	742	1319	42.5	968	2794	50
449	622	22.5	745	1865	37.5	969	4978	77.5
458	698	17.5	747	494	12.5	973	10548	90
466	1245	42.5	750	587	12.5	974	11840	82.5
481	2489	47.5	754	330	17.5	978	3520	92.5
483	1480	50	757	8870	67.5	979	5588	87.5
486	622	17.5	765	784	32.5	980	3951	92.5
509	932	40	775	1109	37.5	985	11840	90
515	2093	32.5	780	7902	67.5	987	3729	92.5
534	370	17.5	787	4699	82.5	989	11175	90
544	370	22.5	789	494	22.5	993	1319	52.5
548	7040	67.5	793	1661	22.5	996	8372	87.5
550	8870	67.5	812	415	22.5	997	4435	87.5
553	1976	20	815	311	17.5	1001	4435	87.5
555	3951	82.5	816	2637	60	1003	1245	47.5
557	415	22.5	825	9397	90	1004	6645	92.5
558	9956	72.5	834	932	30	1006	6272	92.5
561	3520	72.5	835	698	27.5	1010	262	17.5
571	1760	37.5	837	1397	42.5	1012	1175	40
575	3729	67.5	844	1760	22.5			

The result above is an example of a "randomized hearing threshold time series" where a total of 134 hearing thresholds at 67 frequency points on the left and right of Mr. J are rearranged according to the time value at which the thresholds were determined. The last time value is 1012. This means that the hearing threshold for the last test sound was determined at 1,012 seconds, or 16 minutes and 52 seconds, after the RCPTA 67-band test began. The frequency value of the threshold determined at this time was 1,175 Hz on the right, and the hearing threshold result at 1,175 Hz was 40 dBHL.

Understanding Threshold Fluctuations Through the Interpretation of the RCPTA Sequence

The 67-band RCPTA-based hearing threshold results are basically arranged as follows, with frequency cues as the independent variable.

1047	37.5	1047	32.5
1109	37.5	1109	40.0
1175	42.5	1175	40.0
1245	42.5	1245	47.5
1319	42.5	1319	52.5
1397	42.5	1397	50.0
1480	37.5	1480	50.0
1568	37.5	1568	40.0
1661	22.5	1661	37.5
1760	22.5	1760	37.5
1865	22.5	1865	37.5
1976	20.0	1976	37.5
2093	27.5	2093	32.5
2217	35.0	2217	37.5
2349	30.0	2349	42.5

However, when looking at the hearing threshold results based solely on

frequency cues, it is impossible to tell whether these threshold results were derived from random or intentional time points. Therefore, in RCPTA, the time (in seconds) at which each hearing threshold is confirmed is also output, as shown below.

주파수	좌측 역치	시간	주파수	우측 역치	시간
1047	37.5	925	1047	32.5	875
1109	37.5	775	1109	40.0	927
1175	42.5	329	1175	40.0	1012
1245	42.5	466	1245	47.5	1003
1319	42.5	742	1319	52.5	993
1397	42.5	837	1397	50.0	866
1480	37.5	375	1480	50.0	483
1568	37.5	584	1568	40.0	344
1661	22.5	793	1661	37.5	352
1760	22.5	844	1760	37.5	571
1865	22.5	434	1865	37.5	745
1976	20.0	553	1976	37.5	249
2093	27.5	409	2093	32.5	515
2217	35.0	877	2217	37.5	342
2349	30.0	262	2349	42.5	337

In the example above, the time (in seconds) at which each hearing threshold was determined is randomly arranged. As a result, it can be seen that the left and right hearing thresholds for each frequency were determined at random time points. If the time values of the 134 hearing thresholds across the entire frequency range from 250 Hz to 12,000 Hz are rearranged with these time values as independent variables, it will form a random hearing threshold time series as shown below, as we discussed earlier.

195	440	12.5	576	311	22.5	848	2960	72.5
249	1976	37.5	580	740	27.5	850	554	17.5
252	554	12.5	584	1568	37.5	851	277	22.5
257	349	27.5	589	988	35	855	392	32.5
262	2349	30	597	880	27.5	856	3136	82.5
272	7040	72.5	598	2794	70	858	2960	52.5
303	880	27.5	600	4978	72.5	866	1397	50
319	659	27.5	605	294	17.5	875	1047	32.5
329	1175	42.5	607	9397	67.5	877	2217	35
337	2349	42.5	624	587	17.5	878	5274	82.5
339	11175	67.5	629	466	12.5	886	5274	77.5
342	2217	37.5	651	4186	72.5	894	2637	40
344	1568	40	661	740	27.5	902	392	12.5
352	1661	37.5	667	831	27.5	914	10548	90
375	1480	37.5	681	4699	72.5	923	523	2.5
376	262	22.5	696	349	22.5	925	1047	37.5
393	8372	67.5	699	440	12.5	927	1109	40
399	5920	72.5	703	7902	87.5	934	831	37.5
405	988	40	719	330	27.5	939	784	27.5
407	277	22.5	721	7459	92.5	942	4186	87.5
409	2093	27.5	724	466	17.5	952	6645	95
427	2489	35	727	3322	72.5	957	7459	92.5
430	659	22.5	735	5588	82.5	960	3136	57.5
434	1865	22.5	737	9956	77.5	963	6272	87.5
438	294	22.5	741	523	22.5	965	5920	92.5
439	3322	72.5	742	1319	42.5	968	2794	50
449	622	22.5	745	1865	37.5	969	4978	77.5
458	698	17.5	747	494	12.5	973	10548	90
466	1245	42.5	750	587	12.5	974	11840	82.5
481	2489	47.5	754	330	17.5	978	3520	92.5
483	1480	50	757	8870	67.5	979	5588	87.5
486	622	17.5	765	784	32.5	980	3951	92.5
509	932	40	775	1109	37.5	985	11840	90
515	2093	32.5	780	7902	67.5	987	3729	92.5
534	370	17.5	787	4699	82.5	989	11175	90
544	370	22.5	789	494	22.5	993	1319	52.5
548	7040	67.5	793	1661	22.5	996	8372	87.5
550	8870	67.5	812	415	22.5	997	4435	87.5
553	1976	20	815	311	17.5	1001	4435	87.5
555	3951	82.5	816	2637	60	1003	1245	47.5
557	415	22.5	825	9397	90	1004	6645	92.5
558	9956	72.5	834	932	30	1006	6272	92.5
561	3520	72.5	835	698	27.5	1010	262	17.5
571	1760	37.5	837	1397	42.5	1012	1175	40
575	3729	67.5	844	1760	22.5			

In this random hearing threshold time series, the frequency arrangement of the hearing thresholds determined at each time (in seconds) is random. This means that the frequencies presented at each time point had no deliberate relationship with one another. In this state, let's attempt a deliberate observation of the thresholds of neighboring auditory cells. In

the right ear, for frequencies above 10,000 Hz, it is expected that the hearing thresholds of two closely spaced frequencies within the same critical band would be similar. However, when looking at the actual hearing threshold results derived from different random time points, this is not the case. Due to threshold fluctuations, different thresholds are observed for the right ear at 11,175 Hz and 11,840 Hz. The hearing threshold at 11,175 Hz, measured at 339 seconds (5 minutes and 39 seconds) after the start of the test, was 67.5 dBHL, whereas the hearing threshold at 11,840 Hz, measured at 985 seconds (16 minutes and 25 seconds), was 90 dBHL. In fact, the auditory cells that detect 11,175 Hz and 11,840 Hz are very close to each other in the cochlea and are in the same critical band. Nevertheless, the 22.5 dB difference in their thresholds was not due to the actual difference in the level of damage between the cells detecting 11,175 Hz and those detecting 11,840 Hz. The 22.5 dB difference in hearing thresholds arose because, at either the 5:39 or 16:25 time point, there was a collective burst firing or neural synchronization response in the group of auditory cells or the auditory nerve group responsible for the 11,175~11,840 Hz frequency range.

Threshold fluctuation phenomena can only be observed in the high-resolution RCPTA testing environment, where the frequencies of the test tones are presented randomly to both ears. The primary causes of threshold fluctuation, namely burst firing in the auditory nervous system and neural synchronization, are inherently random, making threshold fluctuations an accidental auditory phenomenon that can occur at any time. In the context of the periodicity theory and the absolute refractory period principle briefly discussed earlier, let us now examine the threshold fluctuation phenomena that occur in frequency bands below and above 1,000 Hz, using actual hearing test results for a more detailed analysis.

Cases of Harmonic Template Fluctuation

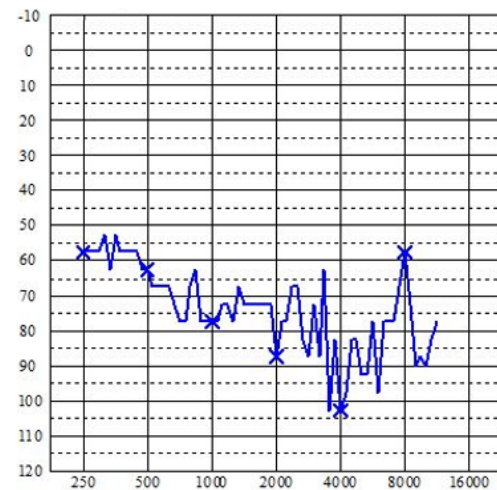
The threshold fluctuation phenomenon in hearing requires different interpretations depending on whether it occurs in the low-frequency range below 1,000 Hz or in the high-frequency range above 1,000 Hz. Comparing the cases of subjects 1808003 and 1817001, we find that subject 1808003 exhibited threshold fluctuation around 500 Hz, while subject 1817001 had it around 4,000 Hz. The threshold fluctuation at 500 Hz in subject 1808003 was not due to damage in the auditory cells surrounding 500 Hz. This suggests that the issue is not with the cells themselves but with the central harmonic template connected to these cells, indicating that damage to the central harmonic template is ongoing. The reason for using the word "indicating" is that this phenomenon eventually disappears. In the micro-audiogram of subject 1808003, the 8th harmonic of 500 Hz, 4,000 Hz, was already significantly damaged. Therefore, the threshold fluctuation at 500 Hz can be interpreted as being caused by the damage in the auditory cells of the 5th, 6th, and 7th harmonics, specifically 2,500, 3,000, and 3,500 Hz. However, no threshold fluctuation was observed around the 2,500 Hz, 3,000 Hz, or 3,500 Hz frequencies where the damage was thought to be occurring. Despite this, the presence of threshold fluctuation around 500 Hz, which is the

greatest common divisor frequency of 2,500 Hz, 3,000 Hz, and 3,500 Hz, suggests that there was potential fluctuation in the specific complex sound-processing area, the "500 Hz series central harmonic template," which contains components of 2,500 Hz, 3,000 Hz, and 3,500 Hz. The fluctuation in the 500 Hz series central harmonic template could be caused by burst firing of auditory cells or auditory nerves in the 2,500 Hz, 3,000 Hz, and 3,500 Hz frequency bands. However, the direct cause may lie in neural synchronization within the basal auditory neural network.

<The threshold fluctuation around 500 Hz in subject 1808003>



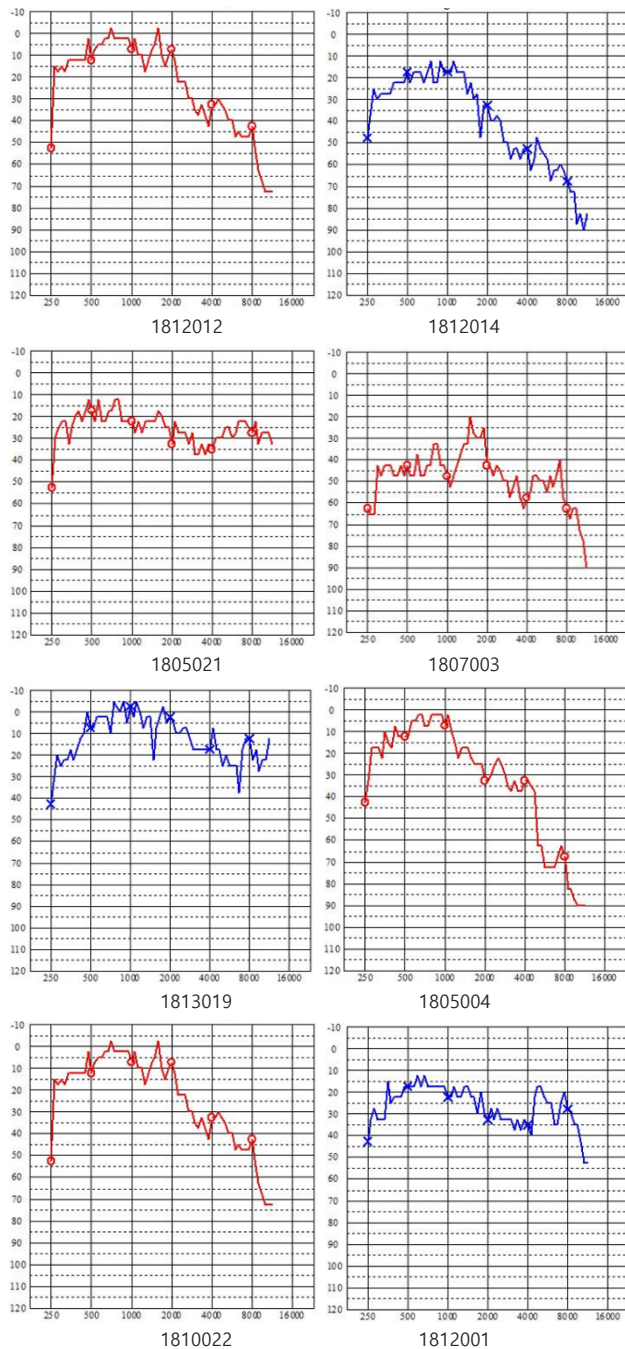
<The threshold fluctuation around 4,000 Hz in subject 1817001>



The threshold fluctuation around 4,000 Hz in subject 1817001 is directly caused by burst firing or neural synchronization responses in the auditory cells or auditory nerve group within that frequency range. Out of the 585 cases from the 195 participants in the MTM clinical trial, harmonic template fluctuations in the auditory cortex were observed in 36 subjects across 42 cases. This means that approximately 18% of the participants exhibited harmonic template fluctuations. Additionally, in about 35% of the 195 participants, at least one or two threshold fluctuation phenomena

were observed in the frequency range above 1,000 Hz.

<Cases of Harmonic Template Fluctuation in the 250 Hz Band>



The 8 graphs represent cases of harmonic template fluctuation observed in the 250 Hz band, selected from the micro-audiogram graphs of 195 participants in the MTM clinical trial. Threshold fluctuations can occur at various frequencies and are primarily caused by burst firing and neural synchronization responses in the auditory cells, auditory nerves, or auditory neurons. However, the threshold fluctuation in the 250 Hz band shown in the eight graphs cannot be directly attributed to the damage of auditory cells in that frequency range. In other words, the threshold

fluctuation in the lower frequency range, such as 250 Hz, occurs not because the peripheral auditory cells that process 250 Hz are malfunctioning, but because the auditory neurons at the central processing level undergo burst firing or neural synchronization for some reason. More specifically, in the low-frequency range from 500 to 1,000 Hz, the operation of the harmonic template in the auditory cortex, which tracks the phase relationship of these frequencies, plays a crucial role. In this case, the fluctuation in threshold at 250 Hz is thought to have resulted from a temporary computational error in the harmonic template network in the auditory cortex. In the frequency range below 1,000 Hz, threshold fluctuations rely more on the rate of firing of the auditory cells, or the temporal cues, rather than the position cues provided by the basilar membrane. Therefore, a temporary error in decoding the temporal cue of the 250 Hz harmonic template is the primary cause of the threshold fluctuation in the 250 Hz range. This error in the central harmonic template network is transient, reappearing intermittently, and its occurrence follows a random time pattern.

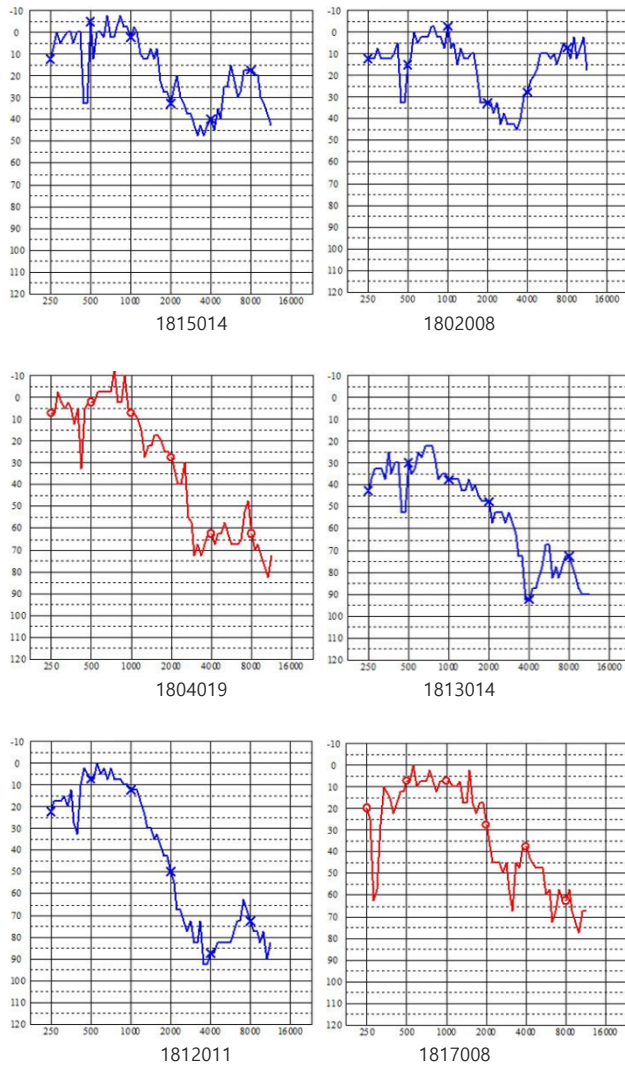
In frequency bands higher than 250 Hz but not exceeding 500 Hz, threshold fluctuations due to harmonic template computational errors were observed in several frequencies. Unlike the threshold fluctuations at 250 Hz, a notable fact is that for almost all the frequencies where threshold fluctuations occurred, a frequency-specific hearing loss was found in the frequency band corresponding to 10 times the frequency of the observed fluctuation. For example, if threshold fluctuations were observed around 350 Hz, a similar fluctuation or clear hearing loss was also seen around the 3,500 Hz band, which is 10 times the frequency. As seen in the six graphs on the right, in the cases of participants 1815014, 1802008, 1804019, and 1813014, threshold fluctuations due to harmonic template computational errors occurred in the vicinity of 400 Hz, and simultaneously, at their 10 times frequency, around 4,000 Hz, threshold fluctuations or notable hearing loss were observed. Similarly, for participants 1812011 and 1817008, where threshold fluctuations were observed in the 300-350 Hz range, fluctuations were also observed in the 3,000~3,500 Hz.

Threshold fluctuations in the low-frequency range below 1,000 Hz, where frequency processing relies on the firing rate of auditory cells or auditory nerve action potentials (also known as periodicity cues) are primarily caused by computational errors in the harmonic template of the central auditory nervous system responsible for those frequency bands.

Computational errors in the central harmonic template occur when the frequency specificity and resolution of the tonotopic frequency map are disrupted, causing a delay of several milliseconds in the brain's frequency decoding process. These errors can also arise when the affected frequency range has undergone irreversible reorganization or is currently in the process of being reorganized. Threshold fluctuations in the low-frequency range typically occur when underlying issues are present in the auditory cells or auditory nerve groups at higher multiple frequency ranges,

making such fluctuations a potentially recurring phenomenon.

<Cases of Harmonic Template Fluctuation in the 250–500 Hz>

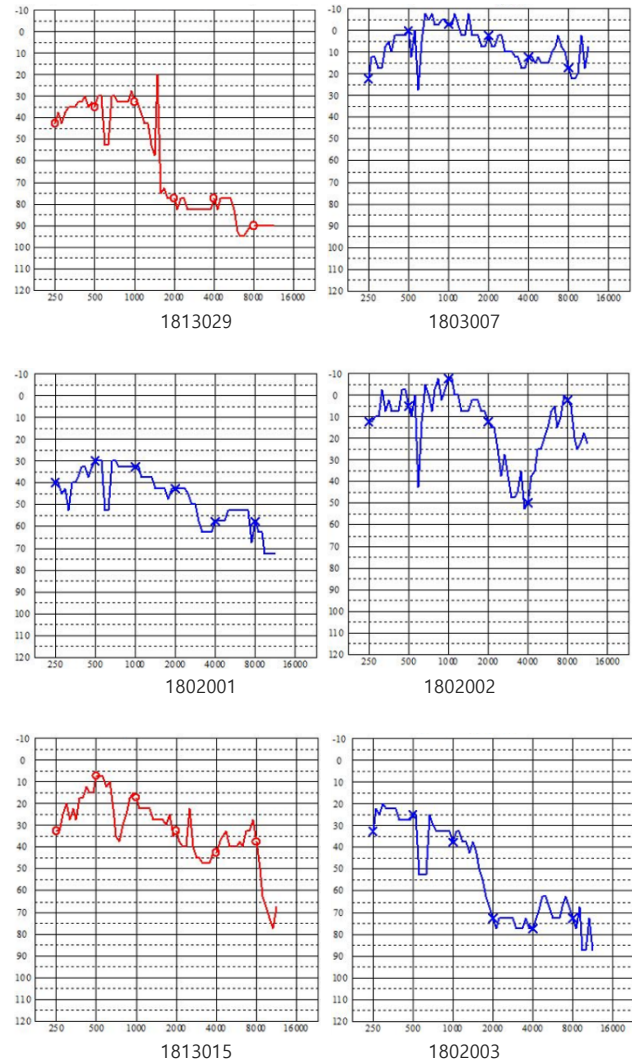


Threshold fluctuations in the low-frequency range below 1,000 Hz and those in the high-frequency range above 1,000 Hz have different direct causes. In the 500~1,000 Hz range, where both periodic and place cues coexist in frequency processing, we examine the types of threshold fluctuation cases that have been observed.

The 500~1,000 Hz frequency range is where conscious perception and cognitive activity in human hearing are most active. In the sensory reception stage of auditory frequency processing, auditory hair cells and neural groups located within the 250~12,000 Hz range are constantly engaged regardless of frequency. However, at the stages of perception and cognition, the brain's decoding mechanism, which simplifies complex acoustic patterns, becomes remarkably more intricate within the 500~1,000 Hz range. This is because both periodic and place cues are simultaneously utilized for frequency processing and determination within this range. In pure tone perception and cognition during hearing tests,

the brain's frequency determination mechanism based on periodic cues completely disappears above 1,000 Hz. Since periodic cues still play a role in the 500~1,000 Hz range, threshold fluctuations observed within this frequency band present an intriguing phenomenon. This is due to the dual origins of threshold fluctuations in this range harmonic template computational errors and auditory hair cell damage. Concrete evidence supports this assertion.

<Cases of Harmonic Template Fluctuation in the 500-1,000 Hz>

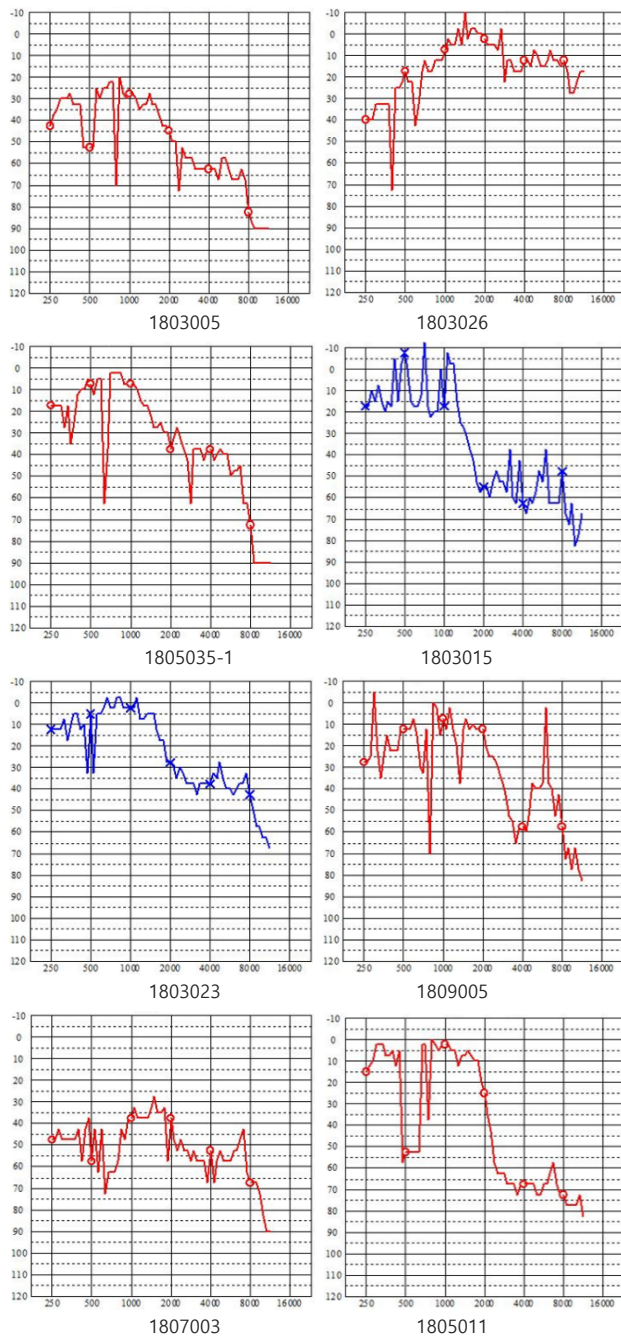


If we categorize the six participants who exhibited harmonic template fluctuations in the 250–500 Hz frequency range (1815014, 1802008, 1804019, 1813014, 1812011, 1817008) as Harmonic template Fluctuation Group A, and the six participants who exhibited harmonic template fluctuations in the 500~1,000 Hz frequency range (1813029, 1803007, 1802001, 1802002, 1813015, 1802003) as Harmonic Template Fluctuation Group B, a comparative analysis of hearing status within the 500~1,000 Hz frequency range reveals that Group B has significantly poorer average hearing thresholds in this range than Group A. Additionally, in Group A,

five out of six participants maintain normal hearing thresholds within an average of 10 dBHL in the 500~1,000 Hz range, whereas only two out of six participants in Group B exhibit similar thresholds. These findings suggest that, unlike threshold fluctuations in the 250~500 Hz frequency range, threshold fluctuations in the 500~1,000 Hz range may primarily result not only from harmonic template dysfunction but also from damage to the auditory hair cells responsible for processing these frequencies.



<Cases of Multiple Harmonic Template Fluctuation in the 250-1,000 Hz>



In the frequency range of 250~1,000 Hz, where frequency processing occurs based on the firing rate cues, or periodicity cues, of auditory hair cell action potentials, multiple threshold fluctuations can be observed. In the MTM clinical trial, approximately 15 participants exhibited such phenomena. Let's examine eight cases of threshold fluctuations occurring within the 250~1,000 Hz frequency range. The group of participants who experienced fluctuations in the 250~500 Hz range had better average hearing thresholds in the 500~1,000 Hz range compared to the group that experienced fluctuations only in the 500~1,000 Hz range. However,

when multiple threshold fluctuations occurred across the entire 250~1,000 Hz frequency range, the distribution of hearing thresholds below 1,000 Hz was highly irregular, showing no consistent pattern. Interestingly, many of these multiple threshold fluctuation phenomena within the 250~1,000 Hz range appeared to be repeatedly reproduced at frequency points that corresponded to higher-order harmonic relationships.

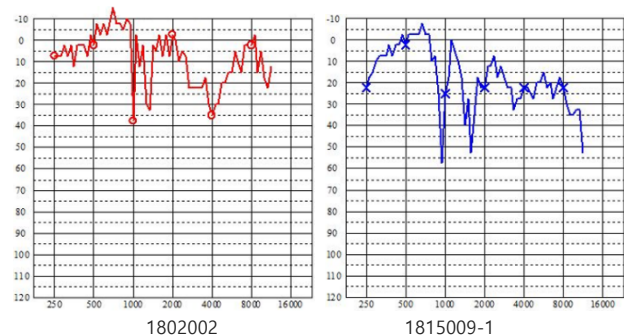
Threshold Fluctuation above 1,000 Hz

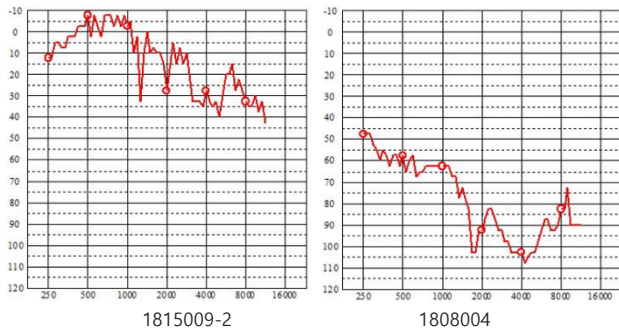
As mentioned briefly in the previous section on the classification of tinnitus, tones are further divided into pure tones and complex tones, from the two classes of sound, tone and noise. A pure tone is a sound that has only one frequency component, while a complex tone is a sound that contains two or more pure tones. Almost all tones in nature that have clear frequency characteristics, such as speech, music, birdsong, etc. are complex tones, not pure tones. Pure tones are used only in audiometric tests and experiments for research purposes, and researchers often use computational algorithms to create their own pure tone sound sources. Pure tones used in audiometry rely on periodic and place cues to decode frequency information in the subject's brain. For frequencies between 500 and 1,000 Hz, periodic cues dominate, but above 1,000 Hz, the role of periodic cues completely disappears in pure tones. Although not covered in this textbook, for non-pure tones, periodic cues still play an important role at the level of the underlying neural network in the frequency band above 1,000 Hz due to the action of the cerebral harmonic template. This is called the phase locking effect and is evidence for volley theory, a theory of frequency processing of complex sounds.

For pure tones in the frequency band above 1,000 Hz, frequency information is processed by place cues in the basilar membrane of the cochlea. If you experience threshold fluctuation in the frequency band above 1,000 Hz, it is very likely that it is directly caused by damage to the auditory hair cells that process these frequencies.

Of course, damage to the central harmonic template itself, rather than just damage to the auditory hair cells, can cause threshold fluctuation in the frequency band above 1,000 Hz.

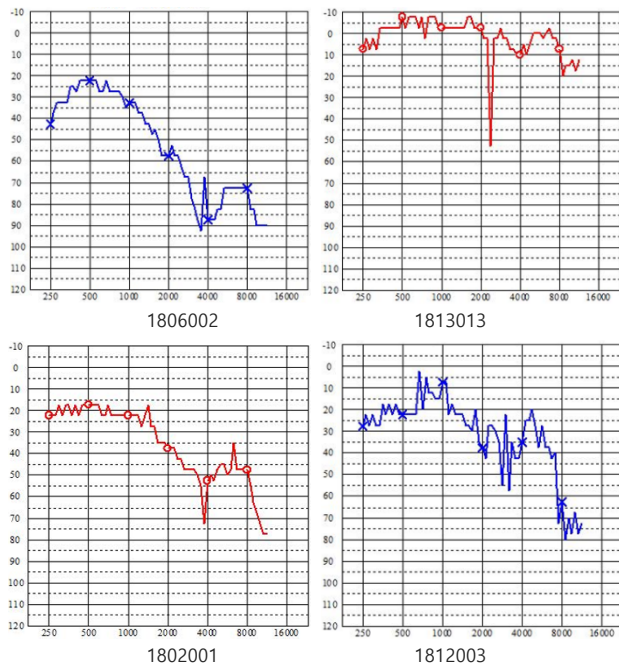
<Cases of Threshold Fluctuation in the 1,000~2,000 Hz>





The number of subjects with clear threshold fluctuation only in the 1,000 to 2,000 Hz frequency band and not in other frequency bands was 3 out of 195. For subjects 1802002 and 1815009, mild hearing damage around 4,000 Hz appears to have caused frequency computational errors in the central harmonic template. This resulted in threshold fluctuation in the 1,000 to 2,000 Hz band. In the case of participant 1808004, the 4,000 Hz frequency range had already reached a profound hearing loss level, suggesting that the reorganization of that frequency region was nearly complete. Therefore, the threshold fluctuation observed around 1,700 Hz in participant 1808004 is unlikely to have originated from harmonic mapping damage in that frequency range. Since the harmonic mapping damage in that frequency range is presumed to be already fixed, it is more reasonable to attribute the threshold fluctuation at 1,700 Hz to direct damage to the auditory hair cells in that frequency range.

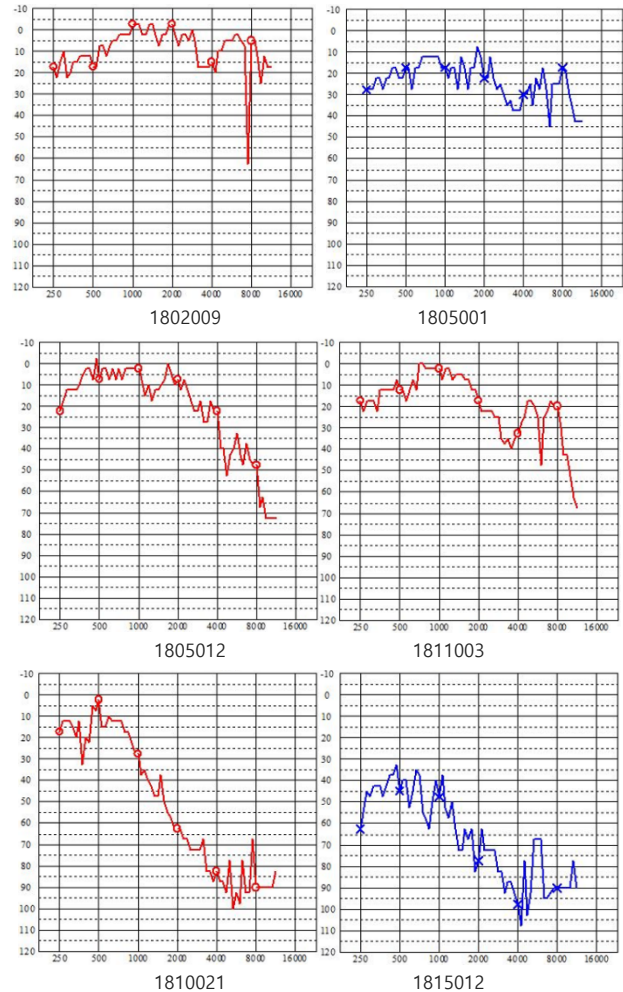
<Cases of Threshold Fluctuation in the 2,000~4,000 Hz>



Among the total of 195 participants, only four exhibited distinct threshold fluctuation phenomena exclusively within the 2,000–4,000 Hz frequency range. In all four cases, the rapid firing and neural synchronization within the frequency range where the threshold fluctuation occurred were the direct causes of the phenomenon. However, in the case of participant

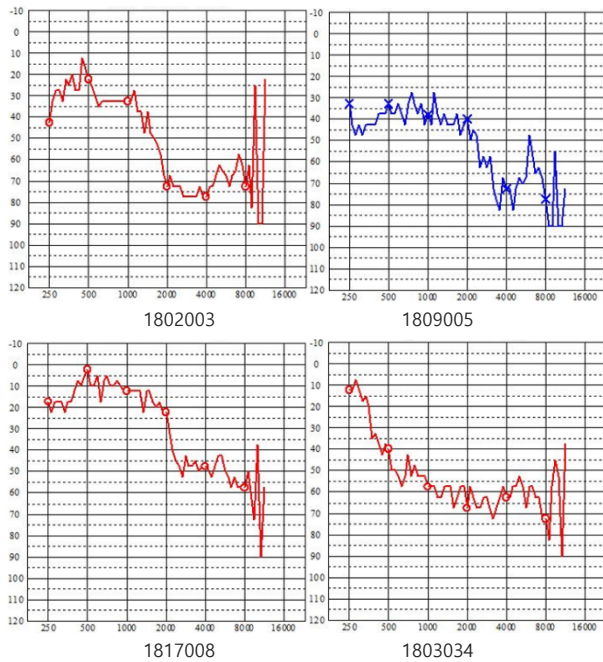
1813013, despite having normal hearing across the entire frequency range, clear threshold fluctuations were observed in the 2,000–4,000 Hz range. This could possibly be attributed to minor hearing impairment in the frequencies above 8,000 Hz. This type of threshold fluctuation tends to disappear and may reappear at another frequency range at an unspecified time.

<Cases of Threshold Fluctuation in the 4,000~8,000 Hz>



The number of subjects who had a clear threshold fluctuation only in the 4,000–8,000 Hz frequency band and not in other frequency bands was 6 out of 195, and the number of subjects who had a clear threshold fluctuation only in the frequency band above 8,000 Hz was 4. It can be said that the threshold fluctuation in the high frequency band above 4,000 Hz is mostly caused by damage to the auditory cells in this frequency band, which is directly related to the rapid firing and neural synchronization of the auditory nerve group.

<Cases in Threshold Fluctuation Above 8,000 Hz>



There are cases in which the threshold fluctuation was not localized to a specific frequency band, but multiple fluctuations widespread over the entire frequency band 250~12,000 Hz. These subject types have very unstable hearing, suggesting that reorganization of the hearing is currently occurring rapidly and that the rate of progression of hearing damage may be relatively rapid. Let's take a look at a few examples of such cases where the threshold fluctuation is widespread across the entire frequency band, but the cause of the fluctuation may be distinctly different.

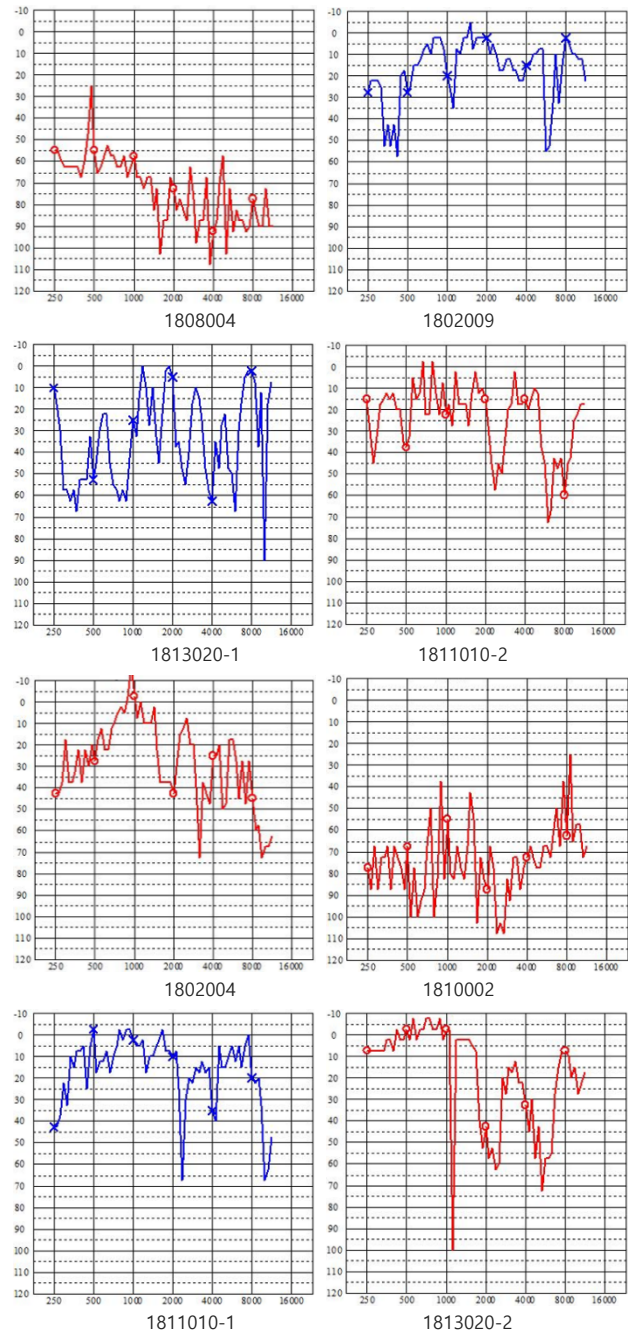
In the case of participant 1810002, auditory hair cell damage is progressing in a similar across the entire frequency range. The fluctuation pattern is very dense, making it difficult to identify specific frequency relationships between the fluctuation frequencies. In hearing environments where simultaneous reorganization is rapidly occurring across the entire frequency range, rapid firing and neural synchronization responses in both the auditory hair cells and auditory nerve group occur very frequently. For participant 1813020, the threshold fluctuation pattern is completely different from that of participant 1810002. Compared to participant 1810002, the displacement of the threshold fluctuation Y-values for participant 1813020 is much deeper, and the threshold fluctuation period is never as dense. One noteworthy feature is that, within the less dense threshold fluctuation pattern, periodicity of the fluctuations is observed.

The threshold fluctuations of participant 1813020 are distributed almost periodically, following a multiple relationship based on the lowest fluctuation frequency value. This periodic fluctuation phenomenon across the entire frequency range is a rare occurrence, found in only one or two participants out of the 195, but it is also an interesting case where the presence of the auditory harmonic mapping, a neural network organization in the brainstem, was revealed through behavioral response

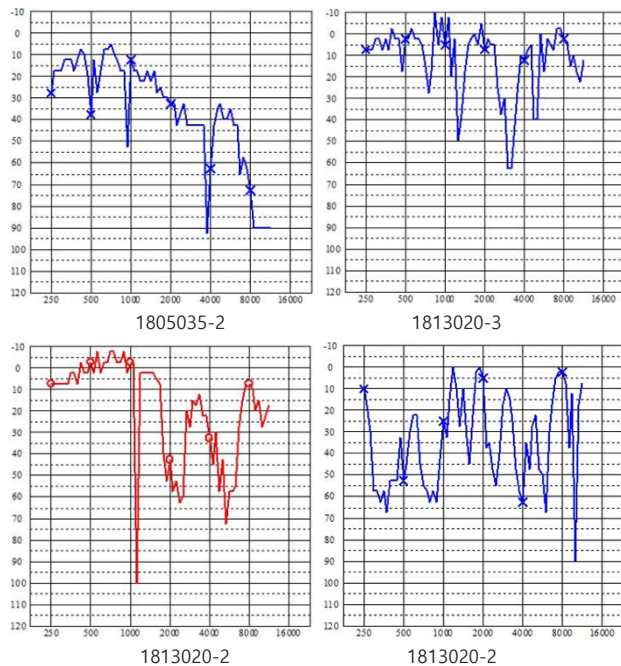
experiments.

In an experimental environment where 67 frequencies are presented randomly to the left and right ears, threshold fluctuations were clearly observed in some frequency ranges for about 35% of the participants. However, when such threshold fluctuations occurred in multiple frequencies across the entire frequency range, almost precisely following a multiple relationship, this was observed in approximately 1~2% of the participants.

<Mixed Fluctuation Cases Across 250~12,000 Hz>



<Evidence of Harmonic Mapping Across the 250–12,000 Hz Band>



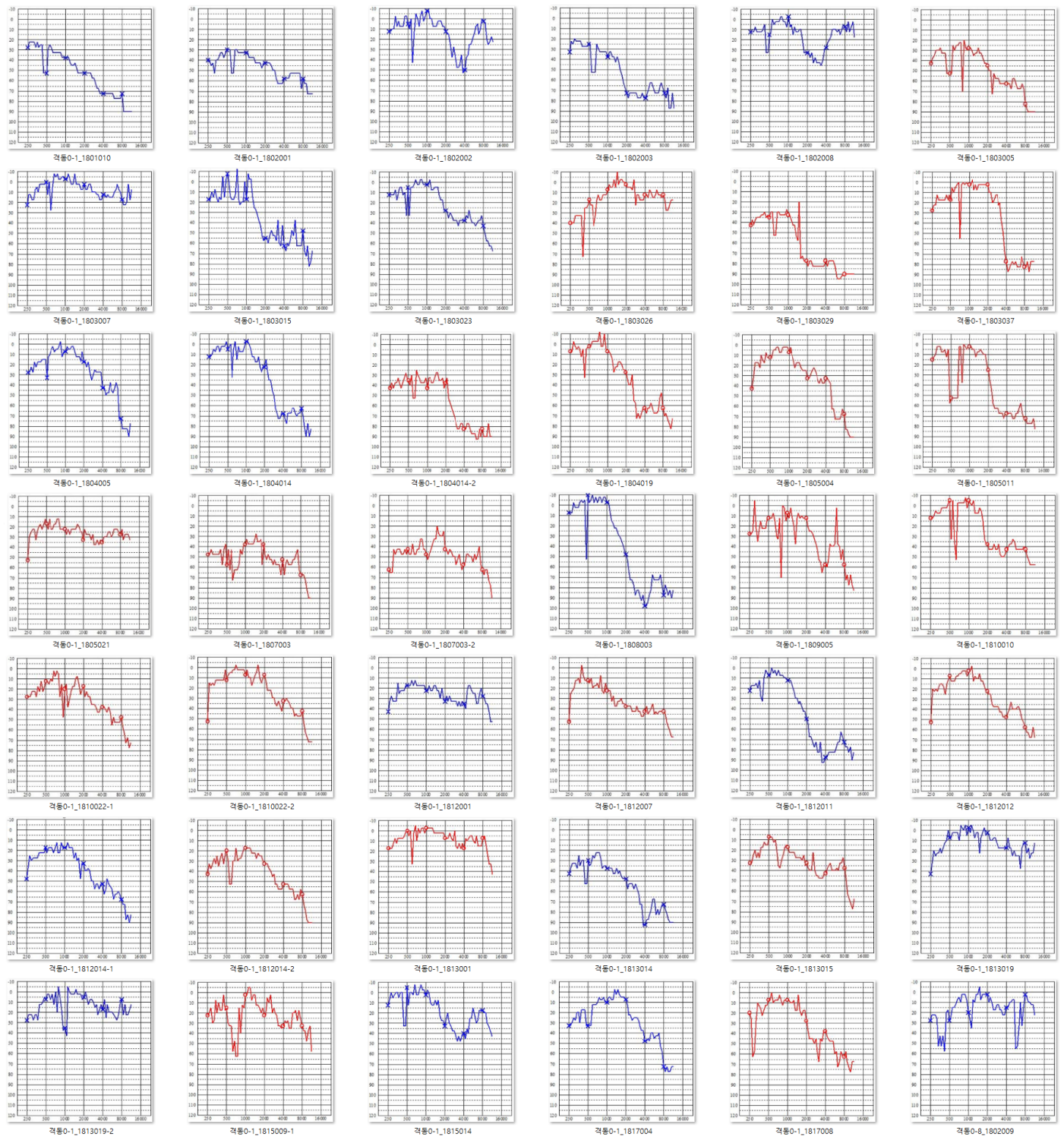
It is very rare for a participant to perceptibly recognize threshold fluctuations occurring within a single critical frequency range. Occasionally, sudden threshold fluctuations may cause tinnitus, allowing one to infer that a threshold fluctuation event briefly occurred. If a sudden threshold fluctuation occurs simultaneously across three or more critical frequency ranges, most people would likely recall the moment as "suddenly experiencing a feeling of ear fullness." Threshold fluctuations occurring due to rapid firing, neural synchronization, or reorganization at the level of auditory cells, auditory nerves, and auditory neurons can be a useful indicator of hearing health.

However, it is important not to evaluate hearing health solely based on the presence or absence of these fluctuations. For example, the interpretation that "if threshold fluctuations occur, there is a hearing problem, and if threshold fluctuations are absent, there is no hearing issue" is incorrect. A better interpretation would be, "if threshold fluctuations are present, hearing is unstable, and if threshold fluctuations is stable." Even individuals with very good hearing can experience threshold fluctuations. In cases of complete hearing degeneration, leading to profound hearing loss, threshold fluctuations are rare. Even individuals with moderate hearing loss who have worn hearing aids for a long time typically do not experience threshold fluctuations, as their hearing has stabilized or become fixed at that level. However, if hearing deteriorates further due to noise exposure or aging, threshold fluctuations may occur again.

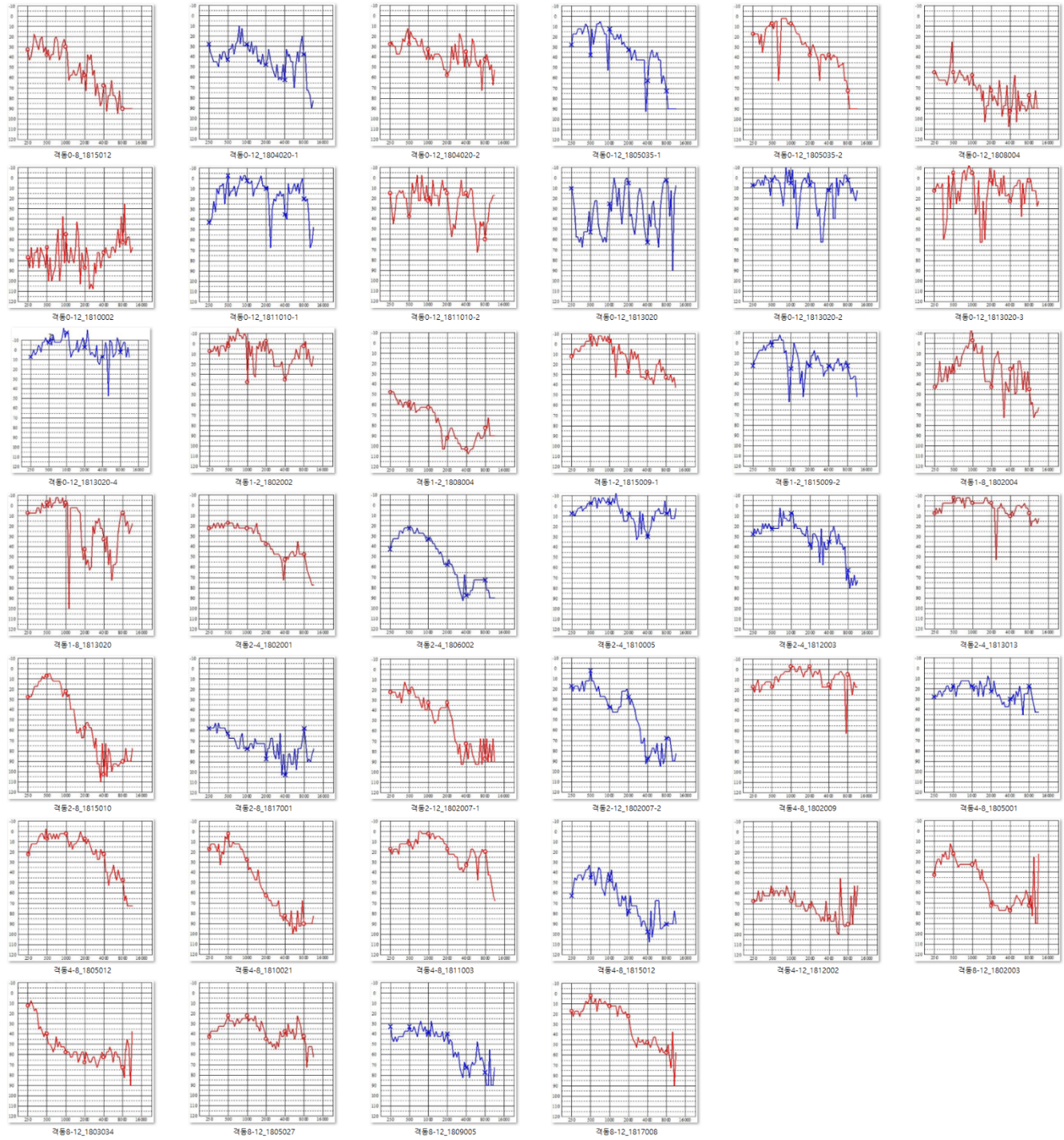
Threshold fluctuation phenomena, along with tinnitus, serve as an internal biological warning signal indicating the onset and progression of hearing loss. The frequency of tinnitus and the frequency at which threshold fluctuations occur are largely identical. Therefore, to accurately determine

the frequency of tinnitus, it is more efficient to conduct an RCPTA-based 67-band micro auditory threshold test, which takes approximately 15 minutes, rather than relying on a subjective tinnitus frequency matching test. Threshold fluctuation phenomena manifest as distinct "patterned" signals within random auditory threshold time series data, completely independent of any intentional judgments from either the participant or the examiner. This makes them a valuable clinical tool for diagnosing and treating tinnitus.





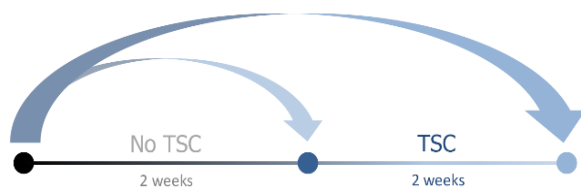
4. Threshold Fluctuation Phenomenon





5. MTM Clinical Practice

From October to November 2018, a multicenter clinical trial on the diagnosis and treatment of tinnitus was conducted for about two months. A total of 17 medical centers in major Korean cities including Seoul, Busan, Incheon, Daejeon, Ulsan, Gwangju, Changwon, Jeonju, Bucheon, Andong, Gumi, Jeju, Wonju, and Chungju participated in the trial. Voluntary subjects were recruited mainly from patients visiting the 17 medical centers, and 258 subjects with tinnitus symptoms participated in the trial. Of the 258 subjects, 195 completed the entire study. In the MTM trial, clinical treatment and outcomes were analyzed for all 195 subjects using a within subject design.



MTM is a treatment protocol that diagnoses and treats tinnitus by inducing underlying hearing changes in tinnitus patients with Threshold Sound Conditioning (TSC) and qualitatively observing and analyzing these changes using a 67-band-based RCPTA

Threshold Sound Conditioning (TSC) and qualitatively observing and analyzing these changes using a 67-band-based RCPTA algorithm. The MTM protocol essentially combines a four-week period into one cycle of care. The first two weeks are for objective observation and analysis of the patient's hearing status. The second two weeks is when the TSC-based medical treatment is applied in earnest. In MTM, tinnitus patients live their lives as usual for the first two weeks after their first visit to the clinic. When diagnosing a patient's hearing and tinnitus status, it is not advisable for a healthcare provider to make assumptions about a patient's hearing based on a single day of testing. Most tinnitus is not an acute condition that requires immediate treatment, so it's important to take the time to quantitatively assess a patient's day-to-day hearing status.

The correct diagnosis and treatment of tinnitus should be made along the way. On the first visit, the patient will undergo a first micro-audiometry and fill out an initial questionnaire. Two weeks later, the patient will return to the clinic for a second visit. On the second visit, a second micro-audiometry is performed and a TSC prescription is made. After the second audiogram, the healthcare provider will analyze the results of the first

audiogram and compare them with the results of the second audiogram. Based on the results of the analysis, the frequency bands that need to be treated for tinnitus are targeted and tracked. This is done to create a single-channel or multi-channel TSC sound signal that is optimized for the patient's current hearing status. Targeting is the process of selecting TSC signals according to the tinnitus frequency bands identified by the RCPTA algorithm, and tracking is the process of finding the patient's descending threshold in the targeted TSC sound signal. To perform accurate targeting and tracking, the REVE134 acoustic stimulator with 134 bands and 20 channels of frequency resolution is used. After two weeks of TSC, patients undergo a third micro-audiometry and complete a second questionnaire at the third visit, which is the fourth week of MTM. In the 4-week MTM protocol, the results of the first two questionnaires and the first, second, and third audiograms are the basis for determining and interpreting changes in the patient's hearing and tinnitus. In addition, a listening diary is completed by the patient. Each time the patient listens to the TSC acoustic signal, the volume of the TSC acoustic signal should be adjusted to the tinnitus patient's descending threshold, i.e., the descending threshold.

values in your listening journal. If you do TSC twice a day for 30 minutes for two weeks straight, you should take 28 notes in total.

Clinical Trial Methods and Procedures

The material posted below is a 4-week MTM clinical protocol. If you decide to proceed with MTM tinnitus diagnosis and treatment in a 4-week cycle, please refer to this MTM protocol for specific procedures. Seventeen medical centers conducted MTM trials according to this protocol, and of a total of 258 subjects who volunteered to participate in the MTM trial, 195 subjects complied with the protocol as directed. In the MTM study, TSC was performed in a quiet room at home or work and a portable MP3 player was provided for this purpose. There are two ways to perform the TSC in the MTM protocol, one utilizing a portable MP3 player and the other online using the patient's smartphone. The smartphone version of the TSC is described later.

Obtaining responses from subjects to a three-question tinnitus questionnaire is an important step in diagnosing the current status of tinnitus and analyzing the results of tinnitus treatment.



The questionnaire is completed by the subject on the first and last day of the 4-week MTM clinic. The format of the first and last day questionnaires is different because the first day questionnaire serves as an enrollment form, whereas the last day questionnaire contains only the questionnaire content. In addition, the purpose of the last day questionnaire is to eliminate as much bias as possible, caused by memory cues related to the content of each questionnaire and the subject's responses from the first visit. Making each questionnaire different in terms of font and size will also be effective in minimizing memory cues. However, it is not recommended to change the order of questions 1, 2, and 3 on the first and second questionnaire, or to change the content of the questionnaire

Questionnaire for Your First Day in MTM

“약 15분간 진행되는 미세청각검사 무료 체험을 위해 본 설문지를 작성해 제출하십시오.
이형의 발생 원인을 손상 청각세포 구간의 미세청각검사를 통해 상세히 관찰할 수 있습니다.”

아래 질문을 읽고 해당 번호에 ○표로 답하십시오.

1. 최근 3일간 나의 이명은

① 언제나 들린다
② 자주 들린다
③ 가끔 들린다
④ 거의 들리지 않았다
⑤ 전혀 들리지 않았다

2. 지금 이 순간 나의 이명 불쾌은

① 크게 들린다
② 적당히 들린다
③ 작게 들린다
④ 거의 들리지 않는다
⑤ 전혀 들리지 않는다

3. 오늘 나의 이명은

① 꾸준히 지속적으로 들린다
② 들렸다 안들렸다 한다
③ 들리지 않는다

MTM 미청 진단 및 치료
연구 참여 신청서
Microtonal Threshold Management

본인은 귀 의뢰기관이 실시하는
「이명 진단 및 치료 연구」
참가를 희망합니다.

성명: _____
나이: _____
전화번호: _____

Questionnaire on the Last Day of MTM Participation

설 문 지

성 명 : _____
아래 질문을 읽고 해당 번호에 ○표로 답하십시오.

1. 최근 3일간 나의 이명은

① 언제나 들렸다
② 자주 들렸다
③ 가끔 들렸다
④ 거의 들리지 않았다
⑤ 전혀 들리지 않았다

2. 지금 이 순간 나의 이명 불쾌은

① 크게 들린다
② 적당히 들린다
③ 작게 들린다
④ 거의 들리지 않는다
⑤ 전혀 들리지 않는다

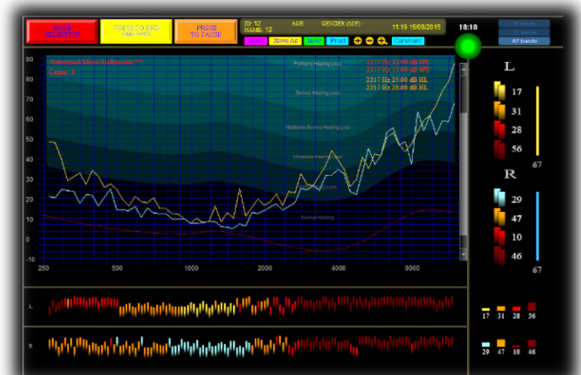
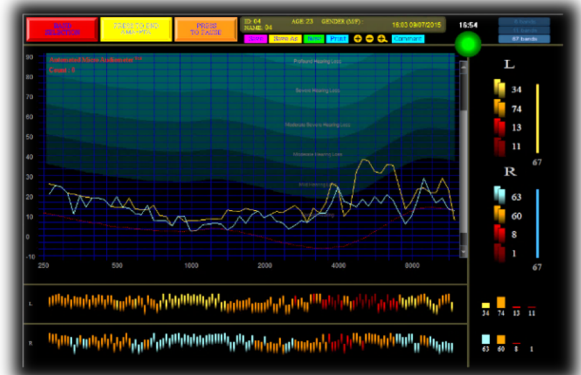
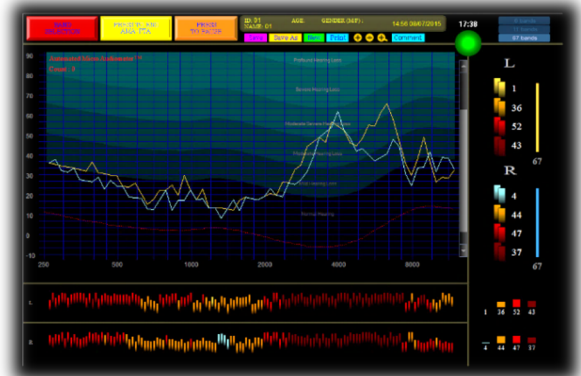
3. 오늘 나의 이명은

① 꾸준히 지속적으로 들린다
② 들렸다 안들렸다 한다
③ 들리지 않는다

67-Band Micro-Audiometry

To perform pure tone audiometry with a high-resolution frequency specification of 67 bands, Earlogic's AMA-PTA Micro Audiometer is required. The AMA-PTA Micro Audiometer is the only device capable of automated audiometric testing based on the RCPTA algorithm. The AMA-PTA 67-band test can be downloaded from the final results are saved as both an AMA file (.ama) and a text file (.txt)

Example AMA Results Screens



Example AMA Results Screens

VER : 10
ID : 1802007
Name : 장말준2차
Age : 75
Gender : m
Date : 10:11 15/10/2018

ElapsedTime : 1012

Left Ear		Right Ear	
262	17.5 1010	262	22.5 376
277	22.5 851	277	22.5 407
294	17.5 605	294	22.5 438
311	17.5 815	311	22.5 576
330	17.5 754	330	27.5 719
349	22.5 696	349	27.5 257
370	17.5 534	370	22.5 544
392	12.5 902	392	32.5 855
415	22.5 812	415	22.5 557
440	12.5 195	440	12.5 699
466	12.5 629	466	17.5 724
494	12.5 747	494	22.5 789
523	2.5 923	523	22.5 741
554	12.5 252	554	17.5 850
587	12.5 750	587	17.5 624
622	17.5 486	622	22.5 449
659	22.5 430	659	27.5 319
698	17.5 458	698	27.5 835
740	27.5 580	740	27.5 661
784	27.5 939	784	32.5 765
831	27.5 667	831	37.5 934
880	27.5 597	880	27.5 303
932	30.0 834	932	40.0 509
988	35.0 589	988	40.0 405
1047	37.5 925	1047	32.5 875
1109	37.5 775	1109	40.0 927
1175	42.5 329	1175	40.0 1012
1245	42.5 466	1245	47.5 1003
1319	42.5 742	1319	52.5 993
1397	42.5 837	1397	50.0 866
1480	37.5 375	1480	50.0 483
1568	37.5 584	1568	40.0 344
1661	22.5 793	1661	37.5 352
1760	22.5 844	1760	37.5 571
1865	22.5 434	1865	37.5 745
1976	20.0 553	1976	37.5 249
2093	27.5 409	2093	32.5 515
2217	35.0 877	2217	37.5 342
2349	30.0 262	2349	42.5 337
2489	35.0 427	2489	47.5 481
2637	40.0 894	2637	60.0 816
2794	50.0 968	2794	70.0 598
2960	52.5 858	2960	72.5 848
3136	57.5 960	3136	82.5 856
3322	72.5 727	3322	72.5 439
3520	72.5 561	3520	92.5 978
3729	67.5 575	3729	92.5 987
3951	92.5 980	3951	82.5 555
4186	87.5 942	4186	72.5 651
4435	87.5 997	4435	87.5 1001
4699	82.5 787	4699	72.5 681
4978	77.5 969	4978	72.5 600
5274	77.5 886	5274	82.5 878
5588	82.5 735	5588	87.5 979
5920	72.5 399	5920	92.5 965
6272	87.5 963	6272	92.5 1006
6645	95.0 952	6645	92.5 1004
7040	72.5 272	7040	67.5 548
7459	92.5 957	7459	92.5 721
7902	87.5 703	7902	67.5 780
8372	67.5 393	8372	87.5 996
8870	67.5 550	8870	67.5 757
9397	67.5 607	9397	90.0 825
9956	77.5 737	9956	72.5 558
10548	90.0 914	10548	90.0 973
11175	90.0 989	11175	67.5 339
11840	82.5 974	11840	90.0 985

Procedure for Microscopic Audiometry

1. 청력검사지침서 제공

부스 의자에 고객을 앉힌 후 검사지침서를 숙지하게끔 안내한다.

2. 전원 켜기

검사기 전원을 켜다.



3. ID 입력

먼저 고객 ID를 입력한 후 나이, 성별, 성명을 기입한다.

고객 ID는 해당년도 2자리수, 의료기관번호 2자리수, 고객번호 3자리수를 조합한 7자리 숫자를 사용한다. (예, 1813027)



4. 이어폰 연결 및 착용

- (1) 고객의 전용이어폰을 부스 안에 설치된 연결잭에 꼽는다.
- (2) 이어폰의 좌우(LR) 방향 및 고객의 이어폰 착용을 확인한다.
- (3) 검사 중 이어폰이 빠지지 않도록 고객의 전용이어폰 착용상태를 한번 더 면밀히 점검한다. 고객에게 양해를 구하고, 귓볼을 살짝 당긴 상태에서 이어폰을 외이도 안쪽 깊숙이 밀어 넣는다.

5. 검사 요령 안내

- (1) '두두두두' 또는 '뽀뽀뽀뽀' 신호음이 들릴 때마다 ● 표시된 버튼을 가볍고 신속하게 한번씩 눌러주세요.
- (2) 신호음이 작더라도 정확히 들렸을 경우에는 버튼을 누르세요.
- (3) 신호음이 들렸는지 여부가 애매하거나, 들리지 않은 경우는 버튼을 누르지 마세요.

6. 검사 실행

- (1) 검사 시작 버튼을 누른다.
- (2) 검사 초기 1~2분 간은
고객의 반응 패턴에 이상이 없는지 면밀히 관찰해야 한다.
고객의 반응 패턴에 이상이 있다면 재교육 후 다시 시작한다.
- (3) 검사 시작 1~2분 이후부터는 검사자는 검사실에서 조용히 퇴장해도 무방하다.
- (4) 검사 시작 12분이 경과하면 검사자는 조용히 입실하여 고객의 반응 패턴을 다시금 주시해야 한다. (검사소요시간: 약 13~17분)



7. 검사 완료

검사가 완료되면 고객으로 하여금 이어폰을 연결잭에서 뺏게 안내 후 의자에 앉은 상태에서 1~2분 정도 휴식을 취하게 한다.

8. 결과 저장

Save 버튼을 눌러

파일명 확인 후

결과를 저장한다. 결과 저장 시 파일명이 자동으로 생성되며, 저장된 파일명에 검사종료시각이 자동 표시된다.



9. 결과지 출력

Print 버튼을 눌러

결과지를 출력한다.



10. 격동구간 대조 분석 및 기록

- (1) 검사결과 화면에서 미세청력 격동구간의 주파수값을 확인한다.
- (2) 검사결과 화면의 격동구간과 출력된 결과지에서의 격동구간을 대조 분석하여 최대격동 주파수값을 결과지에 수기로 표시한다.

11. 전원 끄기

검사기 전원을 끈다.



Clinical Subjects

Volunteer subjects with tinnitus symptoms who visited a medical center for any purpose were enrolled in the MTM trial. A total of 258 subjects completed and returned an informed consent form, but were not eligible for the clinical trial. There were 195 subjects who dutifully completed the entire process as instructed. Of the 195 subjects, 90 (46%) were female and 105 (54%) were male. The average age of all subjects was 55 years old. By age group, there were 2 teens, 8 in their 20s, 20 in their 30s, 33 in their 40s, 54 in their 50s, 44 in their 60s, 27 in their 70s, and 7 in their 80s. The average hearing status of all 195 participants based on the results of the first micro-audiometry was calculated by the arithmetic mean hearing loss index and geometric mean hearing loss index, which were 4,335 ($103 < 4,335 < 92$) for the arithmetic mean hearing loss index and 3,749 ($85 < 3,749 < 110$) for the geometric mean hearing loss index. The mean value of the arithmetic and geometric mean hearing loss was 4,042, and based on this, there were 97 subjects with hearing better than 4,042 and 98 subjects with hearing worse than 4,042.

In the initial questionnaire assessment to determine each subject's tinnitus resistance, the mean tinnitus resistance score for all 195 subjects was 5.45. Ninety-eight subjects, or 50% of the subjects, scored between 3 and 4. Tinnitus resistance scores of 3 to 4 are considered to be the weakest resistance to tinnitus and the most severe daily discomfort from tinnitus.



Creating and listening to TSC acoustic signals

After a secondary audiologic examination, the patient is prescribed TSC sound signals to stimulate single or multiple tinnitus-producing frequency bands. For this purpose, the REVE134 acoustic stimulator with 134 bands and 20 channels is required. The TSC sound signal using the REVE134 acoustic stimulator is as follows.

1. 이어폰 연결 및 착용

- (1) 고객의 전용이어폰을 음향자극기 연결잭에 꼽는다.
- (2) 이어폰의 좌우(LR) 방향 및 고객의 이어폰 착용을 확인한다.

2. 전원 켜기 음향자극기 전원을 켜다.



3. ID 입력

고객 ID를 입력한다. 고객 ID는 미세청력검사 결과지 상의 ID와 동일한 숫자여야 한다.



4. 타게팅과 트래킹

- (1) 좌측 또는 우측 트래킹 버튼을 선택한다.



- (2) 검사결과지 상에 수기로 표시해 둔 최대각동 주파수값을 달팽이관 화면에서 선택한다.

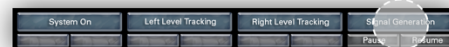


- (3) 타게팅(주파수설정)과 트래킹(하향역치설정)은 반드시 고객과 함께 진행한다.

- 트래킹 시 한 주파수당 가급적 10초 이내에 하향역치를 찾는다.
- 트래킹 중 고객이 자신의 이어폰을 만지는 행위를 금한다.
- 달팽이관 화면에서 주파수를 잘못 선택한 경우 해당 청각세포 부위를 다시 클릭하여 설정을 취소한다.
- 특정 주파수가 이미 선택된 상태에서 바로 옆 주파수 선택은 불가하며, 최소 4밴드(청각세포그룹 4칸) 이상 이동해야 주파수 선택이 가능하다.

5. 치료음 제작

현재까지 작업한 타게팅/트래킹 결과의 저장과 치료음 파일 생성을 위하여 Signal Generation 버튼을 클릭한다.



(달팽이관 화면 중앙의 Decoding 창이 사라지면 치료음 생성 작업이 완료된 것이다. 치료음 파일 생성이 완료되기 전에 작업을 취소하려면 Ctrl+Z 버튼을 누른다.)

6. 종료

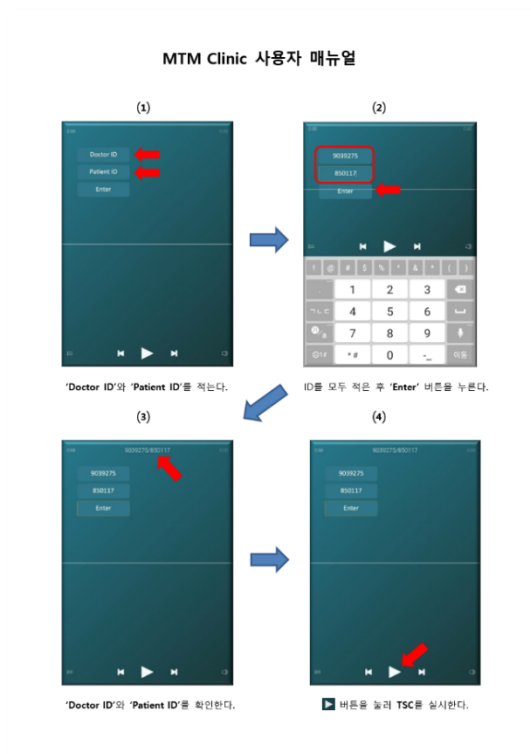
화면 우측 최상단에 위치한 [X]를 클릭하여 음향자극기를 종료한다.

7. 고객에게 치료음 제공

- (1) 바탕화면의 Sound 폴더에 생성된 치료음 파일을 확인한다.
- (2) 전용 MP3플레이어를 연결하여 치료음 파일을 옮겨 담는다.

REVE134 Acoustic Stimulator (Korean FDA Approval Number: 08-401, US FDA Approval Number: K151719)





After you create the TSC acoustic signal, you can finally give the patient the TSC acoustic. There are two ways to deliver the signal: by storing the music on an MP3 player, or by having the

patient access an online MTM player on their smartphone. While the 2018 MTM clinical trial was conducted using MP3 players, people who are comfortable using smartphones can access the online MTM player on their own smartphones and listen to the TSC sound signals customized to their tinnitus frequency band without the need for a separate MP3 player. The top image on the left is a manual that explains how to access the online MTM player on a patient's smartphone and add it to their home screen. The bottom left image is a manual that explains how to use the online MTM player to perform TSC.

MTM Listening Log

The reason for having subjects complete their own listening logs in MTM trials is that even on a single day during the TSC, their own thresholds can change from. This is because the values can change. Subjects should be instructed to check for these changes themselves and to make sure to write down the readings each time. In addition, keeping a listening diary can increase the subject's engagement with TSC. When treating tinnitus patients in the clinic, it is essential to have the patient complete the MTM listening log in order to reach the desired result for both the clinician and the patient. Keeping a listening log is one of the patient's responsibilities in the MTM protocol.

Example MTM Listening Log

성명:

	청취일	청취시각	하향역치		청취일	청취시각	하향역치				
1	월	일	시	분		2	월	일	시	분	
3	월	일	시	분		4	월	일	시	분	
5	월	일	시	분		6	월	일	시	분	
7	월	일	시	분		8	월	일	시	분	
9	월	일	시	분		10	월	일	시	분	
11	월	일	시	분		12	월	일	시	분	
13	월	일	시	분		14	월	일	시	분	
15	월	일	시	분		16	월	일	시	분	
17	월	일	시	분		18	월	일	시	분	
19	월	일	시	분		20	월	일	시	분	
21	월	일	시	분		22	월	일	시	분	
23	월	일	시	분		24	월	일	시	분	
25	월	일	시	분		26	월	일	시	분	
27	월	일	시	분		28	월	일	시	분	
29	월	일	시	분		30	월	일	시	분	

When the MTM listening log form is given to the patient, instructions on how to listen for TSC tones should also be provided. Patients who are new to TSC may not have prior knowledge of how to listen for TSC tones and will need careful guidance from the healthcare provider on how to proceed with TSC listening. Basic instructions on how to listen for TSC may include the following:

1. You should listen to the therapy sounds for 30 minutes each morning and evening.
2. You need to adjust the volume of the therapy sound before you start listening each time.
3. The sound volume should be set to the descending threshold, which is the point at which the "sound therapy" becomes inaudible.
4. Don't touch the volume in the middle of a 30-minute listening session.
5. Listen to the therapy sounds in a quiet room if possible.
6. Fill out a listening journal for each listening session.

MTM Clinical Journal

If clinicians can see all the results of the various tests performed during a clinical encounter at a glance, their clinical work will be more efficient and accurate. The MTM clinical diary is a record of the primary questionnaire scores, primary and secondary tinnitus frequency values, REVE134 targeting index numbers, and tracked dBr values from the primary and secondary audiograms.

Example MTM Clinical Journal

고객 ID						성명					
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☞ 1차 방문

날짜	2018년		월	일	실문지 점수*	점
1차 미세청력검사 후 이명타겟주파수 상세 내역						
L	Hz	dBHL	R	Hz	dBHL	
L	Hz	dBHL	R	Hz	dBHL	
L	Hz	dBHL	R	Hz	dBHL	
L	Hz	dBHL	R	Hz	dBHL	
L	Hz	dBHL	R	Hz	dBHL	

☞ 2차 방문

날짜	2018년		월	일	실문지 점수*	점
2차 미세청력검사 후 이명타겟주파수 내역						
L	Hz	dBHL	R	Hz	dBHL	
L	Hz	dBHL	R	Hz	dBHL	
L	Hz	dBHL	R	Hz	dBHL	
L	Hz	dBHL	R	Hz	dBHL	
L	Hz	dBHL	R	Hz	dBHL	
레브134 연엑스 번호 및 역치값 내역						
L	번	dBr	R	번	dBr	
L	번	dBr	R	번	dBr	
L	번	dBr	R	번	dBr	
L	번	dBr	R	번	dBr	
L	번	dBr	R	번	dBr	

☞ 3차 방문

날짜	2018년		월	일	실문지 점수*	점
3차 미세청력검사 후 이명타겟주파수 내역						
L	Hz	dBHL	L	Hz	dBHL	
L	Hz	dBHL	L	Hz	dBHL	
L	Hz	dBHL	L	Hz	dBHL	
L	Hz	dBHL	L	Hz	dBHL	
L	Hz	dBHL	L	Hz	dBHL	

*실문지 점수 평가 방법 (최대점수 15점, 최소점수 3점) - 3개 질문에 대한 답변번호의 단순합계 (단 3번 질문의 경우 답변 ②은 1점, 답변 ③은 3점, 답변 ④은 5점으로 배점함 것)

6. MTM Effects

Indexing Hearing Loss

The 67-band-based RCPTA audiometric test outputs a total of 134 hearing threshold values left and right at 67 frequency points in the 250-12,000 Hz band. MTM subjects are able to see their true hearing status in high resolution by performing three micro-audiometry (1st, 2nd, 3rd) in one month.

The following table is an example of one subject's actual 1/2/3rd order micro audiometric test results, organized into a single text result file with 3 minutes of 67 RCPTA-based left and right hearing thresholds. The left Hz and right Hz frequency values tested are shown vertically, with the 1/2/3rd hearing threshold results in dBHL for each frequency row. The bottom row of the table shows the sum of the 67 hearing thresholds for that session. This sum is the 67-band RCPTA-based hearing index, which is a measure of an individual's "gross hearing" at a given point in time or hearing loss index. Based on 67 bands. The

RCPTA algorithm has a "maximum hearing loss index" value of 13,360, which is the hearing condition.

좌측 Hz	1차	2차	3차	우측 Hz	1차	2차	3차
262	22.5	32.5	27.5	262	12.5	27.5	22.5
277	22.5	27.5	22.5	277	7.5	27.5	27.5
294	17.5	30	27.5	294	10	27.5	27.5
311	17.5	25	22.5	311	5	27.5	22.5
330	17.5	27.5	22.5	330	2.5	17.5	22.5
349	17.5	22.5	22.5	349	2.5	22.5	17.5
370	12.5	22.5	17.5	370	2.5	22.5	17.5
392	17.5	22.5	22.5	392	2.5	22.5	17.5
415	12.5	22.5	17.5	415	-2.5	22.5	17.5
440	12.5	17.5	12.5	440	-2.5	22.5	17.5
466	17.5	17.5	17.5	466	2.5	22.5	17.5
494	12.5	12.5	12.5	494	-2.5	17.5	12.5
523	12.5	12.5	17.5	523	-2.5	17.5	12.5
554	12.5	12.5	12.5	554	-2.5	17.5	12.5
587	5	12.5	10	587	2.5	12.5	12.5
622	5	12.5	5	622	-2.5	12.5	7.5
659	7.5	12.5	12.5	659	2.5	12.5	7.5
698	2.5	7.5	7.5	698	2.5	12.5	2.5
740	2.5	7.5	10	740	-2.5	7.5	5
784	2.5	7.5	10	784	2.5	7.5	5
831	2.5	12.5	7.5	831	7.5	7.5	7.5
880	2.5	12.5	12.5	880	2.5	12.5	2.5
932	7.5	12.5	7.5	932	2.5	12.5	7.5
988	12.5	12.5	12.5	988	2.5	12.5	2.5
1047	2.5	12.5	7.5	1047	2.5	12.5	7.5
1109	7.5	12.5	12.5	1109	2.5	12.5	7.5
1175	10	12.5	12.5	1175	5	12.5	10
1245	10	17.5	12.5	1245	5	12.5	10
1319	12.5	12.5	12.5	1319	7.5	12.5	12.5
1397	12.5	12.5	12.5	1397	17.5	22.5	22.5
1480	12.5	12.5	12.5	1480	17.5	22.5	12.5
1568	17.5	12.5	0	1568	17.5	17.5	12.5
1661	22.5	7.5	7.5	1661	22.5	17.5	7.5
1760	27.5	12.5	10	1760	22.5	17.5	12.5
1865	27.5	12.5	10	1865	22.5	7.5	7.5
1976	22.5	12.5	10	1976	22.5	12.5	12.5
2093	22.5	17.5	12.5	2093	22.5	17.5	12.5
2217	17.5	17.5	17.5	2217	22.5	20	17.5
2349	22.5	22.5	22.5	2349	22.5	25	17.5
2489	22.5	17.5	22.5	2489	27.5	30	27.5
2637	22.5	22.5	17.5	2637	27.5	32.5	27.5
2794	25	22.5	17.5	2794	30	27.5	27.5
2960	30	22.5	17.5	2960	30	25	22.5
3136	30	22.5	17.5	3136	30	30	22.5
3322	32.5	22.5	17.5	3322	32.5	27.5	22.5
3520	40	22.5	22.5	3520	37.5	32.5	27.5
3729	40	27.5	22.5	3729	37.5	27.5	27.5
3951	35	22.5	22.5	3951	42.5	32.5	27.5
4186	32.5	22.5	17.5	4186	37.5	27.5	22.5
4435	32.5	17.5	22.5	4435	32.5	22.5	22.5
4699	32.5	20	20	4699	40	25	20
4978	32.5	17.5	17.5	4978	37.5	17.5	22.5
5274	30	15	15	5274	35	17.5	15
5588	25	10	20	5588	30	17.5	20
5920	20	15	-2.5	5920	30	22.5	25
6272	15	17.5	22.5	6272	27.5	22.5	27.5
6645	20	25	-7.5	6645	30	25	32.5
7040	27.5	27.5	32.5	7040	37.5	37.5	32.5
7459	27.5	27.5	30	7459	27.5	37.5	32.5
7902	27.5	27.5	27.5	7902	37.5	37.5	35
8372	25	22.5	25	8372	32.5	37.5	32.5
8870	25	27.5	20	8870	35	35	25
9397	37.5	42.5	37.5	9397	47.5	47.5	42.5
9956	57.5	62.5	57.5	9956	62.5	52.5	52.5
10548	72.5	72.5	67.5	10548	57.5	62.5	57.5
11175	77.5	62.5	72.5	11175	77.5	72.5	72.5
11840	72.5	72.5	67.5	11840	72.5	72.5	72.5
	1490	1430	1282		1370	1622	1402

The table on the right shows the finalized Hearing Loss Index of 195 volunteer subjects who completed the MTM trial, excluding 3 SOAEs ⁽¹⁾ for a total of 192 subjects. This is the first evidence that allows for a systematic discussion of MTM effectiveness based on change rates in hearing loss.

1) In individuals with healthy hearing, spontaneous otoacoustic emissions (SOAE) can be mistaken for tinnitus, and in the MTM study, there were three such individuals.

6. MTM Effects

Hearing change rates

Subject	G	A	1st			2nd			Diff of Threshold			Diff Ratio(%)					
			L	R	1st	2nd	3rd	1st	2nd	3rd	1v2	2v3	1v3	1v2	2v3	1v3	
1801001 M	45	1227	1010	882	937	940	745	2164	1950	1627	1213	-233	-537	9.8	16.5	24.8	
1801002 M	52	1252	2962	3005	3377	3510	3585	6199	6432	6670	324	238	501	-5.2	-3.7	-9.1	
1801003 M	48	1427	1404	1447	1480	1513	1546	1980	2777	2980	103	18	85	4.1	-0.4	3.5	
1801005 M	54	1870	1887	1877	1555	1517	1525	3024	3014	3029	11	5	13	0.3	-0.4	-0.1	
1801006 M	57	1685	1685	1685	1710	1710	1685	1817	1785	1785	17	132	-142	300	4.3	11.1	
1801007 F	78	4062	3957	3995	3250	3007	3017	5357	5922	6174	352	-318	378	60	3.4	-4.2	-0.6
1801009 M	47	1340	1340	1340	1340	1340	1340	1507	1507	1507	1507	1507	1507	1507	1507	1507	1507
1801010 M	69	3527	3220	3192	3151	3772	3700	7442	6992	6892	-450	-100	550	6.0	1.4	7.3	
1801011 M	63	2712	2712	2712	2712	2712	2712	3012	3012	3012	3012	3012	3012	3012	3012	3012	3012
1802001 M	63	1125	2997	2985	2395	2717	2340	5520	5734	5735	-146	-49	-195	2.6	0.9	8.5	
1802002 M	78	1125	2997	2985	2395	2717	2340	5520	5734	5735	-146	-49	-195	2.6	0.9	8.5	
1802003 M	62	3532	3165	3360	3367	3365	3402	6899	6530	6762	-369	232	137	5.3	-5.5	-1.9	
1802004 M	63	1125	2997	2985	2395	2717	2340	5520	5734	5735	-146	-49	-195	2.6	0.9	8.5	
1802005 M	78	1125	2997	2985	2395	2717	2340	5520	5734	5735	-146	-49	-195	2.6	0.9	8.5	
1802007 M	75	3337	3050	3132	3272	3447	3420	7399	6497	6552	-542	55	-187	7.6	-0.8	6.9	
1802008 F	37	710	1075	1052	1027	800	1005	1917	1875	2027	-42	152	110	2.1	-8.1	5.7	
1802009 M	52	1252	2962	3005	3377	3510	3585	6199	6432	6670	324	238	501	-5.2	-3.7	-9.1	
1802011 F	59	2520	2505	2500	2230	2215	2232	4570	4607	4622	10	62	-72	-0.2	-1.3	-1.5	
1802012 M	57	1685	1685	1685	1710	1710	1685	1817	1785	1785	17	132	-142	300	4.3	11.1	
1802013 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802014 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802015 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802016 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802017 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802018 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802019 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802020 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802021 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802022 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802023 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802024 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802025 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802026 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802027 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802028 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802029 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802030 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802031 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802032 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802033 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802034 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802035 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802036 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802037 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802038 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802039 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802040 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802041 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802042 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802043 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802044 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802045 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802046 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802047 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802048 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802049 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802050 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802051 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802052 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802053 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802054 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802055 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802056 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802057 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802058 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802059 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802060 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802061 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802062 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802063 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802064 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802065 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802066 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802067 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802068 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802069 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802070 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802071 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802072 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
1802073 M	57	2467	2677	2677	2495	2532	2362	4917	5029	4923	112	97	15	-2.2	-1.0	-0.3	
18020																	

as -21% on the 192 people hearing loss table. What explanation can be given for this situation in which the hearing deteriorated by 21% over the two weeks, despite no prescription in the first two weeks of MTM clinical trials and no assignments were given to the subjects?

Based on a hearing loss index of 195 subjects in the MTM trial, excluding the 3 SOAEs, for a total of 192 subjects, there were 43 cases of worsening hearing change of 5% or more in the first 2 weeks without any prescription, as shown below. This is 22% of the total 192 subjects.

-112.1	1803026	M	34	-12.5	1807009	M	34
-56.4	1809016	M	63	-12.4	1808014	F	21
-48.3	1807007	F	36	-12.4	1810004	M	73
-43.9	1805030	M	39	-11.4	1807005	M	55
-43.2	1810006	F	38	-11.4	1817001	M	60
-32.2	1810002	M	52	-10.7	1804010	M	64
-30.9	1805016	F	64	-9.4	1804020	F	83
-27.1	1807017	F	58	-8.4	1804005	M	66
-26.2	1809018	F	59	-8.4	1809020	M	23
-26.1	1805019	M	62	-8.0	1803028	M	54
-26.0	1813019	F	47	-8.0	1805022	F	55
-22.5	1813021	F	65	-8.0	1815015	F	71
-22.4	1812009	M	25	-7.5	1804002	F	62
-21.0	1803011	M	45	-6.9	1807002	M	62
-20.7	1803020	M	58	-6.7	1804012	F	62
-18.2	1804018	F	61	-6.6	1803035	M	63
-18.1	1809012	F	63	-6.5	1804017	F	70
-17.6	1812014	F	71	-6.3	1806002	M	57
-17.0	1815012	F	74	-6.2	1804011	F	60
-16.9	1811002	F	70	-5.4	1812002	M	47
-16.5	1805021	M	15	-5.2	1801002	M	52
-13.6	1811004	F	40				

The above distribution of "worsening hearing within two weeks" may also be somewhat applicable to the overall sample of people with tinnitus, which is about 30% of the global population. This means that at least 20% of people with tinnitus can experience hearing deterioration at any time, even over a period as short as two weeks. It is not yet clear whether this deterioration is persistent or temporary. Many factors are involved in the formation, development, and degeneration of hearing in vivo, but most systematic studies have been conducted at the animal model level. Although many factors in the human body are involved in the formation, development, and degeneration of human hearing as an active auditory system, it is very difficult to quantitatively study the role of each factor in human hearing. One of the reasons for this is limitations of conventional audiometry in humans. Traditional audiometry still relies on manual manipulation by the audiologist, so quantitative studies of microscopic hearing changes would be prohibitively expensive and time-consuming. Not only is it difficult to observe subtle hearing changes with a low-resolution manual audiometer of 6-11 bands, but it is also

impossible to calculate a 67-band-based hearing loss index for the concept of 'gross hearing'. To overcome the limitations of manual audiometry and audiologist judgment, there have been some attempts to use otoacoustic emissions and auditory brainstem response to provide objective results on microscopic hearing changes. However, otoacoustic emissions are a function of the cochlear. Neither otoacoustic nor auditory brainstem response are appropriate tools for high-resolution fine hearing research because of the limitations of providing cell-specific information, the 15-20 dB minimum rate inherent in otoacoustic brainstem response testing, and the severe limitations in frequency resolution. There are no studies that discuss high-resolution hearing results that have been approached from the 67-band specification. The establishment of the concept of a hearing loss index derived from the 67-band RCPTA algorithm was only possible because of valid results from the MTM trial.

In an MTM clinical, information about a subject's hearing change during the first two weeks of the study without any medical prescription can help determine whether the subject's hearing is currently progressive or not. If a patient's hearing has deteriorated by 21% during the two-week period before the healthcare provider prescribes anything, as in subject 1803011, the healthcare provider is obligated to inform the patient. Furthermore, to determine whether the deterioration in hearing over the past two weeks is a temporary phenomenon or an ongoing phenomenon that may actually warn of rapidly progressive hearing loss, a prospective comparative analysis of the patient's hearing over a period of time with several more micro-audiometry should be performed.

Subject 1803011 had the opposite hearing change. Instead of hearing deterioration in the first two weeks, this is a case of hearing improvement. Consider the case of subject 1810017, a 41-year-old female, whose hearing had already improved in two weeks, even though she was still in the pre-medical prescription phase of the MTM clinical. Subject 1810017 had a left hearing loss index of 792 and a right hearing loss index of 687 on the first micro-audiometry. The second audiogram showed a hearing loss index of 772 and 332 on the left and right, respectively. There is a notable difference between the hearing loss index obtained in the first test and the hearing loss index in the second test conducted two weeks after that.

1810017	F	41	792	772	677	687	332	362	1479	1104	1039
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The sum of the first left and right hearing loss indices is 1479, and the sum of the second left and right hearing loss indices is

1104. The difference in the hearing loss index between the two is 375, which means that the 'gross hearing' of subject 1810017 improved by 375 in the first two weeks after the first test, when no prescription was given. The smaller the hearing loss index number, the better the hearing. 1810017 Based on the subject's first hearing loss index of 1479, the hearing improvement of 375 is

25.3	5.8	29.7
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 indicated as 25.3% on the 192-person hearing loss index table. How can we explain this situation where MTM clinical trials showed no prescription for the first 2 weeks, and the subject was not given any task for 2 weeks, but improved hearing by 25.3%?

Based on a total of 192 cases of hearing loss index excluding SOAE 3 from 195 MTM clinical subjects, a total of 69 patients actually improved their hearing to a level of 5% or more even though there was no prescription in the first 2 weeks. 69 patients accounted for 36% of the total 192.

52.8	1813020	F	21	8.3	1803001	M	54
49.3	1807008	M	36	8.3	1803015	M	50
47.8	1810016	F	42	8.1	1803033	M	44
47.6	1802009	F	27	8.1	1810001	F	37
47.5	1810011	F	54	8.1	1813010	F	50
47.5	1811010	F	13	8.1	1815005	F	70
35.7	1801009	F	38	7.9	1813016	F	64
35.0	1815009	F	44	7.8	1810024	M	66
34.3	1810012	F	57	7.7	1812011	M	59
32.1	1808006	F	46	7.6	1802007	M	75
31.8	1813009	F	48	7.5	1815007	M	47
25.8	1802004	M	59	7.4	1812001	F	41
25.3	1810017	F	41	7.3	1803032	F	65
24.4	1811003	F	53	7.1	1809002	F	49
17.1	1810022	F	53	7.0	1809013	F	71
16.0	1802002	M	34	7.0	1810018	M	50
15.5	1806001	M	46	6.8	1805014	M	76
15.4	1805015	M	34	6.5	1805029	M	58
14.2	1803014	M	48	6.4	1801011	M	59
14.2	1809005	F	68	6.4	1805001	F	48
13.1	1809009	F	39	6.2	1810021	M	55
13.1	1812003	F	60	6.1	1810009	M	29
12.7	1810010	F	48	6.1	1811005	M	49
12.7	1817004	M	50	6.0	1801010	M	69
11.9	1805028	F	45	6.0	1807019	M	63
11.4	1805031	M	59	5.9	1803030	M	40
10.9	1805008	M	60	5.7	1813004	F	60
10.3	1809010	F	58	5.7	1815011	M	76
9.8	1801001	M	45	5.6	1803023	F	70
9.6	1805011	M	51	5.4	1803010	F	49
9.5	1807003	F	72	5.4	1803021	M	46
9.4	1815006	M	53	5.3	1802003	M	82
8.7	1815014	F	48	5.1	1805025	F	58
8.6	1810008	F	58	5.1	1805027	M	45
8.5	1807016	M	71				

The 69 people whose hearing had already improved in the first two weeks, as shown above. Is it fair to extrapolate these percentages to the entire global sample of tinnitus sufferers, as we did with the worsening phenomenon? Before we can say that "approximately 35% or more of the world's tinnitus sufferers

can change their hearing for the better in as little as two weeks without any prescription," but there is a caveat. What is the systematic explanation, if any, for the fact that 43 (22%) of the 192 subjects in the MTM trial had already worsened their hearing in the first two weeks and 69 (35%) had improved their hearing in the first two weeks without any prescription, and what is the plausible cause or reason for this phenomenon?

Let's start with the following premises

- ① People with tinnitus have unstable hearing.
- ② About 20% of people with tinnitus have gotten worse.
- ③ About 35% of people with tinnitus have gotten better.

The three premises above are all statements based on the results of MTM clinical trials. Can all three statements be true? While the MTM clinical results from 192 patients have undergone rigorous statistical validation, the three premises based on these results are not convincing.

First of all, the sentences below, which are based on MTM clinical findings, are understandable because they reflect what actually happened in the clinic.

Subjects with tinnitus in MTM clinical trials had very unstable hearing. Due to this hearing instability (①), approximately 20% of subjects' hearing deteriorated during the two-week no-treatment period, and approximately 35% (②) of subjects' hearing improved within two weeks.

Extrapolating the above statistical facts to the entire population of people with tinnitus, the following statement be made.

The hearing of people with tinnitus is highly unstable. Because of this hearing instability (①), about 20% of the tinnitus population (②) will experience hearing deterioration in two weeks, and about 35% of the tinnitus population (③) will experience hearing improvement in two weeks.

Even if we consider a two-week hearing fluctuation due to hearing instability to be a transient phenomenon, when we extrapolate the hearing change rates over the untreated period from the MTM clinical results to the entire tinnitus population, we can make the following statement, which is truly unacceptable.

People with tinnitus have very unstable hearing, and because of this hearing instability, there are about 1.75 times as many people with whose hearing will improve within two weeks (35/20) as there are people with whose hearing will worsen within two weeks.

Can we accept the logic of the above sentence? If this logic were true, it would mean that tinnitus sufferers' hearing would improve day by day without any prescription. This has never happened, nor can it happen. While the MTM clinical results themselves are acceptable as a phenomenological outcome of an event that has already occurred, why is it that we are reluctant to generalize these rates of hearing change in the off-treatment period to the entire tinnitus population?

It is important to note that both the "hearing worsening within 2 weeks" and "hearing improvement within 2 weeks" events in the off-label phase occurred after the subject's voluntary in-person visit to the clinic location where the trial was conducted. Given the fact that subjects in the walk-in MTM 4-week study had already completed the first micro-audiometry and the first tinnitus questionnaire, it is tempting to wonder whether the initiation of this unique experience in a clinical setting had any positive or negative impact on their hearing over the next two weeks. A more detailed discussion on this will be covered in Chapter 11 reinterpretation of MTM results. The total number of subjects in the MTM study who had a hearing change within +/- 5% during the first two weeks of the no-treatment period was 80. Of the 192 subjects, 42% had stable hearing with no significant change in the first two weeks.

MTM Effects

Hearing is fluid by nature. The hearing of people with tinnitus can be more unstable and fluctuate more than the hearing of a normal person. The MTM effect is a new concept derived from statistical tests that attempt to account for the change in hearing loss index during periods when TSCs are not prescribed. Although no specific studies have yet been conducted on how the act of micro-audiometry and tinnitus questionnaire survey itself affects the hearing change rates, the meaning of the MTM effect is different from that of the TSC effect in that it requires a comprehensive analysis of what may have happened to hearing from the time the subject encounters the MTM trial.

Difference Between Primary and Secondary Results

We've already seen examples of the percentage change in hearing for some of the subjects in the 42 worsening cases and 69 improving cases from the no-treatment period. It's easy to analyze and interpret the data in terms of who's hearing changed and who's hearing didn't change. However, statistical tests should be performed to determine if there is a significant pattern in the hearing change rates across all subjects. To determine what the hearing change rates for all 192 subjects during the two-week no-treatment period, and whether the overall hearing change rates is generalizable to the statement "there was a significant hearing difference between the primary and secondary hearing loss indices," a statistical test should be performed to determine the statistical significance of the difference between the means of the hearing loss indices. The total sum of the 192 primary hearing loss indexes was 843,533 and the mean of the 192 primary hearing loss indexes was 4,393. The total sum of the 192 secondary hearing loss indices was 832,523 and the mean of the 192 secondary hearing loss indices was 4,336. Using the STATISTICA algorithm to perform a t-test statistical test on the primary result, there was no statistically significant difference between the mean primary hearing loss index of 4,393 and the mean secondary hearing loss index of 4,336 ($P=0.2451$).





Due to excessive white noise listening during tinnitus treatment.
What I like about it is that my tinnitus is gone, even though my hearing is actually worse, you're not looking at the "dead cow," you're looking at the "right horn."

Difference Between Secondary and Tertiary Results

TSC prescriptions were given and taken during the two-week period between the second and third micro-audiometry. After completing the second micro-audiometry, subjects were asked to perform two at-home listening tasks of approximately 30 minutes per day for two weeks at from that date. The TSC listening behavior was not intervened at Time 1, but was intervened at Time 2 and Time 3. There was no significant difference between the mean hearing loss scores of the first 192 participants at baseline ($P=0.2451$), but there was a significant difference between the mean hearing loss scores of the second and third participants at baseline ($P=0.2451$). There a significant difference between the mean values of the hearing loss indices? The total sum of the 192 secondary hearing loss indexes was 832,523 and the mean of the 192 secondary hearing loss indexes was 4,336. The total sum of the 192 Tertiary Hearing Loss Indexes for the 192 subjects with TSC listening intervention was 800,483 and the mean of the 192 Tertiary Hearing Loss Indexes was 4,169. Using the STATISTICA algorithm to perform a t-test statistical test on the secondary and tertiary results, there was a statistically significant difference between the mean secondary hearing loss index of 4,336 and the mean tertiary hearing loss index of 4,169 ($P=0.0007$). There was no change in the hearing loss scores of the 192 participants during the first half of the intervention period without the TSC listening behavior, but a statistically significant improvement in the hearing loss scores of the 192 participants during the secondary and tertiary periods of the intervention with TSC ($P=0.0007$). We refer to this as the 'TSC effect'.

Difference Between Primary and Tertiary Results

How the beginning and end of the four-week MTM clinical experience affect the subjects' 'gross hearing', or hearing loss

index, and was the effect positive or negative? If there is a statistically significant difference between the primary and secondary hearing loss indices in the full sample of 192 MTM clinical subjects, then the conclusions based on that can be generalized. The total sum of all 192 primary hearing loss indices was 843,533 and the mean primary hearing loss index of the 192 subjects was 4,393. The sum of the final tertiary hearing loss values for the 192 participants who completed the 4-week MTM trial was 800,483, and the average tertiary hearing loss value for the 192 participants was 4,169. Using the STATISTICA algorithm to perform a t-test statistical test on the primary and secondary results, there was a statistically significant difference between the primary mean of 4,393 and the secondary mean of 4,169 ($P=0.0003$). After four weeks of MTM, including two weeks of TSC, there was a statistically significant improvement in the hearing loss index, which is the sum of all 67 full-frequency point hearing thresholds in the 250-12,000 Hz band, or "gross hearing". This is called the 'MTM effect'. Traditional otologists still view hearing as a pseudo-homeostatic biological phenomenon, and claims such as 'hearing loss is irreversible' or 'once damaged hearing is irreversible' because it is believed that 'damaged hearing' will necessarily be governed by 'homeostasis'. Traditional audiology does not believe in homeostasis, as it is based on the premise that hearing is inherently prone to ageing and deterioration. However, it is unwilling to recognize the "homeostasis" or "irreversibility" of "impaired hearing" when it comes to new technological endeavors or experimental findings that have "enabled fundamental changes and improvements in hearing using modulated acoustic signals.

Statistical Analysis of 1/2/3rd Order Hearing Loss Index Differences

T-test for Dependent Samples (Spreadsheet!)										
Marked differences are significant at $p < .05000$										
Variable	Mean	Std. Dev.	N	Diff.	Std. Dev. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	4393.401	2038.860	192	0.000	0.00000	0.00000	191	1.0000000	0.000	0.000
Var1	4393.401	2038.860	192	0.000	0.00000	0.00000	191	1.0000000	0.000	0.000
Var2	4393.057	2114.030	192	-57.344	681.5201	-1.16589	191	0.245112	-154.358	39.671
Var1	4393.401	2038.860	192	224.219	845.5221	3.67449	191	0.000309	-344.579	-103.859
Var3	4169.182	2139.225	192	-224.219	845.5221	-3.67449	191	0.000309	-344.579	-103.859
Var2	4393.057	2114.030	192	-57.344	681.5201	-1.16589	191	0.245112	-154.358	39.671
Var1	4393.401	2038.860	192	0.000	0.00000	0.00000	191	1.0000000	0.000	0.000
Var2	4393.057	2114.030	192	0.000	0.00000	0.00000	191	1.0000000	0.000	0.000
Var3	4169.182	2139.225	192	-224.219	845.5221	-3.67449	191	0.000309	-344.579	-103.859
Var1	4393.401	2038.860	192	-166.875	674.0815	-3.43028	191	0.000739	-262.831	-70.919
Var2	4393.057	2114.030	192	-166.875	674.0815	-3.43028	191	0.000739	-262.831	-70.919
Var3	4169.182	2139.225	192	0.000	0.00000	0.00000	191	1.0000000	0.000	0.000

Maximum Impact in the Diagnosis and Treatment of Tinnitus in the Shortest Time Possible

MTM does not attempt to conduct complex surveys or lengthy consultations with tinnitus patients. The reason for this is to achieve a quicker, accurate, non-subjective diagnosis and treatment

ent plan. In conventional tinnitus diagnosis and treatment, in addition to a lengthy questionnaire about tinnitus, a subjective frequency matching test is taken to determine the frequency of tinnitus, and a minimum masking level test to determine the intensity of tinnitus, are performed. The minimum masking level test is often referred to as the MML test. Patients are also encouraged to listen to the prescribed sound signal for at least four to five hours per day for at least six months and up to two years. Traditional methods of diagnosing and treating tinnitus can lead to unpredictable hearing changes that are beyond the control of healthcare providers. For example, white noise, which is often used in MML testing and tinnitus treatment, can cause an increase in hearing thresholds and microscopic damage to hearing if the tinnitus masking is used consistently for long periods of time. Traditional tinnitus testing cannot track the intensity of each of the various tinnitus component sounds in complex tinnitus. The MML test tracks the current intensity of the tinnitus with white noise or narrowband noise, which does not allow for "multiple intensity tracking," which is important in complex tinnitus. Frequency Matching tests also make it difficult to track the different tinnitus component sounds in complex tinnitus using traditional methods.

In the conventional tinnitus diagnosis and treatment method, the improvement of tinnitus symptoms is evaluated in the questionnaire survey stage before and after tinnitus treatment with a score evaluation index for each question, but the tinnitus questionnaire score evaluated is done without checking the threshold elevation, or hearing loss, before and after tinnitus treatment is ethically problematic. Traditional tinnitus treatments are primarily concerned with the subjective change in the patient's symptoms before and after treatment. Basic low-resolution audiometry at the 6-11 band level is performed, but it does not look for micro-hearing changes at each frequency. As a result, it is not uncommon to miss a situation in which the tinnitus is ostensibly relieved, but actual hearing thresholds have deteriorated. To like that tinnitus was alleviated even though hearing deteriorated due to excessive white noise during the tinnitus treatment process, it is like throwing the baby out with the bathwater. Even if the tinnitus in a particular frequency band is relieved, if the hearing in that frequency band deteriorates during the course of tinnitus treatment, new tinnitus in another frequency band will occur sooner or later due to the reorganization of the cerebral auditory neural network. Conventional tinnitus treatment does not pay attention to what exactly is happening to the threshold fine-structure of the subject's hearing during the course of tinnitus treatment, which

takes at least six months and up to two years. In contrast to these traditional tinnitus treatments, MTM rarely performs subjective matching tests and MML tests for tinnitus tracking. They are sometimes performed for patients with simple tinnitus. Traditional tinnitus diagnostic methods do not provide accurate results for complex tinnitus, which is the most common type of tinnitus in the population. The traditional frequency matching test and MML test are replaced by the RCPTA algorithm test in the MTM protocol. The RCPTA algorithm output shows the frequency position of each component tinnitus in the complex tinnitus, as well as the tinnitus intensity value.

In traditional tinnitus testing, tinnitus questionnaires are often long, and complex. Tinnitus patients need to pay close attention to read and understand the questionnaire, and it takes a long time to complete all the questions in a sincere and accurate manner. At MTM, we have limited the tinnitus questionnaire to three essential questions. All three questions are about tinnitus intensity and frequency of tinnitus. Because the ultimate goal of MTM is to reduce the intensity and frequency of tinnitus in the shortest possible time without risk of threshold elevation, and to free the patient's consciousness from tinnitus, we avoid asking about other general health issues and complex questions about tinnitus. Another way in which MTM's approach to tinnitus diagnosis and treatment differs significantly from traditional tinnitus diagnosis and treatment is that we limit the duration of listening to modulated sound signals to a minimum of two weeks and a maximum of three months. This is because the protection of fine hearing is as important as the treatment of tinnitus. If you want to repeat a cycle of MTM treatment for a minimum of two weeks and a maximum of 12 weeks, it is recommended that you take a break of at least two to four weeks in between.

The method introduced by MTM instead of the existing subjective frequency matching test and MML test for tracking the tinnitus frequency and tinnitus intensity is the 67-band resolution microaudiometry test using the RCPTA algorithm. RCPTA can be defined as a Random Control Pure Tone Audiometer. RCPTAs are discussed in more detail in Chapter 14.

The effectiveness of MTM is further demonstrated by maximizing time efficiency in diagnosing and treating tinnitus. MTM avoids prolonged treatment and focuses on achieving maximum effectiveness in the shortest possible time. For MTM to be effective, three interventions are essential: a three-question questionnaire, a 67-band RCPTA-based (micro-

audiometry), and REVE134 treatment based on the TSC principle.

- Survey - 3 questions
- Inspection - 67-Band RCPTA
- Treatment - REVE134 by TSC principle

4:4:2 Phenomenon (Based on 4 Weeks of MTM)

"4:4:2" is the most concise mathematical representation of the MTM effect. The 4:4:2 phenomenon is an interesting phenomenon that was observed while performing various analyses and statistical tests on the hearing loss index and tinnitus score results of the 195 subjects in the 4-week MTM trial. The first number 4 is the percentage of subjects who experienced a decrease in the intensity of their tinnitus symptoms or a decrease in the frequency of tinnitus episodes. The middle 4 is the percentage of subjects with no change in tinnitus. The last number, 2, is the percentage of subjects whose tinnitus symptoms worsened. The 4:4:2 MTM effect is the result of subjects experiencing just two weeks of TSC while participating in a four-week MTM trial. The 2018 MTM trial, which observed a 4:4:2 pattern in 195 subjects, was the first study to prospectively monitor changes in micro-audiometric thresholds during the course of tinnitus treatment using high-resolution micro-audiometry using the RCPTA algorithm, repeated three times at two-week intervals.

Let's take a closer look at each group in 4:4:2, with the first four digits being A, the middle four digits being called B, and the last two digits being called C.

Group A: Group with improved tinnitus symptoms

Group B: No change in tinnitus symptoms

Group C: Those with more severe tinnitus

In addition to quantitative audiometry using the RCPTA algorithm, a qualitative questionnaire about tinnitus was administered to determine the intensity and frequency of tinnitus on the first day of the MTM trial and the intensity and frequency of tinnitus on the last day of the MTM trial. Three questions in the questionnaire were to direct the subject's attention to the actual sensory aspects of the tinnitus they were experiencing in their daily life. As subjects read through the questionnaire, they marked either o or √ on the view number that best represented their most recent tinnitus condition. On the first day of MTM clinical participation, the mean tinnitus score of 195 subjects was 5.45. On the day of completion of the

clinical trial, the mean tinnitus score of 195 subjects was 5.98. According to the MTM tinnitus questionnaire allocation criteria, the tinnitus score was calculated as 3 points for the most severe tinnitus and 15 points for the condition without tinnitus at all. There was a statistically significant difference between the mean tinnitus score of 195 patients at the clinical start date of 5.45 and the mean tinnitus score of 195 patients at the clinical end date of 5.98 ($P=0.0003$). Based on these results, if the MTM 4-week protocol is implemented normally under the supervision of a medical practitioner, overall relief of tinnitus symptoms is expected. Of course, there may be individual differences in the changed symptoms. It is also possible to expect and expect better improvement in tinnitus symptoms when applying the 8-week or 12-week protocol instead of MTM 4-week. And that expectation should be able to withstand not only dramatic improvement cases for tinnitus symptoms in individual tinnitus patients, but also some cases of symptom worsening that may be present. The specific cause and background of the cases of deepening tinnitus symptoms falling under 4:4:2 are covered in detail in Chapter 13 of the Gaussian effect of tinnitus.

Group A

What happened to Group A's hearing after their tinnitus symptoms improved? A sober assessment of the patient's hearing before and after tinnitus treatment is one of the difficulties of conventional tinnitus treatment. In the process of tinnitus treatment, it is very common for the threshold of hearing to rise (hearing loss). The reason why tinnitus treatment is insisted on despite the increase in threshold is because the purpose of conventional tinnitus treatment is to relieve tinnitus symptoms regardless of the change in hearing. A statistical test was performed on the hearing changes in Group A, which showed improvement in tinnitus symptoms in the MTM clinical trial. During the 4-week MTM period, the number of subjects who experienced a decrease in the intensity or frequency of tinnitus after 2 weeks of TSC was 77, which is 39.5% of the total 195 subjects. The mean hearing loss index of 77 people in Group A was 3,823 at Day 1 (primary) test result, 3,669 at Week 2 (secondary) test result, and 3,604 at Week 4 (tertiary) test result. The secondary and tertiary comparison result reflects the TSC effect, and the primary and tertiary comparison result reflects the MTM effect. There was no statistically significant difference in the mean between the secondary and tertiary results ($P=0.2524$). However, there was a statistically significant difference ($P=0.0440$) when comparing the means of the primary and tertiary hearing loss indices over the entire 4-week MTM period, including the 2 weeks of TSC. Based on these results, it

can be concluded that Group A patients who improved their tinnitus symptoms after 4 weeks of MTM did not improve their hearing in just 2 weeks, but there was significant hearing improvement within 4 weeks. The mean tinnitus scores of these 77 patients were 5.66 and 7.95 in the first and second order, respectively.

Group A: Statistical test results for audiologic changes in 77/195 (39.5%) subjects who experienced a decrease in tinnitus intensity or frequency after 2 weeks of TSC.

Variable	Mean	Std. Dev.	N	Diff.	Std. Dev. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var2	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var3	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var4	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var5	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var6	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var7	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var8	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var9	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var10	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var11	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var12	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var13	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var14	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var15	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var16	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var17	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var18	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var19	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var20	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var21	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var22	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var23	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var24	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var25	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var26	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var27	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var28	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var29	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var30	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var31	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var32	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var33	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var34	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var35	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var36	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var37	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var38	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var39	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var40	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var41	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var42	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var43	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var44	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var45	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var46	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var47	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var48	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var49	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var50	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var51	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var52	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var53	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var54	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var55	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var56	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var57	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var58	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var59	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var60	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var61	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var62	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var63	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var64	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var65	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var66	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var67	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var68	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var69	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var70	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var71	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var72	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var73	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var74	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var75	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var76	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000
Var77	3823.104	2114.179	77	0.000	0.0000	0.00000	76	1.00000	0.000	0.00000

Group B

What about the hearing of Group B who had no change in tinnitus symptoms? We performed a statistical test on the hearing loss index of the group B patients who had no change in tinnitus symptoms during the MTM clinical trial. 76 subjects, 39% of the 195 subjects, had no change in tinnitus intensity or frequency of tinnitus after 2 weeks of TSC during the 4 weeks of MTM, but there was a significant change in their hearing. The mean hearing loss index of 76 people in Group B was 4,636 at Day 1 (primary) test result, 4,677 at Week 2 (secondary) test result, and 4,371 at Week 4 (tertiary) test result. The secondary and tertiary comparison result reflects the TSC effect, and the primary and tertiary comparison result reflects the MTM effect. Comparison of the mean of the hearing loss index for only the secondary and tertiary period of group B, i.e., the 2-week period of TSC, showed a statistically significant difference ($P=0.0012$). There was also a statistically significant difference when comparing the mean of the primary and tertiary hearing loss index for the entire 4-week MTM period including the 2-week TSC ($P=0.0084$). Based on these results, it can be concluded that for Group B, who had no change in tinnitus symptoms after 4 weeks of MTM, there was both a significant hearing improvement from the 2-week TSC and a significant hearing improvement from participation in 4 weeks of MTM. The mean tinnitus score for the 76 participants in Group B was 4.38 at both Time 1 and Time 2.

Group B: Statistical tests of audiometric changes in 76/195 subjects (39.0%) who had no change in tinnitus intensity and frequency of tinnitus occurrence after 2 weeks TSC

T-test for Dependent Samples (Spreadsheet1)										
Marked differences are significant at p < .05000										
Variable	Mean	Std.Dev.	N	Diff.	Std.Dev. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	4636.895	1810.387								
	4636.895	1810.387	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var2	4636.895	1810.387								
	4637.334	1905.576	76	-41.039	642.3792	-0.55695	75	0.579219	-105.259	187.829
Var3	4636.895	1810.387								
	4371.323	1905.204	76	265.566	855.6031	2.70587	75	0.008429	-461.079	-70.052
Var4	4636.895	1810.387								
	4637.334	1905.576	76	-41.039	642.3792	-0.55695	75	0.579219	-105.259	187.829
Var5	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var6	4636.895	1810.387								
	4637.334	1905.576	76	-41.039	642.3792	-0.55695	75	0.579219	-105.259	187.829
Var7	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var8	4636.895	1810.387								
	4371.323	1905.204	76	306.605	793.9234	3.36673	75	0.001202	-488.025	-125.186
Var9	4636.895	1810.387								
	4371.323	1905.204	76	306.605	793.9234	3.36673	75	0.001202	-488.025	-125.186
Var10	4636.895	1810.387								
	4637.334	1905.576	76	-265.566	855.6031	-2.70587	75	0.008429	-461.079	-70.052
Var11	4636.895	1810.387								
	4371.323	1905.204	76	306.605	793.9234	3.36673	75	0.001202	-488.025	-125.186
Var12	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var13	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var14	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var15	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var16	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var17	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var18	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var19	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var20	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var21	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var22	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var23	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var24	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var25	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var26	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var27	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var28	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var29	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var30	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var31	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var32	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var33	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var34	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var35	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var36	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var37	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var38	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var39	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var40	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var41	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var42	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var43	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var44	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var45	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var46	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var47	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var48	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var49	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var50	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var51	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var52	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var53	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var54	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var55	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var56	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var57	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var58	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var59	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var60	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var61	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var62	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var63	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var64	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var65	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.000
Var66	4636.895	1810.387								
	4637.334	1905.576	76	0.000	0.00000	0.00000	75	1.000000	0.000	0

T-test for Dependent Samples (Spreadsheet)										
Marked differences are significant at p < .05000										
Variable	Mean	Std. Dev.	N	Diff.	Std. Dev. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	4725.929	2305.630								
Var1	4725.929	2305.630	42	0.000	0.00000	0.00000	41	1.000000	0.000	0.0000
Var1	4725.929	2305.630								
Var2	4656.500	2501.264	42	39.429	529.3234	0.48274	41	0.631847	-204.377	125.5202
Var2	4725.929	2305.630								
Var3	4622.214	2347.576	42	103.714	631.3010	1.06470	41	0.293243	-300.442	93.0130
Var2	4656.500	2501.264								
Var2	4725.929	2305.630	42	-39.429	529.3234	-0.48274	41	0.631847	-204.377	125.5202
Var2	4656.500	2501.264								
Var3	4622.214	2347.576	42	0.000	0.00000	0.00000	41	1.000000	0.000	0.0000
Var3	4656.500	2501.264								
Var3	4622.214	2347.576	42	64.286	684.7705	0.60841	41	0.546274	-277.675	149.1038
Var3	4656.500	2501.264								
Var3	4622.214	2347.576	42	-103.714	631.3010	-1.06470	41	0.293243	-300.442	93.0130
Var3	4656.500	2501.264								
Var3	4622.214	2347.576	42	-64.286	684.7705	-0.60841	41	0.546274	-277.675	149.1038
Var3	4656.500	2501.264								
Var3	4622.214	2347.576	42	0.000	0.00000	0.00000	41	1.000000	0.000	0.0000

TSC Effects

A clinical trial study of TSC, conducted in collaboration with Stanford University School of Medicine and the Palo Alto Medical Foundation, has changed conventional medical knowledge about hearing. The results were presented by Stanford faculty at the American Academy of Neurology in April 2015, and an abstract published in the online edition of *Neurology* 2015 with the following title.

RANDOMIZED CONTROLLED TRIAL EVALUATING
THRESHOLD SOUND CONDITIONING IN THE TREATMENT OF
SENSORINEURAL HEARING LOSS

Abstract presented at Neurology 2015

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101011 April 06, 2015; 94(14 Supplement) APRIL 22, 2015

Randomized Controlled Trial Evaluating Threshold Sound Conditioning in the treatment of Sensorineural Hearing Loss (\$26,006)

SungHo Cho, Eunye Kwak, Sangseop Kwak, Jaime Lopez

First published April 6, 2015.

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Abstract

OBJECTIVE: To evaluate safety and efficacy of threshold sound conditioning (TSC) as possible treatment for sensorineural hearing loss. **BACKGROUND:** Sensorineural hearing loss, an irreversible phenomenon, is one of the most common human disorders, with increasing incidence in elderly patients, severely restricting normal activities and lowering quality of life. However, there are data for central neuronal plasticity and potential for recovery. The introduction of sound conditioning has the potential to activate auditory pathway plasticity and improve basal frequency hearing as measured by pure tone audiometry (PTA). **DESIGN/METHODS:** Double-blind, randomized, placebo-controlled trial of 42 subjects. Data were analyzed using an intention-to-treat design. PTA was performed and hearing thresholds were measured at 8~9 frequencies (0.25, 0.5, 1, 2, 3, 4, 6, 8, and 12 kHz) in both ears of each subject, once at baseline, and a second time following TSC intervention. Subjects used a TSC conditioning-enhanced hearing aid 1 hour per day at the hearing threshold level, for 2~3 weeks. **RESULTS:** Seventy-eight percent of the TSC group showed a significant difference from 44% in the control group on auditory threshold amelioration; $p=0.008091$ using ameliorated or mixed change as the dependent variable, and $p=0.000546$ using ameliorated and mixed combined as a dependent variable by Scheffe's post hoc test. 77% of female subjects showed a significant difference in dependent variables from the 47% of the male subjects; $p=0.025468$. 75% of older subjects showed no significant difference from 53% of the younger subjects; $p=0.139149$. **CONCLUSIONS:** TSC outputs an algorithmic acoustic signal with a preset intensity to the frequency band of the damaged hair cell. Previously published human data, and this prospective clinical study demonstrate a statistically significant improvement in a narrow band frequency threshold. These data have important clinical implications as a potential long term therapy for this widespread and growing disability.

Disclosures: Dr. Cho has nothing to disclose. Dr. Kwak has nothing to disclose. Dr. Kwak has nothing to disclose. Dr. Lopez has received research support from Earlogic/The Good Ear Company.

Wednesday, April 22 2015, 2:00 pm-3:45 pm

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TSC Review Board Approval Letter from Stanford University
Institutional Review Board

STANFORD UNIVERSITY
Stanford, CA 94305 [Mail Code 5579]

Darrell M Wilson, M.D. (650) 724-8943
CHAIR, PANEL ON MEDICAL HUMAN SUBJECTS

Certification of Human Subjects Approvals

Date: October 16, 2012
To: Jaime R. Lopez, MD, Neurology
Ms Edylen Anit Gulpo, S. Charles Cho MD, Shirley Paulose MD
From: Darrell M Wilson, M.D., Administrative Panel on Human Subjects in Medical Research

Protocol Safety and Efficacy Evaluation of Threshold Sound Conditioning by Conditioning-enhanced Hearing Aid
Protocol ID: 22475 **IRB Number:** 4593 (Panel: 5)

The IRB approved human subjects involvement in your research project on 10/16/2012. **"Prior to subject recruitment and enrollment, if this is: a Cancer-related study, you must obtain Cancer Center Scientific Review Committee (SRC) approval; a GCRG study, you must obtain GCRG approval; a VA study, you must obtain VA R and D Committee approval; and if a contract is involved, it must be signed."**

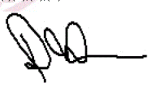
The expiration date of this approval is 10/16/2013 at Midnight. If this project is to continue beyond that date, you must submit an updated protocol in advance for the IRB's re-approval. If this protocol is used in conjunction with any other human use it must be re-approved. Proposed changes to approved research must be reviewed and approved prospectively by the IRB. No changes may be initiated without prior approval by the IRB, except where necessary to eliminate apparent immediate hazards to subjects. (Any such exceptions must be reported to the IRB within 10 working days.) Unanticipated problems involving risks to participants or others and other events or information, as defined and listed in the Report Form, must be submitted promptly to the IRB. (See Events and Information that Require Prompt Reporting to the IRB at <http://humansubjects.stanford.edu>.)

All continuing projects and activities must be reviewed and re-approved on or before Midnight of the expiration date. The approval period will be less than one year if so determined by the IRB. It is your responsibility to resubmit the project to the IRB for continuing review and to report the completion of the protocol to the IRB within 30 days.

Please remember that all data, including all signed consent form documents, must be retained for a minimum of three years past the completion of this research. Additional requirements may be imposed by your funding agency, your department, or other entities. (See Policy on Retention of and Access to Research Data at <http://stanford.edu/dept/DoR/rph/2-10.html>.)

This institution is in compliance with requirements for protection of human subjects, including 45 CFR 46, 21 CFR 50 and 56, and 38 CFR 16.

Waiver of Individual Authorization for recruitment under 45 CFR 164.512(i)(2)(iii)(A), (B), (C)


Darrell M Wilson, M.D., Chair

Approval Period: 10/16/2012 THROUGH 10/16/2013
Review Type: EXPEDITED - CONTINUING REVIEW
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Expedited Under Category: 1
Assurance Number: FWA00000935 (SU), FWA00000934 (SHC)

Abstract of TSC Clinical Study Results from Stanford
University School of Medicine

Randomized Controlled Trial Evaluating Threshold Sound
Conditioning in the treatment of Sensorineural Hearing
Loss

OBJECTIVE: To evaluate safety and efficacy of threshold sound conditioning (TSC) as possible treatment for sensorineural hearing loss.

BACKGROUND: Sensorineural hearing loss, an irreversible phenomenon, is one of the most common human disorders, with increasing incidence in elderly patients, severely restricting normal activities and lowering quality of life. However, there are data for central neuronal plasticity and potential for recovery. The introduction of sound conditioning has the potential to activate auditory pathway plasticity and improve basal frequency hearing as measured by pure tone audiometry (PTA).

DESIGN/METHODS: Double-blind, randomized, placebo-controlled trial of 42 subjects. Data were analyzed using an intention-to-treat design. PTA was performed and hearing thresholds were measured at 8~9 frequencies (0.25, 0.5, 1, 2, 3, 4, 6, 8, and 12 kHz) in both ears of each subject, once at baseline, and a second time following TSC intervention. Subjects used a TSC conditioning-enhanced hearing aid 1 hour per day at the hearing threshold level, for 2~3 weeks. **RESULTS:** Seventy-eight percent of the TSC group showed a significant difference from 44% in the control group on auditory threshold amelioration; $p=0.008091$ using ameliorated or mixed change as the dependent variable; and $p=0.000546$ using ameliorated and mixed combined as a dependent variable by Scheffe's post hoc test. 77% of female subjects showed a significant difference in dependent variables from the 47% of the male subjects; $p=0.025468$. 75% of older subjects showed no significant difference from 53% of the younger subjects; $p=0.139149$. **CONCLUSIONS:** TSC outputs an algorithmic acoustic signal with a preset intensity to the frequency band of the damaged hair cell. Previously published human data, and this prospective clinical study demonstrate a statistically significant improvement in a narrow band frequency threshold. These data have important clinical implications as a potential long-term therapy for this widespread and growing disability.

Threshold Sound Conditioning

The Stanford Medical School TSC trial, which ran from 2012 to 2015, was the first study to formally introduce the term TSC. It was co-authored by Eunye Kwak, the author of this textbook, and Sam Kwak, the inventor of the TSC technology. The TSC trial, which was approved for clinical research by the Stanford University Institutional Review Board (IRB), was a double-blind trial, meaning that doctors had no way of knowing whether a subject was in the control or experimental group. The subjects themselves did not know which group they were in. The results of the trial were subjected to conservative statistical analysis at the Scheffe post hoc level and statistical validation was performed under multiple variables. The effectiveness of TSC technology in the Stanford study was expected to be applicable to tinnitus symptoms, not just hearing improvement, for MTM clinicians. MTM clinical research is based on the simple hypothesis that if tinnitus patients' hearing improves, their tinnitus will be relieved.

In the MTM clinical study, it was necessary to systematically determine how just two weeks of TSC could change tinnitus, which was just as important as validating the effect of MTM on hearing loss scores in the four-week MTM protocol. This was just as important as verifying the effect of MTM on the hearing loss index when the MTM 4-week protocol was applied. Post hoc analyses of the left-right combination of frequencies and the absolute ratio between tinnitus treatment frequencies often showed different TSC effects. It is not possible to include all analyses and results in detail in this book, *Diagnosis and Treatment of Tinnitus - Volume 1*. This is because the analysis of the results under different dependent variable conditions using various statistical tools is still ongoing. However, some interesting findings regarding the effects of 2 weeks of TSC are discussed in detail in Chapter 7 and beyond. Other microanalyses and post hoc statistical analyses will be discussed in detail in the forthcoming *Diagnosis and Treatment of Tinnitus - Volume 2*.

The effectiveness of TSC should be checked periodically, at least every two weeks. While it is possible to see some changes in hearing threshold due to TSC on a day-to-day basis, it takes at least two weeks to observe the overall trend. As important as it is to look at the macro effects of TSC based on the hearing loss index, it is also important to look at the micro effects of TSC, which can vary for each frequency. TSC is called unichannel TSC when it is performed on only one frequency band, and multichannel TSC when it is performed on multiple frequency bands simultaneously. There are two types of TSC: single-

channel TSC, in which only one ear is affected by a single frequency band, and multichannel TSC, in which both ears are affected by the same single frequency band. If TSC occurs simultaneously in both ears, even if it is only one frequency band each, it becomes multichannel TSC if both frequency signals stimulate different threshold bands.

To better understand TSC effects, it is essential to understand key principles of TSC, such as the "critical band," "frequency specificity," and "intermittent/sustained firing" at the auditory cell level. Under normal active auditory system conditions, approximately 500 to 600 auditory cells in the same threshold band prefer an 'individual response' to frequency coding, but a 'collective response' to intensity coding. In other words, when we need to detect small changes in frequency, auditory cells are activated only at a specific unit auditory cell group optimized for a specific location cue or a specific periodic cue as much as possible. This is so that subtle differences between different frequencies can be discerned. The number of different frequency values that humans can distinguish within a single threshold band is approximately 7 to 12 in a normal active auditory system. While auditory cells prefer individual responses when processing frequency information, they prefer simultaneous collective responses when processing intensity information. This is because auditory center needs firing rate information from as many auditory cells as possible within a given threshold band to detect small differences in sound intensity. To discriminate subtle differences in sound intensity, high-resolution information about the firing rates of auditory cells is required, which can only be obtained from the responses of as many auditory cells as possible within the same threshold band. At the auditory cell level, the same 1,000 Hz frequency is perceived whether all 1,000 periodic cues are faithfully activated for a total duration of 1 second, or whether only 10 periodic cues are activated for a short period of time, say 0.01 second, instead of 1 second. However, its intensity is perceived differently. Approximately 500 to 600 auditory cells in the same threshold band, when processing the intensity information of a particular frequency, randomly switch back and forth between firing at the periodic cue and firing at the positional cue, or "intermittent firing," in very short bursts. From this, neurons in the auditory center get the cues they need to decode intensity information. Consider the 30 dB and 90 dB examples of a 1,000 Hz frequency signal. When processing intensity information at a frequency of 1,000 Hz, all auditory cells within the same threshold band respond collectively and simultaneously at both 30 dB and 90 dB intensities. However, the absolute total amount of time that an individual auditory cell's individual firing lasts is different at 30

dB and 90 dB. The reason why the total amount of firing rate that establishes 30 dB of information and the total amount of firing rate that establishes 90 dB of information can be different, even though the absolute number of firing cells is the same, is because intermittent firing is more frequent in soft sounds than in loud sounds. In other words, "sustained firing" is more frequent in loud sounds than in soft sounds. The TSC effect results from the transformation of abnormally excessive intermittent firing into normal sustained firing in auditory cells and auditory neurons at each auditory stage. When performing TSC, the intensity of the modulated acoustic signal is matched to the descending threshold level rather than the ascending threshold level because more intermittent firing occurs at the descending threshold than at the ascending threshold. At a certain descending threshold level, if TSC reduces the total number of intermittent utterances and increases the total number of sustained utterances, you will perceive the increased intensity. Hearing improves.

To better understand and observe the TSC effect, it is also important to define the concept of a "harmonic template". As previously described in Chapter 3, Understanding Hearing, a harmonic template is a set of simultaneous auditory otoacoustic potentials. The term "auditory evoked potential" refers to the underlying auditory neural network of the tonotopic organization, a system that controls phase locking a key principle in the brain that simplifies complex patterns of auditory signals. In the active auditory system, the tympanic membrane is for frequency computation in the processing of simultaneous audible frequency information, simplifying the complex spectral patterns of sound into a single fundamental component for decoding. The TSC effect is very closely related to the activation of the tuning fork, which is discussed in several chapters of this textbook. A good conceptualization of the tuning fork is crucial to observing and reading the TSC effect.

Observing and Analyzing TSC Affects

In the MTM clinical trial, the effects of TSC are observed and analyzed based on three main factors: the hearing loss index, tinnitus resistance, and descending threshold. Based on the 67-band-based change rate data of the primary, secondary, and tertiary hearing loss indexes, it is possible to observe and analyze the TSC effect by comparing the difference between the primary and tertiary hearing loss indexes and the difference between the secondary and tertiary or primary and tertiary hearing loss indexes. Superficially, it can be interpreted the secondary and tertiary results reflect only the TSC effect, and

the primary and tertiary results reflect the overall MTM effect including the TSC effect. However, it is difficult to assume that the primary and secondary results do not reflect the TSC effect at all. This is because, before starting the two-week TSC experience, the subjects had already undergone two microaudiometry and one survey. Thus, in a strict sense, the primary and secondary results already include expectational cues regarding TSC. Therefore, while it is reasonable to compare the primary and secondary results with the secondary and tertiary results to examine the TSC effect, it is also valid to compare the primary and secondary results with the primary and tertiary results. Comparing the primary and secondary results with the primary and tertiary results can offset the psychological expectational cues regarding TSC that were equally present during the primary and secondary periods. Therefore, considering the psychological variables, comparing the primary and secondary results with the primary and tertiary results is regarded as a more rigorous and neutral observation and analysis of the TSC effect. From this perspective, it is appropriate to interpret the MTM effect, as represented by the primary and tertiary results, as the "macroscopic TSC effect, considering the involvement of expectational cues." For a neutral observation and analysis of the TSC effect by comparing the primary and secondary results with the secondary and tertiary results, no prior information regarding the TSC experience schedule or plan should be introduced to the subjects' awareness during the primary and secondary periods.

The following image is a hearing loss index graph that visualizes the collective hearing changes induced by TSC using dotted lines. It is a useful resource for quickly identifying and explaining the TSC effect projected onto a large sample of subjects. The graph displays the hearing loss index changes of 192 subjects out of the total 195 participants in the MTM clinical trial, excluding 3 subjects with SOAE. To accurately interpret this graph, let's review some key details. In the hearing loss index graph, each dot forming the lines represents a 1% hearing change rate. Decimal values in the hearing change rate are not reflected in the dotted lines. For example, a line with 9 dots indicates a 9% hearing change rate, while a line with 35 dots represents a 35% hearing change rate. Negative hearing change rates are shown as leftward orange dotted lines, while positive rates are represented by rightward yellow dotted lines. A negative hearing change rate indicates a rise in the hearing threshold during the period, meaning an increase in the hearing loss index (hearing deterioration). Conversely, a positive hearing change rate indicates a decrease in the hearing threshold, representing a reduction in the hearing loss index (hearing

improvement). In the hearing loss index graph, the gray dot at the center serves as the reference point. The dots above the gray dot represent the hearing change rates of the 192 subjects during the primary and secondary periods, while the dots below the gray dot represent the hearing change rates of the same 192 subjects during the primary and tertiary periods. Each horizontal dotted line or row corresponds to the hearing change rate of an individual subject. Rows without dotted lines indicate that the subject's hearing change rate was less than 1%.

The topmost yellow dotted line has 9 points. This is actually the hearing change rates during the primary and secondary periods for subject 1801001, who had a 9.8% lower secondary hearing loss index compared to the primary hearing loss index. In other words, compared to the baseline hearing on the primary micro-audiometry, the hearing measured on the secondary micro-audiometry was 9.8% better. A lower hearing loss index indicates a smaller degree of hearing loss. The dotted line in the second row is colored orange and has five dots for negative hearing change rates. The results are for the first half of the time period before the TSC intervention, during which 1801002 subjects had hearing change rates of -5.2%

Let's take a look at change in hearing for subjects 1801001 and 1801002 during the primary and tertiary periods, i.e. after the TSC intervention. The yellow dotted line just below the gray dot in the center is hearing change rates for subject 1801001 during the primary and tertiary periods. The number of dots is 24, and the actual hearing change rates is 24.8. The second subject, 1801002, has a hearing change of -9.2% shown by the orange dashed line with 9 points during the primary and tertiary periods. Subject 1801001's hearing improved by 9.8% during the primary and secondary periods before TSC, and after the two-week TSC trial, his hearing improved by 15 more, to 24.8%. Subject 1801002 had a -5.2% change in hearing during the primary and secondary periods before TSC. His hearing was already slightly worse without TSC intervention. As for the hearing condition at the time after 2 weeks of TSC experience, the hearing change rates during the primary and secondary were -9.2%, with -5.2% to -4% added.

Examining the two most prominent dotted lines, the longest orange dotted line represents subject 1803026. Their hearing change rate during the primary and secondary periods, before TSC intervention, was -112.1%. After the 2-week TSC experience, their hearing change rate improved to -33.5%. This indicates a 78.6% improvement in hearing status, from -112.1% before TSC intervention to -33.5% afterward. Among the yellow dotted lines,

the longest one represents subject 1807008. Their hearing change rate after TSC intervention was 119.4%, compared to 49.3% before the intervention. This reflects a 70.1% improvement.

The effectiveness of TSC can also be assessed through tinnitus questionnaires. The tinnitus questionnaire used in MTM treatment is useful for systematically examining changes in tinnitus symptoms by scoring tinnitus resistance. By observing and analyzing the quantitative changes in tinnitus resistance during the MTM experience, the effectiveness of TSC can be confirmed

Change in tinnitus resistance during MTM participation period

Q1. 최근 3일간 나의 이명은?	2주 TSC 결과
1. 언제나 들렸다.	126 -> 119
2. 자주 들렸다.	32 -> 29
3. 가끔 들렸다.	33 -> 32
4. 거의 들리지 않는다.	3 -> 13
5. 전혀 들리지 않는다.	1 -> 2
Q2. 지금 이 순간 나의 이명 볼륨은?	2주 TSC 결과
1. 크게 들린다.	65 -> 57
2. 적당히 들린다.	69 -> 68
3. 작게 들린다.	38 -> 31
4. 거의 들리지 않는다.	17 -> 25
5. 전혀 들리지 않는다.	6 -> 14
Q3. 오늘 나의 이명은?	2주 TSC 결과
1. 꾸준히 지속적으로 들린다.	133 -> 125
2. 들렸다 안들렸다 한다.	51 -> 49
3. 전혀 들리지 않는다.	11 -> 21

The results above show the change in tinnitus intensity and frequency of tinnitus in all 195 subjects (including 3 SOAEs) before and after the 4-week MTM protocol. Note that only 2 weeks of TSC were performed during the 4-week MTM period. Notably, the number of respondents selecting the final option ("I do not hear any tinnitus at all") in the three-item questionnaire approximately doubled after the 4-week MTM experience (including 2 weeks of TSC).

The scoring criteria for the tinnitus questionnaire used to assess tinnitus resistance are as follows:

- **Questions 1 and 2** each offer five response options. The scores assigned based on the respondents' answers are: ① = 1 point, ② = 2 points, ③ = 3 points, ④ = 4 points, ⑤ = 5 points
- **Question 3** offers three response options, with the following point allocation: ① = 1 point, ② = 3 points, ③ = 5 points

In the MTM clinical trial, the tinnitus questionnaire prompts participants to assess the severity of their tinnitus symptoms from three different temporal perspectives:

- "The past 3 days"
- "At this very moment"
- "Today"

The tinnitus questionnaire used to assess tinnitus resistance is scored on a scale ranging from 3 to 15 points, where:

- 3 points indicates the weakest tinnitus resistance, and
- 15 points indicates the strongest tinnitus resistance.

Just as the concept of a hearing impairment index is introduced in MTM based on hearing thresholds at 67 different frequencies, it is also possible to introduce a "tinnitus severity index" or "tinnitus index" based on tinnitus resistance scores. This concept is also discussed in Chapter 10, which addresses the correlation between tinnitus and hearing loss. The criteria for converting tinnitus resistance scores into tinnitus index values are as follows:

- Tinnitus resistance 3 points = Tinnitus index 6
- Tinnitus resistance 4 points = Tinnitus index 5
- Tinnitus resistance 5 points = Tinnitus index 4
- Tinnitus resistance 6–7 points = Tinnitus index 3
- Tinnitus resistance 8–10 points = Tinnitus index 2
- Tinnitus resistance 11–15 points = Tinnitus index 1

In the MTM clinical trial, the various effects of 2 weeks of TSC are observed and analyzed across three primary metrics:

- Hearing impairment index
- Tinnitus resistance
- Descending threshold

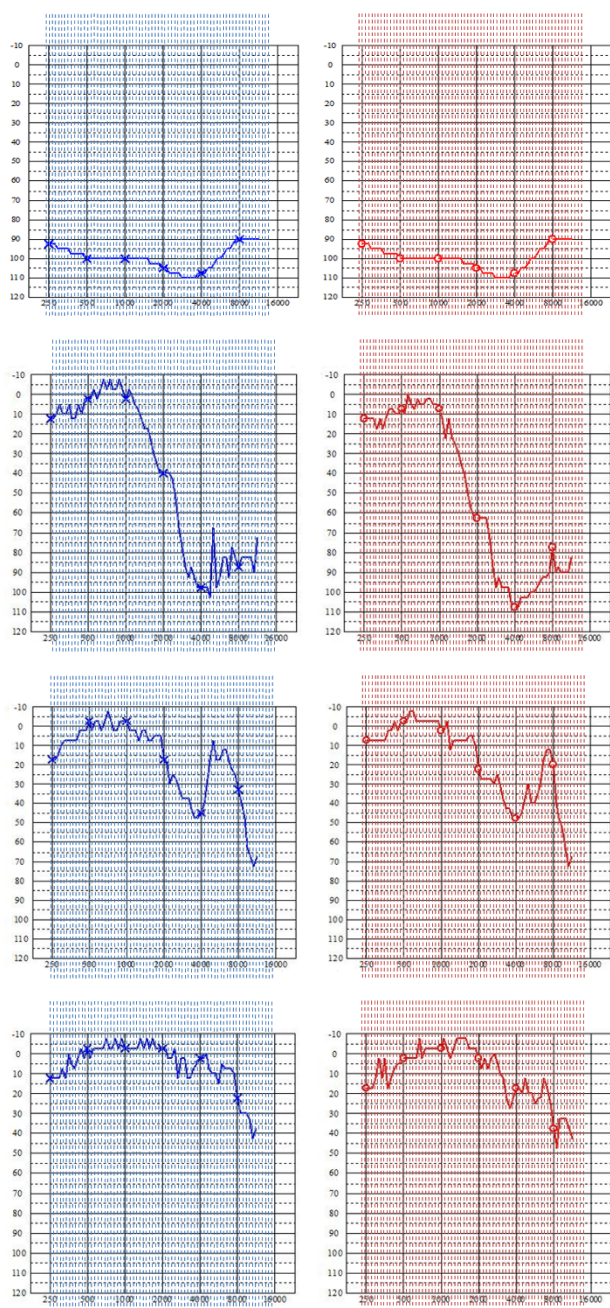
The hearing impairment index and tinnitus resistance are assessed in the clinic, whereas the descending threshold is evaluated by the participants themselves in their own living environments during the TSC period. Participants are required to closely monitor their daily descending threshold changes and manually record them. An example of a listening journal entry, where a participant documents their daily descending threshold changes during the 2-week TSC listening process, is shown below. In the example, the participant's handwritten journal thoroughly records the descending threshold volume levels for each day.

청취 일지

성명: _____

	청취일	청취시간	하향역치		청취일	청취시간	하향역치
1	10월 16일	12시 52분	20	2	10월 16일	21시 35분	22
3	10월 17일	09시 40분	20	4	10월 17일	18시 55분	21
5	10월 18일	05시 40분	20	6	10월 18일	15시 35분	21
7	10월 19일	09시 20분	19	8	10월 19일	18시 55분	19
9	10월 20일	13시 25분	20	10	10월 20일	19시 55분	19
11	10월 21일	07시 00분	19	12	10월 21일	17시 40분	20
13	10월 22일	09시 25분	18	14	10월 22일	22시 20분	20
15	10월 23일	11시 10분	19	16	10월 23일	17시 35분	20
17	10월 24일	15시 30분	18	18	10월 24일	22시 45분	19
19	10월 25일	16시 43분	18	20	10월 25일	23시 20분	19
21	10월 26일	13시 20분	19	22	10월 26일	23시	19
23	10월 27일	06시 30분	18	24	10월 27일	20시 40분	18
25	10월 28일	06시 40분	19	26	10월 28일	16시 45분	19
27	10월 29일	10시 49분	18	28	10월 29일	19시 45분	18
29	10월 30일	05시 45분	17	30	10월 30일	15시 45분	17

Hearing loss, tinnitus resistance, and descending thresholds are all equal criteria for observing and analyzing the effects of TSC, but if we were to choose one to represent the three, it would be the hearing loss index. The hearing loss index obtained from the 67-band RCPTA algorithm is the most refined quantitative hearing index among the various hearing assessment measures. The national audiometric standards are all based on a simple or additive average of the hearing thresholds at each frequency, with a very limited number of sample frequencies used for averaging. As shown in the table, conventional audiometric scales based on the evaluation and averaging of hearing thresholds at only six or seven frequencies on the bold vertical lines, whereas the hearing loss index is based on the evaluation and of hearing thresholds all 67 vertical dotted lines (which look like blue and red backgrounds in the audiogram graph below, but are actually dotted lines).



The individual hearing impairment index change rates for each participant are visualized through graphs, making it easier to observe the collective hearing change patterns. The first image is the dotted-line graph previously examined, where the hearing impairment index change rates are arranged in the order of subject IDs. The second image rearranges the same hearing impairment index change rates from the first graph in ascending order, reordering the rows of the dotted lines accordingly. The left side represents the hearing change rate during the period between the primary and secondary micro-audiometry, indicating the change in hearing during that period. The right

side displays the hearing change rate between the primary and tertiary periods. The third graph further rearranges the second graph by symmetrically aligning the negative change rates (orange dotted lines) and the positive change rates (yellow dotted lines) to the left and right, respectively.



Subject			L			R			Sum			Diff of Threshold			Diff Ratio(%)			Time	TSC Level				TQ		N of Targ				Subject		
ID	G	A	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1vs2	2vs3	1vs3	1vs2	2vs3	1vs3	/28	Start	End	D	1st	2nd	D	L	R	G	A	ID		
1801001	M	45	1227	1010	882	937	940	745	2164	1950	1627	-214	-323	-537	9.8	16.5	24.8	27	25	17	8	5	3	-2	3	0	M	45	1801001		
1801002	M	52	2372	2902	3085	3377	3530	3585	6109	6432	6670	323	238	561	-5.2	-3.7	-9.1	20	23	23	0	3	3	0	2	2	M	52	1801002		
1801004	F	38	1465	1447	1400	915	830	895	2380	2277	2295	-103	18	-85	4.3	-0.7	3.5	44	18	16	2	8	9	1	4	0	F	38	1801004		
1801005	M	54	1870	1857	1877	1155	1157	1152	3025	3014	3029	-11	15	4	0.3	-0.4	-0.1	28	32	32	0	3	3	0	2	2	M	54	1801005		
1801006	F	57	1080	1087	955	1605	1730	1430	2685	2817	2385	132	-432	-300	-4.9	15.3	11.1	28	17	13	4	4	4	0	1	2	F	57	1801006		
1801007	F	78	4062	3957	3995	5230	5017	5357	9292	8974	9352	-318	378	60	3.4	-4.2	-0.6	26	24	16	8	3	3	0	2	1	F	78	1801007		
1801009	F	38	532	355	427	775	485	455	1307	840	882	-467	42	-425	35.7	-5.0	32.5	27	20	19	1	6	7	1	0	3	F	38	1801009		
1801010	M	69	3527	3220	3192	3915	3772	3700	7442	6992	6892	-450	-100	-550	6.0	1.4	7.3	28	21	19	2	9	11	2	4	3	M	69	1801010		
1801011	M	59	2960	2712	2412	3067	2927	2572	6027	5639	4984	-388	-655	-1043	6.4	11.6	17.3	15	23	19	4	3	4	1	4	2	M	59	1801011		
1802001	M	63	3125	2997	2985	2395	2377	2340	5520	5374	5325	-146	-49	-195	2.6	0.9	3.5	30	25	20	5	3	3	0	3	2	M	63	1802001		
1802002	M	34	920	782	715	680	562	382	1600	1344	1097	-256	-247	-503	16.0	18.3	31.4	16	24	20	4	3	4	1	2	3	M	34	1802002		
1802003	M	82	3532	3165	3360	3367	3365	3402	6899	6530	6762	-369	232	-137	5.3	-3.5	1.9	27	25	22	3	5	3	-2	3	3	M	82	1802003		
1802004	M	59	2037	1562	1337	2637	1905	1907	4674	3467	3244	-1207	-223	-1430	25.8	6.4	30.5	13	9	16	-7	5	4	-1	3	M	59	1802004			
1802007	M	75	3337	3050	3132	3702	3447	3420	7039	6497	6552	-542	55	-487	7.6	-0.8	6.9	28	24	23	1	3	3	0	3	2	M	75	1802007		
1802008	F	37	710	1075	1022	1207	800	1005	1917	1875	2027	-42	152	110	2.1	-8.1	-5.7	28	22	14	8	12	8	-4	3	3	F	37	1802008		
1802009	F	27	1157	332	250	660	620	372	1817	952	622	-865	-330	-1195	47.6	34.6	65.7	11	10	10	0	13	13	0	2	2	F	27	1802009		
1802011	F	59	2520	2545	2590	2230	2215	2232	4750	4760	4822	10	62	72	-0.2	-1.3	-1.5	25	23	21	2	8	6	-2	3	3	F	59	1802011		
1803001	M	54	1515	1365	1275	1235	1155	790	2750	2520	2065	-230	-455	-685	8.3	18.0	24.9	39	2	2	0	4	9	5	3	3	M	54	1803001		
1803002	M	57	2467	2677	2570	2450	2352	2362	4917	5029	4932	112	-97	15	-2.2	1.9	-0.3	25	5	5	0	3	3	0	3	3	M	57	1803002		
1803003	M	75	2622	2750	2785	3152	3262	3412	5774	6012	6197	238	185	423	-4.1	-3.0	-7.3	40	14	12	2	10	13	3	1	2	M	75	1803003		
1803004	M	67	2812	2867	2817	2995	2957	2935	5807	5824	5752	17	-72	-55	-0.2	1.2	0.9	22	9	6	3	4	6	2	3	3	M	67	1803004		
1803005	F	84	4022	4022	4470	2742	2742	3315	6764	6764	7785	0	1021	1021	0.0	-15.0	-15.0	21	19	17	2	9	10	1	1	1	F	84	1803005		
1803007	F	37	215	487	475	310	562	747	525	1049	1222	524	173	697	-99.8	-16.4	-132.7	29	13	12	1	8	13	5	1	0	F	37	1803007		
1803008	M	78	3120	3025	2820	3172	3040	2812	6292	6065	5632	-227	-433	-660	3.6	7.1	10.4	22	18	16	2	3	3	0	3	3	M	78	1803008		
1803010	F	49	942	950	1030	782	680	732	1724	1630	1762	-94	132	38	5.4	-8.0	-2.2	29	17	15	2	9	10	1	3	3	F	49	1803010		
1803011	M	45	477	745	410	1710	1902	1735	2187	2647	2145	460	-502	-42	-21.0	18.9	1.9	24	29	26	3	5	5	0	0	3	M	45	1803011		
1803014	M	48	2350	1790	1915	2310	2205	2115	4660	3995	4030	-665	35	-630	14.2	-0.8	13.5	26	13	13	0	3	3	0	4	4	M	48	1803014		
1803015	M	50	2687	2650	2370	2685	2272	2305	5372	4922	4675	-450	-247	-697	8.3	5.0	12.9	28	22	11	11	4	4	0	4	4	M	50	1803015		
1803016	F	46	3762	3522	3245	3732	3752	3615	7494	7274	6860	-220	-414	-634	2.9	5.6	8.4	30	20	18	2	3	3	0	3	3	F	46	1803016		
1803017	F	60	1215	965	1085	757	957	1357	1972	1922	2442	-50	520	470	2.5	-27.0	-23.8	29	22	22	0	8	10	2	4	2	F	60	1803017		
1803018	M	33	1370	1335	1325	1332	1342	1322	2702	2677	2647	-25	-30	-55	0.9	1.1	2.0	38	22	21	1	4	3	-1	3	3	M	33	1803018		
1803019	F	37	517	542	642	550	550	472	1067	1092	1114	25	22	47	-2.3	-2.0	-4.4	28	3	2	1	8	13	5	3	3	F	37	1803019		
1803020	M	58	1435	1577	1382	1135	1527	1382	2570	3104	2764	534	-340	194	-20.7	10.9	-7.5	28	20	18	2	11	13	2	3	1	M	58	1803020		
1803021	M	46	1952	1830	1805	1470	1405	1377	3422	3235	3182	-187	-53	-240	5.4	1.6	7.0	19	24	20	4	4	4	0	3	2	M	46	1803021		
1803022	M	72	2845	3007	3012	2545	2547	3005	5390	5554	6017	164	463	627	-3.0	-8.3	-11.6	26	20	14	6	5	5	0	3	4	M	72	1803022		
1803023	F	70	1535	1570	1595	1552	1342	1437	3087	2912	3032	-175	120	-55	5.6	-4.1	1.7	25	11	8	3	5	5	0	4	3	F	70	1803023		
1803024	F	31	1222	1262	1040	1155	1100	1040	2377	2362	2080	-15	-282	-297	0.6	11.9	12.4	27	14	14	0	11	11	0	2	1	F	31	1803024		
1803025	M	36	1552	1450	1397	2997	2937	2922	4549	4387	4319	-162	-68	-230	3.5	1.5	5.0	31	23	27	-4	4	4	0	0	4	M	36	1803025		
1803026	M	34	1255	2487	1825	927	2142	1090	2182	4629	2915	2447	-1714	733	-112.1	37.0	-33.5	27	3	2	1	4	4	0	3	0	M	34	1803026		
1803028	M	54	2635	2857	2842	2165	2327	2190	4800	5184	5032	384	-152	232	-8.0	2.9	-4.8	26	17	17	0	3	3	0	2	2	M	54	1803028		
1803029	M	76	4132	4700	4835	4792	4087	4147	8924	8787	8982	-137	195	58	1.5	-2.2	-0.6	29	26	24	2	4	3	-1	2	3	M	76	1803029		
1803030	M	40	2262	1972	1950	2255	2275	2177	4517	4247	4127	-270	-120	-390	5.9	2.8	8.6	21	25	23	2	3	10	7	4	3	M	40	1803030		
1803032	F	65	3307	2995	3087	4692	4415	4075	7999	7410	7992	-589	582	-7	7.3	-7.8	0.0	18	26	25	1	3	3	0	3	4	F	65	1803032		
1803033	M	44	1390	1242	1167	675	655	417	2065	1897	1584	-168	-313	-481	8.1	16.4	23.2	27	22	23	-1	8	9	1	4	0	M	44	1803033		
1803034	F	56	2127	2505	12	3542	3520	610	6159	6025	622	-134	-5403	-5537	2.1	89.6	89.9	21	21	20	1	4	4	0	0	4	F	56	1803034		
1803035	M	63	1075	1192	1150	1197	1232	1212	2272	2424	2362	-152	-62	90	-6.6	2.5	-3.9	28	25	27	-2	11	13	2	0	1	M	63	1803035		
1803037	M	43	1982	1950	1780	1942	2157	1902	3924	4107	3682	183	-425	-242	-4.6	10.3	6.1	19	24	20	4	3	3	0	3	0	M	43	1803037		
1804001	F	63	2705	2712	2762	2870	2845	3017	5575	5557	5779	-18	222	204	0.3	-3.9	-3.6	36	28	20	8	7	9	2	1	2	F	63	1804001		
1804002	F	62	1920	2085	1997	1412	1497	1620	3332	3582	3617	250	35	285	-7.5	-0.9	-8.5	27	32	19	13	5	5	0	3	3	F	62	1804002		
1804005	M	66	1707	1865	1732	1527	1642	1432	3234	3507	3164	273	-343	-70	-8.4	9.7															

Subject			L			R			Sum			Diff of Threshold			Diff Ratio(%)			Time	TSC Level				TQ			N of Targ			Subject		
ID	G	A	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1vs2	2vs3	1vs3	1vs2	2vs3	1vs3	/28	Start	End	D	1st	2nd	D	L	R	G	A	ID		
1807012	M	58	2850	2852	2950	2757	2890	2902	5607	5742	5852	135	110	245	-2.4	-1.9	-4.3	38	22	22	0	5	8	3	2	2	M	58	1807012		
1807016	M	71	2990	2615	2855	2660	2550	2727	5650	5165	5582	-485	417	-68	8.5	-8.0	1.2	32	21	16	5	6	5	-1	2	2	M	71	1807016		
1807017	F	58	1975	2450	2045	1455	1910	1545	3430	4360	3590	930	-770	160	-27.1	17.6	-4.6	28	17	10	7	5	5	0	2	2	F	58	1807017		
1807019	M	63	3800	3605	3377	2415	2237	2097	6215	5842	5474	-373	-368	-741	6.0	6.2	11.9	30	17	14	3	3	4	1	2	2	M	63	1807019		
1808003	M	56	2695	2515	2540	3237	3212	3262	5932	5727	5802	-205	75	-130	3.4	-1.3	2.1	28	15	15	0	3	4	1	1	1	M	56	1808003		
1808004	F	83	4252	4380	4170	4902	5220	4372	9154	9600	8542	-446	-1058	-612	-4.8	11.0	6.6	26	24	25	-1	15	12	-3	2	2	F	83	1808004		
1808005	F	81	3797	4200	4222	3285	3200	3052	7082	7400	7274	318	-126	192	-4.4	1.7	-2.7	24	23	24	-1	7	5	-2	2	2	F	81	1808005		
1808006	F	46	795	485	590	775	580	750	1570	1065	1340	-505	275	-230	32.1	-25.8	14.6	27	20	17	3	10	6	-4	1	2	F	46	1808006		
1808012	M	69	3342	3442	3277	3022	2832	2752	6364	6274	6029	-90	-245	-335	1.4	3.9	5.2	31	21	8	13	3	4	1	1	1	M	69	1808012		
1808014	F	21	452	332	322	330	547	340	782	879	662	97	-217	-120	-12.4	24.6	15.3	28	7	12	5	4	8	4	1	1	F	21	1808014		
1809002	F	49	1437	1297	1342	1480	1410	1662	2917	2707	3004	-210	297	87	7.1	-10.9	-2.9	30	23	19	4	3	3	0	2	2	F	49	1809002		
1809003	M	51	1075	997	962	972	1022	695	2047	2019	1657	-28	-362	-390	1.3	17.9	19.0	28	16	8	8	4	6	2	2	2	M	51	1809003		
1809004	F	63	2500	2197	2027	2425	2712	2180	4925	4909	4207	-16	-702	-718	0.3	14.3	14.5	30	20	20	0	3	4	1	2	2	F	63	1809004		
1809005	F	68	3867	3492	3240	2645	2090	1612	6512	5582	4852	-930	-730	-1660	14.2	13.0	25.4	30	16	16	0	3	3	0	2	0	F	68	1809005		
1809007	F	74	1762	1877	2187	2032	1732	1737	3794	3609	3924	-185	315	130	4.8	-8.7	-3.4	28	22	19	3	3	4	1	1	2	F	74	1809007		
1809009	F	39	410	300	277	542	527	290	952	827	567	-125	-260	-385	13.1	31.4	40.4	28	29	27	2	6	7	1	1	0	F	39	1809009		
1809010	F	58	1587	1365	1162	2312	2130	1817	3899	3495	2979	-404	-516	-920	10.3	14.7	23.5	30	20	17	3	3	3	0	2	2	F	58	1809010		
1809011	F	71	3670	3572	3522	3487	3520	3265	7157	7092	6787	-65	-305	-370	0.9	4.3	5.1	28	17	12	5	4	4	0	0	2	F	71	1809011		
1809012	F	63	805	1055	1225	1125	1225	1012	1930	2280	2237	350	-43	307	-18.1	1.8	-15.9	28	15	15	0	9	9	0	0	1	F	63	1809012		
1809013	F	71	3315	2900	3655	2937	2910	2640	6252	5810	6295	-442	485	43	7.0	-8.3	-0.6	28	17	13	4	3	4	1	2	2	F	71	1809013		
1809016	M	63	4242	3720	2720	1987	2020	1740	4309	6740	4460	2431	-2280	151	-56.4	33.8	-3.5	29	6	5	1	5	6	1	2	2	M	63	1809016		
1809018	F	59	2057	2902	2215	1710	1855	1562	3767	4757	3777	990	-980	10	-26.2	20.6	-0.2	27	18	25	-7	3	3	0	2	2	F	59	1809018		
1809020	M	23	217	397	257	972	892	812	1189	1289	1069	100	-220	-120	-8.4	17.0	10.0	30	17	13	4	7	8	1	1	2	M	23	1809020		
1809021	F	48	3272	3205	3245	3250	3077	2992	6522	6282	6237	-240	-45	-285	3.6	0.7	4.3	28	20	23	-3	7	10	3	1	2	F	48	1809021		
1810001	F	37	770	647	757	745	745	877	1515	1392	1634	-123	242	119	8.1	-17.3	-7.8	26	24	15	9	8	10	2	1	1	F	37	1810001		
1810002	M	52	2185	4770	2592	4972	4695	5025	7157	9465	7617	2308	-1848	460	-32.2	19.5	-6.4	26	17	15	2	3	3	0	3	4	M	52	1810002		
1810004	M	73	3010	3447	4120	3247	3590	4055	6257	7037	8175	780	1138	1918	-12.4	-16.1	-30.6	26	22	22	0	6	8	2	3	3	M	73	1810004		
1810005	F	33	402	535	642	355	465	657	757	1000	1299	243	299	542	-32.1	-29.9	-71.5	25	1	0	1	7	9	2	2	2	F	33	1810005		
1810006	F	38	325	435	362	465	697	692	790	1132	1054	342	-78	264	-43.2	6.8	-33.4	22	26	10	16	11	13	2	1	2	F	38	1810006		
1810008	F	58	3417	3085	3000	1950	1817	1510	5367	4902	4510	-465	-392	-857	8.6	7.9	15.9	19	20	19	1	4	3	-1	4	2	F	58	1810008		
1810009	M	29	3402	3282	3280	3365	3072	3160	6767	6354	6440	-413	86	-327	6.1	-1.3	4.8	29	22	25	-3	5	4	-1	4	3	M	29	1810009		
1810010	F	48	1010	852	740	1840	1635	1350	2850	2487	2090	-363	-397	-760	12.7	15.9	26.6	14	32	32	0	5	5	0	3	4	F	48	1810010		
1810011	F	54	4305	2580	2515	4285	1925	1957	8590	4505	4472	-4085	-33	-4118	47.5	0.7	47.9	26	24	24	0	3	4	1	4	4	F	54	1810011		
1810012	F	57	2100	1252	1875	572	502	387	2672	1754	2262	-918	508	-410	34.3	-28.9	15.3	23	19	8	9	3	5	2	4	3	F	57	1810012		
1810016	F	42	1420	790	522	1325	642	565	2745	1432	1087	-1313	-345	-1658	47.8	24.0	60.4	26	13	3	10	9	14	5	4	3	F	42	1810016		
1810017	F	41	792	772	677	687	332	362	1479	1104	1039	-375	-65	-440	25.3	5.8	29.7	14	20	19	1	6	5	-1	4	3	F	41	1810017		
1810018	M	50	2032	1920	1862	1682	1532	1360	3714	3452	3222	-262	-230	-492	7.0	6.6	13.2	24	22	21	1	5	6	1	4	3	M	50	1810018		
1810021	M	55	3430	3287	3160	3750	3447	3282	7180	6734	6442	-446	-292	-738	6.2	4.3	10.2	20	23	23	0	3	3	0	4	4	M	55	1810021		
1810022	F	53	3347	2920	2960	2072	1570	1600	5419	4490	4560	-929	70	-859	17.1	-1.5	15.8	23	9	9	0	4	7	3	4	3	F	53	1810022		
1810024	M	66	2060	1830	1882	3507	3302	3180	5567	5132	5062	-435	-70	-505	7.8	1.3	9.0	25	21	14	7	4	3	-1	3	2	M	66	1810024		
1811002	F	70	2695	3367	4312	2977	3265	3420	5672	6632	7732	960	1100	2060	-16.9	-16.5	-36.3	8	25	25	0	6	10	4	1	1	F	70	1811002		
1811003	F	53	1650	1267	1035	1752	1302	970	3402	2569	2005	-833	-564	-1397	24.4	21.9	41.0	25	18	11	7	12	12	0	1	2	F	53	1811003		
1811004	F	40	872	1060	722	445	437	447	1317	1497	1169	180	-328	-148	-13.6	21.9	11.2	21	17	15	2	10	14	4	1	1	F	40	1811004		
1811005	M	49	2450	2367	2267	1865	1682	1622	4315	4049	3889	-266	-160	-426	6.1	3.9	9.8	28	26	25	1	4	6	2	2	2	M	49	1811005		
1811006	M	58	1520	1522	1485	2102	2030	2040	3622	3552	3525	-70	-27	-97	1.9	0.7	2.6	27	28	16	12	4	3	-1	2	2	M	58	1811006		
1811007	M	71	3802	3770	3775	4427	4470	4535	8229	8240	8310	11	70	81	-0.1	-0.8	-0.9	28	25	20	5	3	4	1	2	2	M	71	1811007		
1811009	M	65	2367	2205	2062	1940	1915	1762	4307	4120	3824	-187	-296	-483	4.3	7.1	11.2	26	20	20	0	3	3	0	3	2	M	65	1811009		
1811010	F	13	3880	1980	1095	3797	2050	1647	7677	4030	2742	-3647	-1288	-4935	47.5	31.9	64.2	0	0	0	0	7	10	3	3	4	F	13	1811010		
1812001	F	41	1735	1727	1777	602	437	317	2337	2164	2094	-173	-70	-243	7.4	3.2	10.3	23	26	24	2	5	4	-1	1	0	F	41	1812001		
1812002	F	47	4805	5072	5055	4772	5030	4890	9577	10102	9																				

7. MTM Clinical Results Analysis 1

1001000000	14	45	1227	1016	802	957	349	745	2164	1993	1627	-241	-202	32	85	248	27	17	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
1001000000	14	45	1227	1016	802	957	349	745	2164	1993	1627	-241	-202	32	85	248	27	17	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
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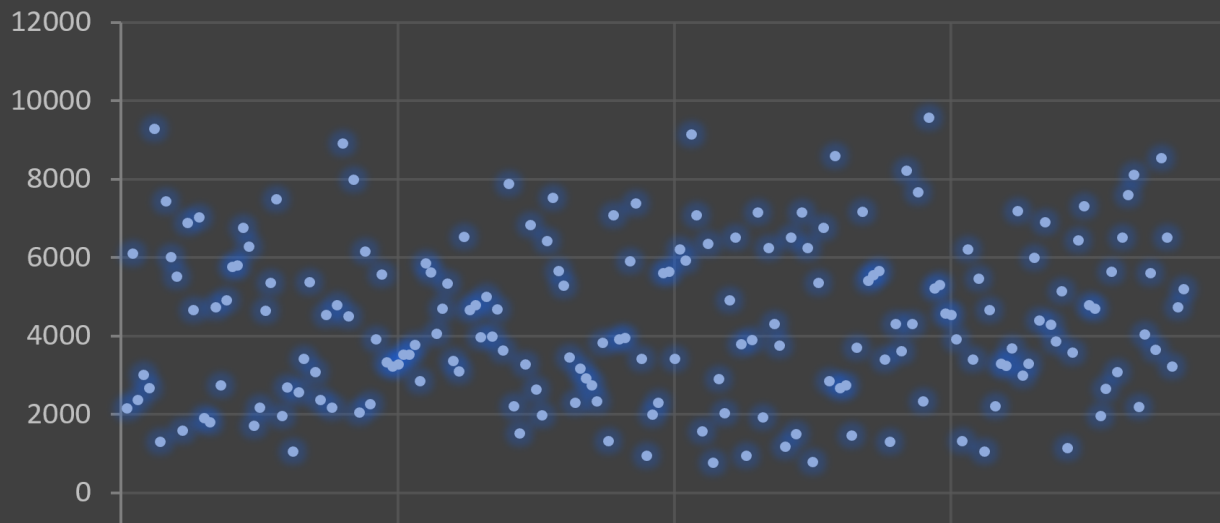
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Aggregation of MTM Clinical Results

<The MTM Baseline Statistical Analysis Results Table> above provides information on the primary, secondary, and tertiary hearing loss indices, the difference between each hearing loss index, the hearing change rates, the change in volume at the descending threshold during TSC home listening, and the change in tinnitus resistance score for all 195 subjects who completed the MTM trial. In the MTM trial, subjects had to visit the clinic three times during the 4-week study period, complete two surveys, three micro-audiometry, and a 2-week TSC listening task for tinnitus treatment. A total of 258 subjects volunteered to participate in the MTM study after seeing a letter from their healthcare provider about their health issues. Most of them completed the primary survey and primary micro-audiometry, but only 195 subjects completed the final tertiary micro-audiometry and the secondary survey.

The MTM Basic Statistical Analysis Results Table records the unique ID, gender, and age of the subjects who visited the medical centers. The threshold results of the primary, secondary, and tertiary micro-audiometry at 67 frequencies on the left and right sides are displayed, along with the gross hearing on each side. For a single subject with one round of micro-audiometry, the sum of the left and right hearing values for that round is the subject's gross hearing value. This gross hearing value is the hearing loss index. In <The MTM Baseline Statistical Analysis Results Table>, the 'Diff of Threshold' section shows the

arithmetic difference in the hearing loss index between the primary, secondary, and the secondary, tertiary, and the primary, tertiary micro-audiometry for each of the 195 subjects. In the 'Diff of Threshold' section, a minus (-) indicates a decrease in hearing loss and a plus (+) indicates an increase in hearing loss. In other words, a negative value in 'Diff of Threshold' indicates an improvement in hearing. In the MTM Basic Statistical Analysis Results Table, the values in the 'Diff Ratio (%)' section are the change rates in the hearing loss index between the primary, secondary, and the secondary, tertiary, and the primary, tertiary micro-audiometry. In contrast to the 'Diff of Threshold' section, here, a negative value indicates an increase in the threshold and a positive value indicates a decrease in the threshold, so a positive value in the 'Diff Ratio (%)' section indicates an improvement in hearing. The 'Time' field shows the total number of times the subject listened to the TSC sound signal over a two-week period. The figures shown in the 'TSC Level' section are the TSC listening volume values recorded by each of the 195 subjects, showing the median of the first three sessions, the median of the last three sessions, and the difference between them. 'TQ' is the Tinnitus Questionnaire score to assess tinnitus resistance. Subjects completed the Tinnitus Questionnaire at Visit 1 and Visit 3, with a minimum score of 3 and a maximum score of 15. 'N of Targ' is the number of component frequencies of the TSC acoustic signal provided to each subject, which is the number of left and right targeting frequencies on the REVE134 acoustic stimulator prescribed to each subject.



<Distribution of hearing loss index based on the results of the primary micro-audiometry>

Hearing Impairment Index Distribution

The graph above illustrates the distribution of 195 hearing impairment indices based on the results of the primary micro-audiometry conducted on the 195 participants in the MTM 4-week clinical trial. In the micro-audiometry, the RCPTA algorithm determines 134 hearing thresholds across 67 frequencies for both the left and right ears. The application of the RCPTA algorithm in audiograms is similar to the double-blind method in clinical trials. The algorithm randomly presents the test tones in terms of both frequency and intensity for each ear, preventing participants from gaining any memory cues regarding the presentation patterns. Since the hearing thresholds are determined automatically by computer control during the entire test process, the examiner (audiologist) cannot influence or artificially manipulate the final threshold results, as long as the algorithm operates properly. Because the hearing thresholds are determined by the algorithm rather than manual adjustments by the examiner, no subjective judgment, expectations, or predictions from the examiner affect the hearing threshold results. The gross hearing impairment index for each participant is calculated by summing all 134 hearing threshold values (67 frequencies for each ear) obtained through the RCPTA algorithm. The hearing impairment index based on the RCPTA algorithm serves as an individual's gross hearing score at a specific point in time. In the 67-band RCPTA algorithm, the "maximum hearing impairment index" indicating the most severe hearing loss is 13,360. The arithmetic mean and geometric mean of the 195 hearing impairment indices from the distribution are as follows:

Arithmetic mean: 4,335 → 103 participants < 4,335 < 92 participants

Geometric mean: 3,749 → 85 participants < 3,749 < 110 participants

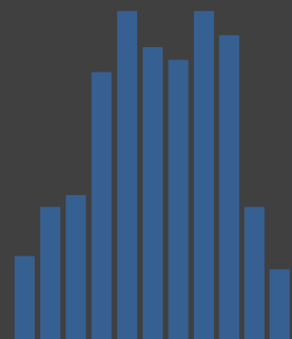
The midpoint between the arithmetic mean and geometric mean is 4,042. Based on this value:

97 participants have better hearing (hearing impairment index below 4,042)

98 participants have worse hearing (hearing impairment index above 4,042)

Number of Participants by Hearing Impairment Index Group
(Based on the primary Micro-audiometry)

Below 1,000 → 7 participants
 1,000–1,550 → 11 participants
 1,550–2,155 → 12 participants
 2,155–2,820 → 22 participants
 2,820–3,550 → 27 participants
 3,550–4,350 → 24 participants
 4,350–5,230 → 23 participants
 5,230–6,200 → 27 participants
 6,200–7,270 → 25 participants
 7,270–8,450 → 11 participants
 Above 8,450 → 6 participants



전체 피험자 195명의 1차 총청력(난청지수) 평균

산술평균 $845272/195 = \underline{4334.72}$ (103명 vs 92명)

기하평균 $\sqrt[195]{6.4326 \times 10^{693}} = \underline{3748.68}$ (85명 vs 110명)

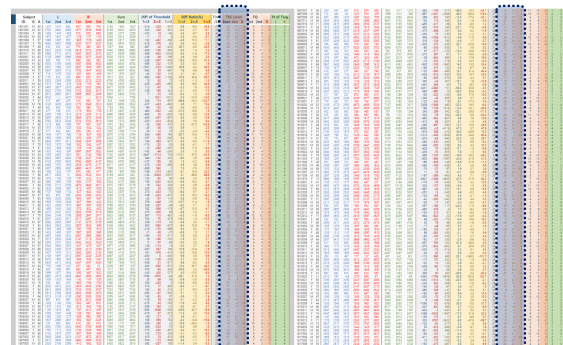
How Clinical Results are Analyzed

To analyze the results of the MTM trial, both macro and micro analyses were performed. Macro analyses focus on collective patterns and characteristics across all subjects in the study. Micro analyses focus on the detailed patterns and characteristics of each individual subject's results. In the MTM trial, each of the 195 subjects had a different frequency composition of the TSC sound signal when prescribed TSC. The number of frequency bands targeted in a single subject was often multiple rather than singular, requiring a microanalysis to compare the effect of TSC on each frequency in each subject. The amount of micro-statistical analysis required to examine the pattern and specificity of hearing change for each frequency in the MTM trial results on a subject-by-subject basis is very large, the analysis is still underway. The final results of the microscopic statistical analysis will be presented in the Diagnosis and Treatment of MTM Tinnitus, Volume 2. In this Volume 1 textbook, the results of macroscopic analyses of MTM clinical trials are focused in Chapters 7, 8, 9, and 10. T-tests were used to compare statistical differences between the results of two different groups, and regression analyses were tested against the Gaussian model, an auditory theory of the correlation function between tinnitus and hearing loss. This chapter also includes a discussion and analysis of the self-similarity principle of hearing, whereby the collective hearing pattern of all 195 subjects is projected to the individual hearing pattern, the hearing pattern in a single critical band, and the hearing pattern at the level of a single auditory cell. Chapter 7 presents the macroscopic findings from the MTM trial, focusing on changes in the descending thresholds, changes in the distribution of tinnitus resistance scores, changes in the distribution of hearing loss indices, and changes in testing time. It also presents the contour patterns of the 195 patients' 67-band micro-audiograms, categorized by each type.

Change in Descending Threshold

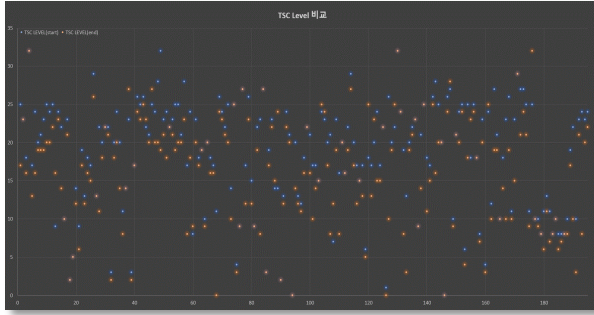
On the second visit, the MTM clinical subject will complete a secondary microtone audiogram and participate in the TSC sound signal generation process with the medical staff. To generate TSC sound signals on the 134-band, 20-channel REVE134 acoustic stimulator, the subject's own earphones are connected to the REVE134 acoustic stimulator. The subject listens to the TSC sound signal located in the same frequency band as the subject's tinnitus frequency and finds the descending threshold value of the sound signal within 10

seconds. If the subject has only one tinnitus frequency, they will only need to find the descending threshold for one TSC tone, but if they have multiple tinnitus frequencies, they will need to find the descending threshold for all tinnitus frequencies. With the cooperation of the subject, medical staff will merge the single or multiple TSC sound signals calibrated with the descending threshold values into a single sound file. The time required for the merging process depends on the number of TSC signals, but should be within 30-40 seconds. The resulting TSC sound signals are stored on the MTM clinical MP3 player and provided to the subject. The subject listens to the TSC tones in a quiet room for 30 minutes twice a day for a total of 2 weeks. Because the subject's TSC listening is a self-directed task, the subject is required to keep a handwritten listening log for each TSC listening session. In the log, record the descending threshold value of the TSC sound signal. The "TSC Level" section of the "TM Basic Statistical Analysis Results Table" at the beginning of this Chapter 7 shows the median of the first three and the last three listening logs recorded by the subject and the difference (D) between these medians.



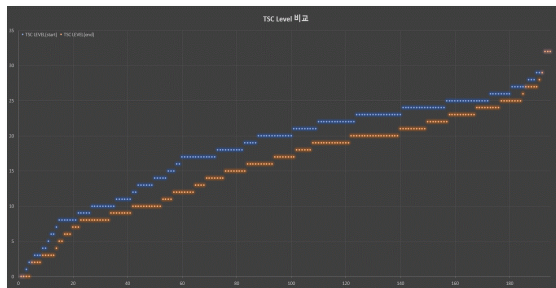
In the graph below, the blue dots are the median of the first three subthreshold volume readings recorded by hand by MTM clinical subjects, and the orange dots are the median of the last three readings. The points are randomly distributed, so it's not obvious from the graph, but you can see that the blue points are relatively higher and the orange points are somewhat lower.

Randomized array graph of descending threshold volume values



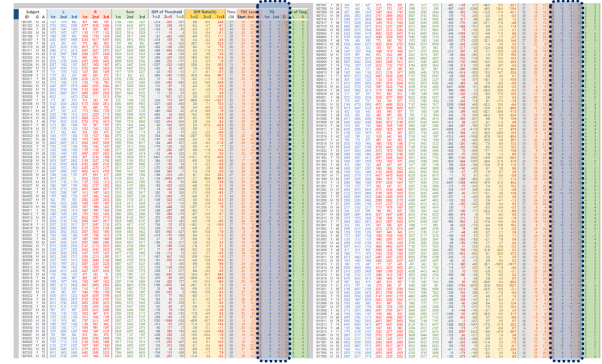
To examine the 2-week descending threshold volume changes of the 195 participants, the mean of the first 3-session median values was compared to the mean of the last 3-session median values for all participants. The volume started at 18.7 and decreased significantly to 16.19 at the end of the 2-week TSC ($P=0.0000$). This result demonstrates that the descending threshold volume values recorded by the 195 participants themselves in the MTM clinical listening logs changed in a statistically significant manner over the 2-week period. When the TSC Level values from the MTM basic statistical analysis table are arranged in ascending order, the difference between the blue dots and orange dots becomes clearly visible, as shown in the following graph.

An ascending array graph of descending threshold volume values

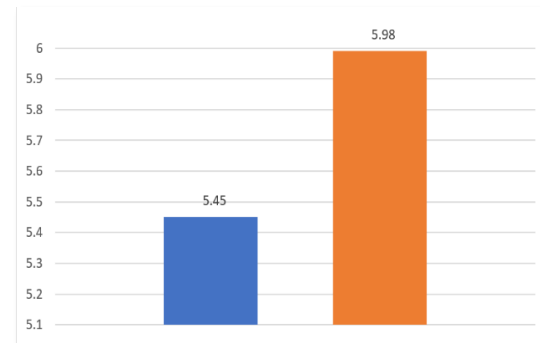


Changes in the Distribution of Tinnitus Resistance Scores

In the TM Basic Statistical Analysis Results Table, the 'TQ' column shows the tinnitus tolerance score results for all 195 subjects. The Tinnitus Questionnaire completed at Visit 1 and Visit 3 was scored from a minimum of 3 to a maximum of 15 points. A tinnitus tolerance score of 3 is the lowest tinnitus tolerance and indicates very severe tinnitus symptoms, while a score of 15 indicates no tinnitus symptoms in the last 3 days.

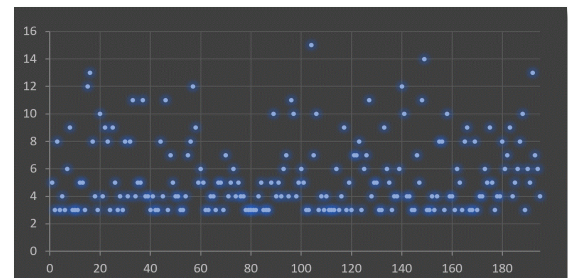


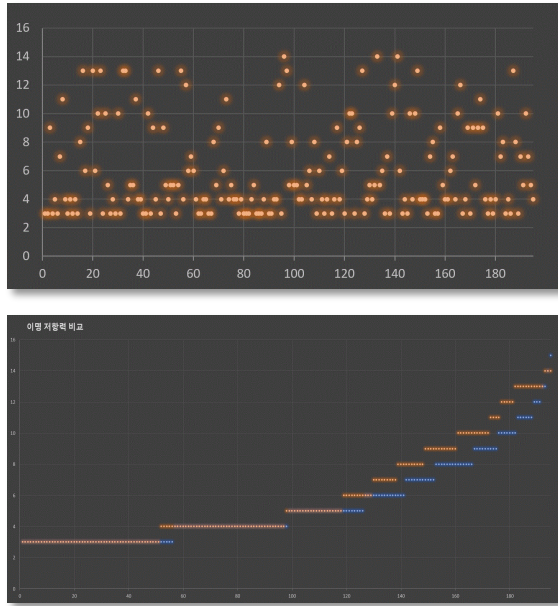
The mean tinnitus resistance score for all 195 subjects was 5.45 in the first round and 5.98 in the second round. This represents an improvement of 0.53 points in tinnitus resistance. This improvement was statistically significant ($P=0.0003$).



$P=0.0003$, T-test

In the 3-tinnitus resistance score distribution graphs below, the blue dots are the primary questionnaire scores and the orange dots are the secondary questionnaire scores. From the ascending distribution graph, we can observe that the distribution of primary tinnitus resistance scores is lower than the distribution of secondary scores, with more blue dots for lower scores and more orange dots for higher scores. This allows us to visually see that across the entire cohort of subjects, there was a statistically significant improvement in tinnitus resistance of 0.53 points after two weeks of listening to TSC tones between the four weeks of MTM clinical participation.



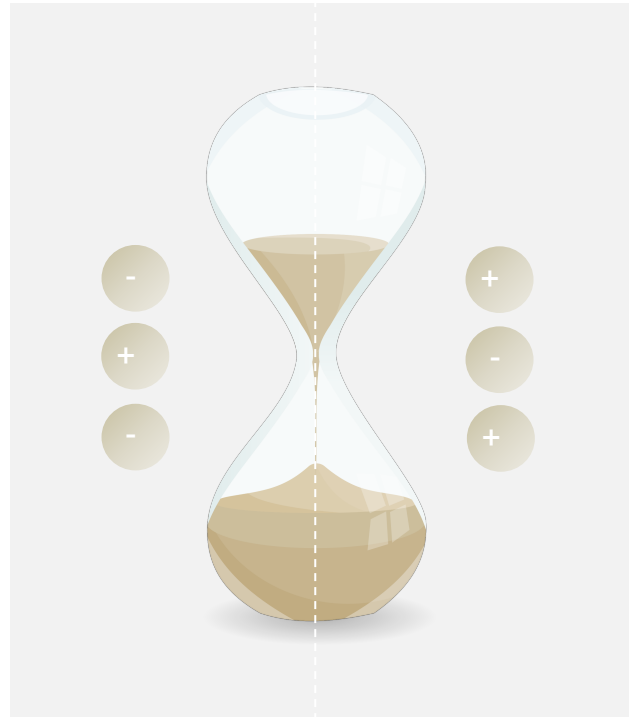


Changes in the Distribution of the Hearing Loss Index

The MTM protocol is a practice and procedure for diagnosing and treating tinnitus based on the RCPTA 67-band algorithm and TSC acoustic technology. The ultimate goal of tinnitus treatment using MTM is to fundamentally improve hearing. The ideal way to treat tinnitus is to improve hearing. The improvement of each subject's hearing is measured by the change rates in the hearing loss index derived from the results of the primary, secondary, and tertiary audiograms. The effectiveness of TSC in hearing can be shown by demonstrating that the "symmetrical hourglass hypothesis" is false when collectively comparing the change rates in the hearing index in the primary and secondary periods without TSC intervention with the change rates in the hearing index in the primary and tertiary periods according to the 2-week experience of TSC.

The "symmetrical hourglass hypothesis" is the view of otologists and audiologists that TSC does not improve hearing in clinical MTM. Most otologists and conventional audiologists assert that once hearing is damaged, it is irreversible and assume that 'there cannot be a significant improvement in the collective hearing loss index after 2 weeks of listening to TSC sound signals' because, according to their conventional beliefs, hearing loss should be irreversible and an 'incurable disease' that obeys the law of diminishing returns. Therefore, there would not be a significant difference between the rate of change of the hearing loss index in the first half of the TSC no-treatment period and

the rate of change of the hearing loss index in the third period of the TSC-prescribed period. Their argument is likened to the free-falling motion of sand grains in a perfectly horizontal, perfectly symmetrical hourglass and its consequences.



Assume that the hourglass above contains a total of 3.9 million grains of sand, and that they are labeled + or - on their surface. Split the image of the hourglass vertically down the middle and count the number of + and - grains on the left and right sides, respectively. Is there a statistically significant difference in the left-right distribution of +/- grains? Unless some "special force" is continuously applied to the +/- grains in free fall toward the bottom of the horizontal hourglass, there should be no significant difference between the left and right distributions of +/- grains. This is the "Hypothesis of free-falling +/- sand grains in a horizontal symmetric hourglass", or the "Symmetric Hourglass Hypothesis" for short.

To demonstrate that the symmetric hourglass hypothesis of most otologists and traditional audiologists follow is incorrect, the MTM trial attempted to establish an alternative hypothesis, the asymmetric hourglass model, by calculating the probability of rejecting it. To do this, a T-test was performed on change rates in hearing loss during the primary period of the TSC no-treatment and change rates in hearing loss during the tertiary period

of the TSC treatment. The following figures detail change rates in hearing loss Index for 192 patients (195 excluding 3 SOAEs) during the primary and secondary periods, and change rates in hearing loss Index during the primary and tertiary periods.

192 Patients' Change in Hearing Loss Index during the primary and secondary periods (TSC no-treatment Period)

9.8	-21.0	-8.4	4.3	-12.5	3.6	7.4	7.9
-5.2	14.2	4.5	-26.1	-2.4	8.1	-5.4	0.8
4.3	8.3	0.6	-0.9	8.5	-32.2	13.1	-26.0
0.3	2.9	-10.7	-16.5	-27.1	-12.4	4.8	52.8
-4.9	2.5	-6.2	-8.0	6.0	-43.2	2.6	-22.5
3.4	0.9	-6.7	-2.1	3.4	8.6	0.9	3.1
35.7	-2.3	-4.6	5.1	-4.8	6.1	-3.3	4.0
6.0	-20.7	-6.5	-2.6	-4.4	12.7	-22.4	8.1
6.4	5.4	-18.2	5.1	32.1	47.5	7.7	9.4
2.6	-3.0	-4.8	11.9	1.4	34.3	4.4	7.5
16.0	5.6	-9.4	6.5	-12.4	47.8	-17.6	-0.1
5.3	0.6	6.4	-43.9	7.1	25.3	-4.4	35.0
25.8	3.5	-0.6	11.4	1.3	7.0	-0.4	3.7
7.6	-112.1	2.8	3.8	0.3	6.2	0.7	5.7
2.1	-8.0	-1.6	-4.3	14.2	17.1	5.7	-17.0
47.6	1.5	-0.3	15.5	4.8	7.8	-2.1	8.7
-0.2	5.9	-3.2	-6.3	13.1	-16.9	1.7	-8.0
8.3	7.3	10.9	4.4	10.3	24.4	-2.5	2.2
-2.2	8.1	-4.0	-3.1	0.9	-13.6	31.8	-0.9
-4.1	2.1	9.6	-6.9	-18.1	6.1	8.1	-11.4
-0.2	-6.6	3.7	9.5	7.0	1.9	3.3	-2.4
0.0	-4.6	6.8	-11.4	-56.4	-0.1	0.9	12.7
3.6	0.3	15.4	-48.3	-26.2	4.3	-1.6	-0.2
5.4	-7.5	-30.9	49.3	-8.4	47.5	-2.9	3.6

192 Patients' Change in Hearing Loss Index during the primary and tertiary periods (TSC treatment Period)

24.8	1.9	2.1	-8.4	-32.1	4.3	10.3	3.2
-9.1	13.5	14.3	1.2	-4.3	-7.8	-3.8	0.7
3.5	12.9	-3.2	-3.5	1.2	-6.4	13.9	-30.3
-0.1	8.4	1.9	-0.2	-4.6	-30.6	4.6	102.7
11.1	-23.8	1.2	-9.1	11.9	-33.4	-1.3	-2.1
-0.6	2.0	6.1	-2.7	2.1	15.9	5.3	-4.2
32.5	-4.4	-1.1	6.3	6.6	4.8	-3.7	1.3
7.3	-7.5	-8.5	-1.6	-2.7	26.6	-8.8	3.1
17.3	7.0	-16.5	2.8	14.6	47.9	0.0	12.4
3.5	-11.6	-1.1	8.3	5.2	15.3	-1.6	10.3
31.4	1.7	7.9	0.7	15.3	60.4	-0.4	2.4
1.9	12.4	11.5	18.9	-2.9	29.7	16.2	31.7
30.5	5.0	1.1	13.4	19.0	13.2	-2.0	-8.9
6.9	-33.5	3.3	-1.1	14.5	10.2	2.9	5.7
-5.7	-4.8	2.1	-19.8	25.4	15.8	1.1	20.2
65.7	-0.6	1.6	-1.6	-3.4	9.0	5.9	0.7
-1.5	8.6	-0.3	1.0	40.4	-36.3	4.4	-59.7
24.9	0.0	-1.9	10.3	23.5	41.0	-3.2	3.8
-0.3	23.2	10.4	-8.5	5.1	11.2	5.3	7.8
-7.3	89.9	9.6	-7.3	-15.9	9.8	27.2	-7.5
0.9	-3.9	7.2	7.9	-0.6	2.6	3.5	-0.1
-15.0	6.1	6.5	-5.3	-3.5	-0.9	0.2	23.0
10.4	-3.6	44.0	-33.1	-0.2	11.2	-3.6	3.4
-2.2	-8.5	-26.6	119.4	10.0	64.2	-3.1	8.9

Is there a significant difference between the above two samples from the same group of 192 subjects, change rates in hearing loss index after the second and third period? To find out, we performed a t-test and found that there is a significant statistical difference between the two samples ($P = 0.0000$).

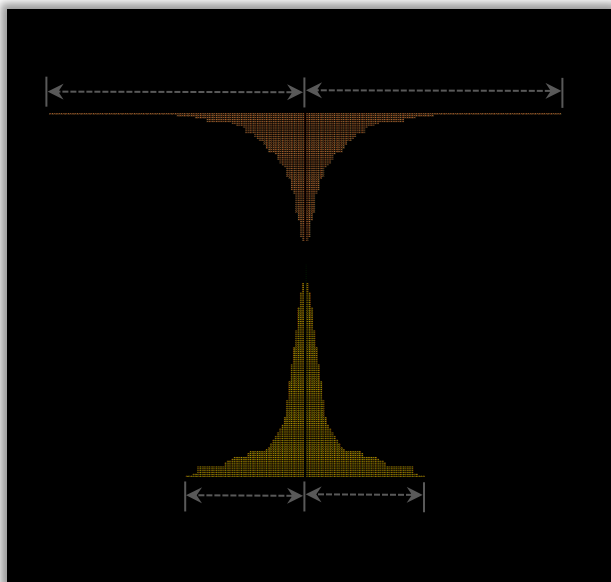
T-test for Dependent Samples (Spreadsheet)								
Marked differences are significant at $p < .05000$								
Variable	Mean	Std. Dev.	N	Diff.	Std. Dev. Diff.	t	df	p
Var1	0.992187	17.63038	192	0.00000	0.00000	0.00000	191	1.000000
Var2	0.992187	17.63038	192	-4.63750	15.93299	-4.03308	191	0.000000
Var1	5.629688	20.29207	192	0.00000	0.00000	0.00000	191	1.000000
Var2	5.629688	20.29207	192	-4.63750	15.93299	-4.03308	191	0.000000

The Var1 value in the table above shows that the mean value of change rates in hearing loss index for the 192 subjects during the primary and secondary periods is 0.9%. As we saw in Chapter 6, MTM Effects, there was no statistically significant difference between the hearing loss indices from the primary and the secondary test ($P = 0.2451$). Meaning that a percent change of 0.9% is a negligible change. In the table above, Var2 is the result of 192 subjects during the primary and tertiary periods with mean change rates in hearing loss index of 5.6%. There was a statistically significant difference between the hearing loss index at the first micro audiometric test and the hearing loss indices from the primary and the secondary test ($P = 0.0003$). Meaning that a change rate of 5.6% is not a negligible change and demonstrates the effectiveness of the TSC in causing this change. Finally, the T-test showed that there was a statistically significant difference between 0.9% that is the mean change rates in hearing loss index during the primary and secondary periods and 5.6% that is the mean change rates in hearing loss index during the primary and tertiary periods ($P < 0.0000$). It is important to note that stimulation of only two or three critical bands on each side of the 250-12,000 Hz frequency band for only two weeks (60 minutes per day) resulted in an average improvement in "gross hearing capacity" of 5.6% for the entire group of 192 subjects in the 250-12,000 Hz frequency band.

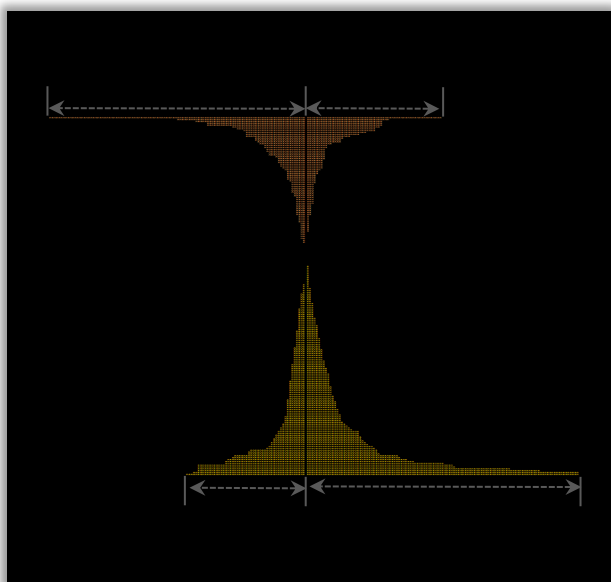


Asymmetric Hourglass Model 1

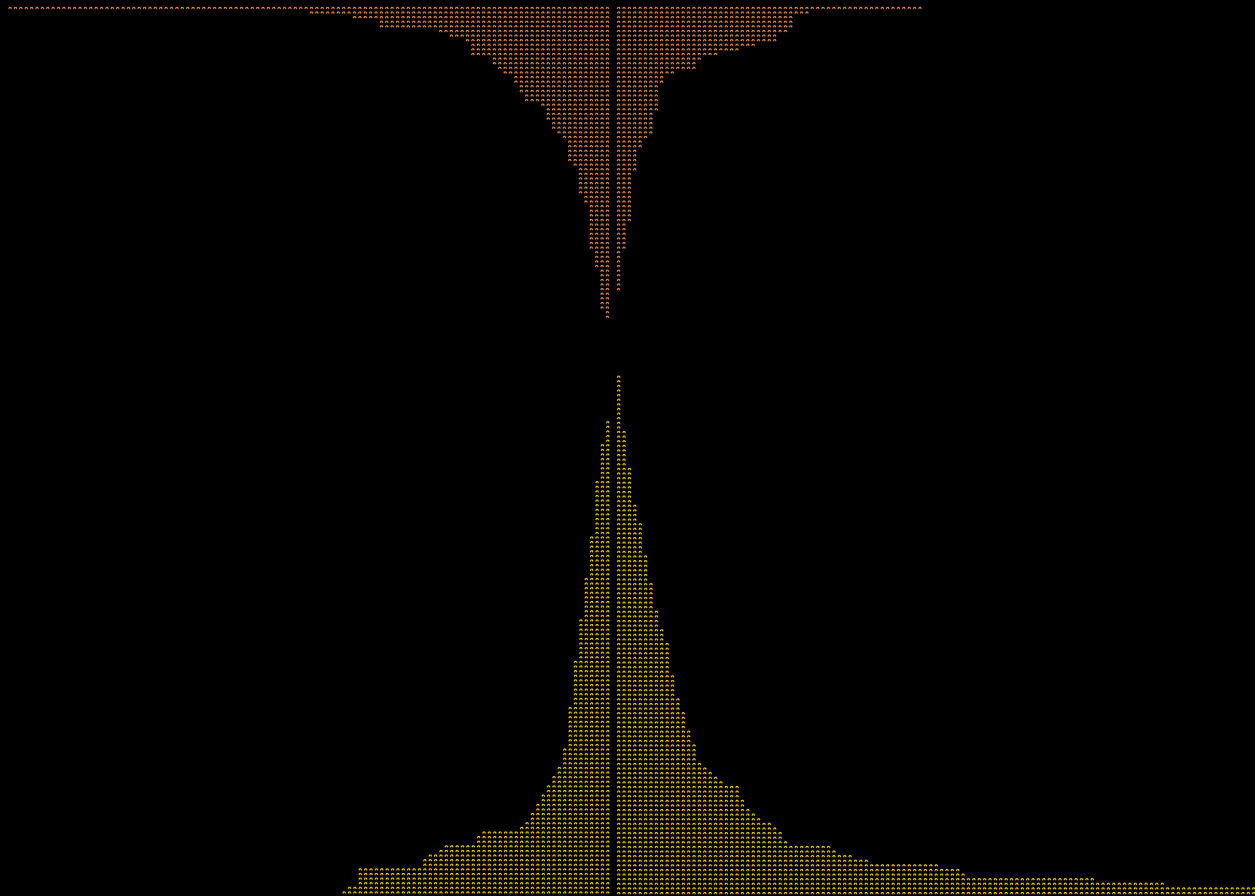
If TSC had no effect on the collective hearing of the 192 tinnitus patients, the "hourglass" image would be symmetrical, as shown above.



However, an analysis of an MTM clinical study of 192 tinnitus patients found that the symmetry hourglass hypothesis was not statistically significant. MTM clinical results based on the RCPTA 67-band algorithm support the asymmetry sandglass model, as shown in the image below. In the asymmetry hourglass model, the "special force" contributing to the asymmetrical distribution of sand particles is the TSC.



Asymmetric Hourglass Model 2



Changes in Test Time

The RCPTA 67-band algorithm stores 134 hearing threshold results at 67 frequencies for a subject, along with the times at which each hearing threshold was determined, measured in seconds. The total time it took to complete a single test, measured in seconds, is also reported. The total time it took for the 195 tinnitus patients perform the primary, secondary, and tertiary micro-audiometry was 546,837 seconds. The total time for the 195 patients' primary micro-audiometry was 184,087 seconds (51 hours 08 minutes 07 seconds), secondary micro-audiometry was 180,846 seconds (50 hours 14 minutes 06 seconds), and the tertiary audiogram was 181,904 seconds (50 hours 31 minutes 44 seconds). The average test time per subject was 944 seconds (15 minutes 44 seconds) to determine 134 gross hearing thresholds on the left and right side at 67 frequencies for the primary micro-audiometry performed on the first clinic visit. For the secondary test, it was 927 seconds (15 minutes 27 seconds) and for the tertiary test, 932 seconds (15 minutes 32 seconds). average time per subject was 17 seconds less for the secondary test than the primary test, and a T-test of the 17-second difference was statistically significant ($P=0.0351$).

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	944.0359	137.3913	195	0.0000	0.0000	0.00000	194	1.000000	0.0000	0.00000
Var1	944.0359	137.3913	195	0.0000	0.0000	0.00000	194	1.000000	0.0000	0.00000
Var1	944.0359	137.3913	195	0.0000	0.0000	0.00000	194	1.000000	0.0000	0.00000
Var2	927.4154	127.2638	195	-16.6205	109.3796	-2.12190	194	0.035115	-32.0690	-1.17207
Var3	932.8410	120.6453	195	-11.1949	109.7672	-1.42418	194	0.156002	-26.6981	4.30833
Var2	927.4154	127.2638	195	-16.6205	109.3796	-2.12190	194	0.035115	-32.0690	-1.17207
Var2	927.4154	127.2638	195	0.0000	0.0000	0.00000	194	1.000000	0.0000	0.00000
Var2	927.4154	127.2638	195	0.0000	0.0000	0.00000	194	1.000000	0.0000	0.00000
Var3	932.8410	120.6453	195	-5.4256	82.7227	-0.91589	194	0.360861	-6.2579	17.10915
Var3	932.8410	120.6453	195	-11.1949	109.7672	-1.42418	194	0.156002	-26.6981	4.30833
Var3	932.8410	120.6453	195	-11.1949	109.7672	-1.42418	194	0.156002	-26.6981	4.30833
Var3	932.8410	120.6453	195	5.4256	82.7227	0.91589	194	0.360861	-6.2579	17.10915
Var3	932.8410	120.6453	195	0.0000	0.0000	0.00000	194	1.000000	0.0000	0.00000

test two weeks after the primary test because the subjects were more familiar with and skilled at the test, but the RCPTA algorithm test does not require subjects to be skilled. No matter how unfamiliar the test is, it only takes about 10 seconds for subjects to adjust to the test method, which requires them to press a button when they hear the test sound and do nothing when they don't hear it. Why was there a significant difference in test time between the primary and secondary rounds of micro-audiometry? Based on the fact that, among the 195 MTM clinical participants,

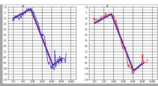
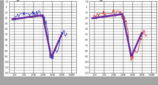
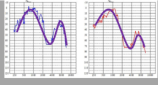
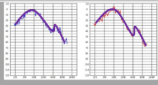
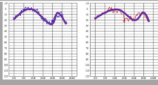
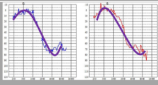
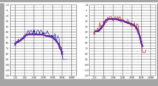
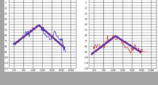
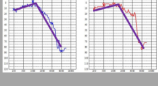
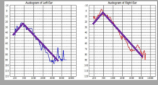
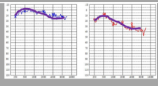
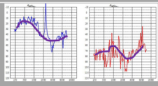
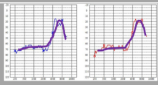
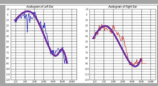
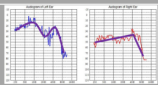
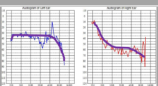
- 36% showed a hearing improvement of 5% or more during the TSC no-treatment phase (primary and secondary periods), while
- 22% experienced a hearing deterioration of 5% or more during the same phase,

it is conceivable that some psychological factors may have stabilized the threshold fluctuation range even without TSC intervention during the primary and secondary periods. This stabilization might have been the cause of the significantly reduced test time between the primary and secondary micro-audiometry sessions.

Micro-audiogram Typology Table

It is highly unlikely that a 67-band micro-audiometry will show identical results between different tinnitus patients; even within the same tinnitus patient, the shape of the 67-band micro-audiometry can change from test to test. However, as shown in the following table, MTM clinicians have attempted to categorize 15 micro-audiogram types by examining all 195 subjects for commonalities in micro-audiogram contours. The following micro-audiogram type classification table is more practical than academic in nature.



유형	그래프 윤곽	특징	피험자 ID	난청지수변화	하향역치	TQ
Z		0.25~1 KHz 하강 1~4 KHz 상승 4~12 KHz 하강	1801002,1803002,1803007,1803028,1803030,1805014,1810021,1811007,1815002,1815010,1815011	1 st 5964 2 nd 5889 3 rd 6000	시작 16.5 끝 15.5	1 st 3.8 2 nd 4.8
2		0.25~2 KHz 유사 2~4 KHz 상승 4~12 KHz 하강	1802002,1803014,1805011,1805019,1805030,1817005	1 st 4244 2 nd 4530 3 rd 3846	시작 15.5 끝 13.8	1 st 3.8 2 nd 4.2
3		0.25~1 KHz 하강 1~4 KHz 상승 4~8 KHz 하강 8~12 KHz 상승	1801001,1801004,1801005,1801006,1801011,1802004,1803004,1803015,1803018,1803020,1803023,1803035,1804002,1804005,1804007,1804009,1804011,1804017,1804019,1805003,1805006,1805018,1805020,1805031,1806001,1806002,1807002,1807005,1807017,1808003,1808012,1809002,1809005,1809007,1809016,1810004,1810018,1810024,1811005,1811009,1812007,1812008,1813005,1813012,1813014,1813015,1815003,1815006,1815014,1815015,1816001,1816003	1 st 4136 2 nd 4161 3 rd 4073	시작 19.1 끝 16.3	1 st 4.9 2 nd 5.3
부드러운 3		3 형태보다 변동 폭이 작고 부드러운 편, 0.25~1 KHz 하강, 1~4 KHz 상승, 4~8 KHz 유사 또는 상승, 8~12 KHz 상승	1802001,1803001,1803017,1803019,1803033,1804012,1805001,1805002,1805008,1805015,1805024,1805026,1805027,1805028,1805029,1805034,1805035,1807009,1807016,1807019,1808006,1809003,1809004,1809010,1809012,1809021,1810001,1810006,1810009,1810010,1812005,1812006,1812012,1813002,1813003,1813007,1813018,1815007,1815008	1 st 3647 2 nd 3531 3 rd 3532	시작 19.8 끝 17.0	1 st 5.3 2 nd 6.1
M		0.25~1 KHz 하강 1~4 KHz 상승 4~8 KHz 하강 8~12 KHz 상승	1801009,1802008,1804001,1804018,1807003,1807008,1808014,1809009,1810005,1810017,1812001,1813001,1813008,1817003	1 st 3097 2 nd 2996 3 rd 2883	시작 16.7 끝 14.4	1 st 7.5 2 nd 7.9
乙		0.25~1 KHz 하강 1~4 KHz 상승 4~12 KHz에서 4 KHz와 유사	1802011,1803003,1803037,1806007	1 st 4602 2 nd 4740 3 rd 4750	시작 21.3 끝 18.8	1 st 6.3 2 nd 6.5
아치		0.25~1 KHz 하강 2~4 KHz에서 1 KHz와 유사 4~12 KHz 상승	1803024,1803025,1810008,1810016,1810022,1811003	1 st 3977 2 nd 3358 3 rd 3094	시작 16.2 끝 13.8	1 st 7.3 2 nd 8.5
곡절 부호 ^		0.25~2 KHz 하강 2~12 KHz상승	1801007,1803026,1813019,1813021,1817004	1 st 4459 2 nd 5153 3 rd 4566	시작 20.2 끝 15.8	1 st 4.8 2 nd 5.8
ㄱ		0.25~1 KHz 하강 1~12 KHz 상승	1803021,1804010,1805004,1805012,1807012,1809013,1809018,1812014,1813004,1813011,1815005	1 st 4580 2 nd 4671 3 rd 4511	시작 19.2 끝 17.6	1 st 3.8 2 nd 4.4
지팡이		0.25~0.5 KHz 하강 0.5~12 KHz 상승	1803005,1803008,1803022,1803032,1805007,1805009,1809011,1810011,1811006	1 st 5976 2 nd 5466 3 rd 5531	시작 20.1 끝 15.6	1 st 4.3 2 nd 4.8
얇은 물결		0.25~1 KHz 하강 2~4 KHz 상승 4~12 KHz 하강 또는 4 KHz와 유사	1803010,1803011,1805016,1805021,1807007,1809020,1811004,1812002,1812009,1813010	1 st 2509 2 nd 2755 3 rd 2513	시작 20.4 끝 17.8	1 st 7.6 2 nd 9.5
깊은 물결		격동이 매우 많은 상태	1802009,1804020,1808004,1808005,1810002,1810012,1811002,1811010,1813013,1813020,1815009,1815012,1817001	1 st 5413 2 nd 5289 3 rd 4639	시작 13.4 끝 11.8	1 st 7.5 2 nd 7.5
기타		위의 유형에 해당되지 않는 형태	1801010,1802003,1803016,1805022	1 st 7068 2 nd 6937 3 rd 6885	시작 20.8 끝 17.8	1 st 5.0 2 nd 5.0
3, 乙 혼합		한쪽은 3 형태 한쪽은 乙 형태	1804014,1806005	1 st 4893 2 nd 4942 3 rd 4724	시작 17.0 끝 16.0	1 st 6.5 2 nd 3.5
ㄱ, 3 혼합		한쪽은 ㄱ 형태 한쪽은 3 형태	1805025,1812003,1812011,1813009,1813016	1 st 4796 2 nd 4252 3 rd 4521	시작 16.0 끝 15.0	1 st 7.4 2 nd 7.8
기타		위의 유형에 해당되지 않는 형태	1802007,1803029,1803034,1817008	1 st 6833 2 nd 6582 3 rd 5255	시작 23.8 끝 22.3	1 st 3.8 2 nd 3.5

8. Analysis of MTM Clinical Results 2

Subject	ID	G	A	L	R			Sum	Diff of Threshold		Diff Ratio(%)		Time	TSC Level		TQ	N of Targ	L	R
					1st	2nd	3rd		1st	2nd	1st	2nd		Start	End				
1600007	5	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600008	6	271	292	81	271	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600009	7	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600010	8	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600011	9	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600012	10	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600013	11	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600014	12	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600015	13	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600016	14	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600017	15	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600018	16	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600019	17	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600020	18	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600021	19	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600022	20	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600023	21	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600024	22	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600025	23	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600026	24	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600027	25	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600028	26	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600029	27	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600030	28	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600031	29	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600032	30	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600033	31	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600034	32	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600035	33	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600036	34	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600037	35	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600038	36	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600039	37	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600040	38	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600041	39	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600042	40	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600043	41	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600044	42	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600045	43	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600046	44	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600047	45	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600048	46	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600049	47	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600050	48	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600051	49	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600052	50	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600053	51	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600054	52	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600055	53	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600056	54	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600057	55	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600058	56	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600059	57	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600060	58	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600061	59	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600062	60	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600063	61	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600064	62	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600065	63	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600066	64	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600067	65	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600068	66	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600069	67	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600070	68	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600071	69	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600072	70	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600073	71	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600074	72	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600075	73	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600076	74	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600077	75	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600078	76	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600079	77	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600080	78	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600081	79	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600082	80	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600083	81	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600084	82	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600085	83	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600086	84	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600087	85	187	292	81	187	292	256	162	-12	-32	81	24	21	1	1	1	1	1	1
1600088	86	187	292	81	187	292	256	162	-12	-32	81	24							

Hearing Change Over 4 Weeks in 192 People

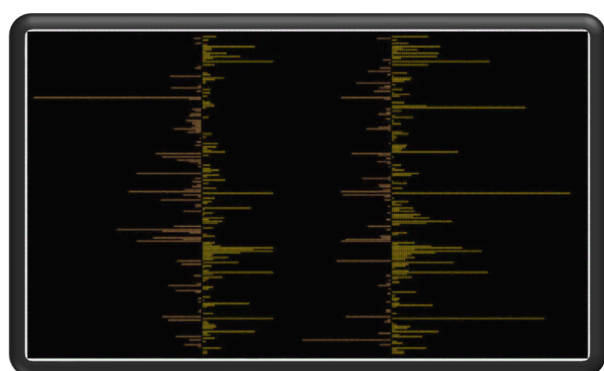
One of the main objectives of the MTM clinical study was to establish the MTM 4-week protocol as the minimum standard of care for the accurate diagnosis and treatment of tinnitus. The RCPTA 67-band algorithm was used for the accurate diagnosis of tinnitus, and various quantitative numerical information such as tinnitus frequency, tinnitus intensity, and hearing loss index were calculated and identified through this algorithm. In addition, a total of 258 patients from 17 medical centers in Korea participated in the MTM clinical study to find out how effective the TSC acoustic technology is in treating tinnitus and hearing loss after just two weeks of application. Of these, 195 patients completed the 4-week MTM trial and measured spontaneous otoacoustic emissions (SOAE) as tinnitus. Tinnitus and hearing information from 192 subjects, excluding 3 misidentified subjects, was analyzed from various angles.

Let's take a closer look at the results of several samples to see

how much hearing improvement and tinnitus changed in the group of 192 subjects who experienced TSC acoustic technology twice a day for two weeks for 30 minutes. In the above <MTM Basic Statistical Analysis Results Table>, the blue dotted line is the sum of the 134 left and right hearing threshold values for a total of 195 subjects, including the 3 SOAEs, and is the "gross hearing" or hearing loss index. To get a clearer picture of their results, we first excluded the three SOAEs from further analysis and then performed multiple analyses on the remaining 192 participants.

The following graph shows the rate of change of the hearing index arranged in the order of subject ID. Based on the center of the two graphs, the orange/yellow lines on the left indicate the rate of change of the hearing index of the primary and secondary period, and the orange/yellow lines on the right indicate the rate of change of the hearing index of the primary and secondary period. The orange line toward the left indicates that the hearing deteriorates when the rate of change of the

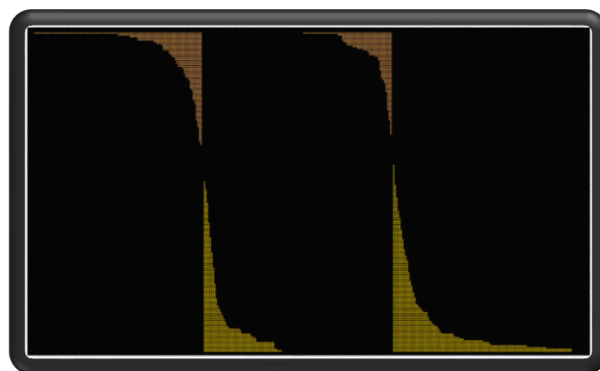
hearing index is negative during the period. The yellow line toward the right indicates that the hearing improvement is positive when the rate of change of the hearing index is positive. The orange lines of the primary and secondary period are shorter in the primary and secondary period, and the yellow lines of the primary and secondary period are longer in the primary and secondary period.



**<4-week hearing changes for 192 subjects
in order of ID>**

From the above graph, the hearing deterioration of 192 tinnitus patients who participated in the MTM clinical trial decreased in 4 weeks and the hearing improvement increased in 4 weeks.

Let's look at the hearing changes of 192 subjects from a different perspective. The results of the above graph, in which the rate of change in the hearing index is arranged in order of the subject ID, show that the vertical arrangement of the numbers is random in terms of the rate of change itself. By arranging the random arrangement of the rate of change in the hearing index from top to bottom on the graph in ascending order, the hearing change pattern can be observed more clearly. In the graph below, the left side of the primary and secondary periods indicates the rate of change in the hearing index, and the right side indicates the rate of change in the primary and tertiary periods. Orange indicates deterioration of hearing, and yellow indicates improvement in hearing during that period. From the graph below, it can be seen that the hearing deterioration (orange graph) of the 192 patients group in the MTM clinical trial decreased in 4 weeks and the hearing improvement (yellow graph) increased in 4 weeks.



**<4-week hearing changes of 192 subjects
in ascending order>**

The fact that the 4-week MTM protocol prevents hearing deterioration and promotes hearing improvement in moribund patients can be more clearly identified through an ascending graph of the rate of change in the hearing index. Can this phenomenon be said to be a universal phenomenon that can be reproduced in all other medical institutions that adopt the MTM 4-week protocol?

The following graph is an "asymmetric hourglass model" based on the actual clinical results examined in Chapter 7. It is a graph that rearranged the ascending graph of the rate of change in the hearing loss index to be opposed to each other. The asymmetric hourglass model below must be symmetrical left and right if the MTM 4-week protocol had no effect on improving the hearing of tinnitus patients. However, the reason why the MTM clinical results were asymmetric as follows is that the two-week TSC prescription and the entire MTM clinical tools had a significant effect on the fundamental hearing of tinnitus patients.



**<4-week hearing changes of 192 subjects
in ascending order in left-right opposite>**

Let's look at the statistical verification results. In the statistical results table below, Var1, Var2, and Var3 are the hearing loss indices measured at the 1/2/3rd minute, respectively. The mean of the primary hearing loss index (Var1) of 192 patients was 4,393, the mean of the secondary hearing loss index (Var2) was 4,336, and the mean of the tertiary hearing loss index (Var3) was 4,169. No significant hearing change was observed between the primary and secondary period without a TSC prescription, that is, Var1 and Var2 ($P=0.2451$).

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	4393.401	2038.860	192	0.000	0.00000	0.00000	191	1.000000	0.000	0.000
Var2	4336.067	2114.030	192	-57.344	681.5201	-1.16589	191	0.245112	-154.358	39.671
Var3	4169.182	2139.225	192	-224.219	845.5221	-3.67449	191	0.000309	-344.579	-103.859
Var1	4393.401	2038.860	192	0.000	0.00000	0.00000	191	1.000000	0.000	0.000
Var2	4336.067	2114.030	192	-57.344	681.5201	-1.16589	191	0.245112	-154.358	39.671
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Var2	4336.067	2114.030	192	-57.344	681.5201	-1.16589	191	0.245112	-154.358	39.671
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Var2	4336.067	2114.030	192	-57.344	681.5201	-1.16589	191	0.245112	-154.358	39.671
Var3	4169.182	2139.225	192	-224.219	845.5221	-3.67449	191	0.000309	-344.579	-103.859

However, there were statistically significant hearing changes in the secondary and tertiary period, i.e., Var2 and Var3, where TSC was prescribed. A P value of 0.0007 means that the confidence level of the statistics reaches 99.93%. If about 1,000 medical institutions introduce the MTM 4-week protocol under the same clinical conditions, it can be interpreted that 999 medical institutions may experience significant hearing changes even after only two weeks of TSC prescription. The hearing improvement effect of the 2-week TSC experience was still found to induce significant hearing improvement changes even when comparing the mean of the primary hearing loss index (Var1) and the mean of the tertiary hearing loss index (Var3) over the entire 4-week MTM clinical period ($P=0.0003$).

Analyze the Change in Four Metrics

Healthcare providers implementing MTM clinical protocols to alleviate tinnitus symptoms and improve hearing in their patients must be proficient in obtaining, analyzing, and interpreting the following four quantitative audiometric measures.

Tinnitus Changes
Hearing Changes 1
Hearing Changes 2
Descending Threshold Change

<Tinnitus Changes>

Quantitative changes in tinnitus should be recorded and observed by securing the tinnitus resistance score based on the

three-question tinnitus questionnaire before and after TSC prescription, respectively.

<Hearing Change 1>

A total of three 67-band micro-audiometry results, including the primary, secondary, and tertiary, should be conducted every two weeks, and the hearing change results should be secured 4-week by analyzing the hearing difference between the primary and the tertiary results.

<Hearing Change 2>

A total of three 67-band micro-audiometry results, including the primary, secondary, and tertiary, should be conducted every two weeks, and the hearing change results of the TSC 2-week prescription should be secured by analyzing the hearing difference between the secondary and the tertiary results.

<Descending Threshold Change>

During the 2-week TSC implementation period, the patient should record the descending threshold value by hand. For this purpose, the medical staff should provide the patient with a patient's listening diary form, and the patient should record the descending threshold value every 28 listening points based on the 2-week TSC.

The MTM protocol is an audiologic practice that treats tinnitus by promoting fundamental improvements in hearing. When observing and analyzing changes in tinnitus symptoms, healthcare providers must look closely at both macroscopic gross hearing and microscopic frequency-specific hearing status. Because it would require extensive analysis to examine the hearing changes in a group of 192 tinnitus patients by tinnitus frequency or by individual, this book focuses only on macroscopic hearing change analysis and does not detail the microscopic hearing changes in the clinical results. In the MTM study, the TSC acoustic signal was listened to at an average of 4.67 frequency points in each ear per subject. Therefore, the arithmetic sum of the TSC listening frequency bands of the 192 subjects is approximately 897 TSC frequency points (192 subjects x 4.67 TSC frequencies). To examine the pattern of hearing change at of the 897 TSC frequency points of the 192 subjects in terms of various variables such as frequency-specific unheard hearing change rate, hearing loss index, gross hearing change rate, descending threshold change rate, tinnitus resistance, age, and gender, multivariate analysis of variance (MANOVA) or post hoc tests were used.

Post hoc test and other in-depth statistical analysis techniques

were used to validate this data. A broader analysis of 120,149 samples (192 patients x 134 frequencies x 4.67 TSC frequencies) would be required to examine the patterns of how a total of 897 TSC frequency points in 192 patients induced hearing changes in relation to 67 (134 in each ear) individual frequency points in the entire frequency band 250-12,000 Hz, and their interrelationships (e.g., with overtone plates or critical bands). The results of these analyses will be discussed in detail in the upcoming book *Diagnosis and Treatment of MTM Tinnitus*, Volume 2.

As the MTM trial was focused on tinnitus, the tinnitus resistance metric was used as the centerpiece of the other three hearing metrics (Hearing Change 1, Hearing Change 2, and Descending threshold change), let's see what happened. In Chapter 6, MTM effects, we discussed the 4:4:2 effect in 195 subjects, including 3 SOAEs. Let's look at the statistical significance of the hearing changes in the 77 subjects in Group A, 76 subjects in Group B, and 42 subjects in Group C. The tinnitus-weighted Statistical evidence suggests that the phenomenon is not due to hearing deterioration. In the four metric change analysis in Chapter 8, examine the extent to which all three-hearing metrics (Hearing Change 1, Hearing Change 2, and Descending threshold Change) improved at once for each of the three changes in tinnitus symptoms (improved tinnitus, no change in tinnitus, and worsening tinnitus) for the 195 participants.

Of the total 195 subjects, 42 subjects reported an increase in the intensity or frequency of tinnitus after 2 weeks of TSC. Of these subjects, two subjects (1806001 and 1805035) had a decrease in hearing across all three-hearing metrics (Hearing Change 1, Hearing Change 2, and Descending threshold Change). Subject 1806001 had a primary hearing loss index of 1,335 and a tertiary hearing loss index of 1,357, indicating that his hearing was nearly normal, while subject 1805035 was an 83-year-old male patient with age-related hearing loss.

Subject ID	G	A	L			R			Sum	Diff Ratio(%)			Time /28	TSC Level		
			1st	2nd	3rd	1st	2nd	3rd		1vs2	2vs3	1vs3		Start	End	D

1806001	M	46	725	595	682	610	532	675	1335	1127	1357	15.5	-20.4	-1.6	38	14	24	-10
1805035	M	83	1937	2060	2367	1902	1947	2235	3839	4007	4602	-4.3	-14.8	-19.8	24	14	15	-1

Of the 42 subjects who reported increased tinnitus intensity or increased frequency of tinnitus after 2 weeks of TSC, 16 subjects improved on all three audiometric measures, as shown in the following table. For 16 of the 42 subjects (38%), the increase in tinnitus was likely due to the underlying hearing improvement.

Subject ID	G	A	L			R			Sum	Diff Ratio(%)			Time /28	TSC Level		
			1st	2nd	3rd	1st	2nd	3rd		1vs2	2vs3	1vs3		Start	End	D

Of the 195 total subjects, 77 subjects reported a decrease in the intensity or frequency of tinnitus after 2 weeks of TSC. Of these, 32 subjects improved on all three audiometric measures. Their results were as follows.

Subject ID	G	A	L			R			Sum	Diff Ratio(%)			Time /28	TSC Level		
			1st	2nd	3rd	1st	2nd	3rd		1vs2	2vs3	1vs3		Start	End	D

The number of subjects who reported no change in tinnitus intensity or frequency of tinnitus after 2 weeks of TSC was 76. Of these, 37 subjects improved on all three audiometric measures. Their results were as follows.

Subject ID	G	A	L			R			Sum	Diff Ratio(%)			Time /28	TSC Level		
			1st	2nd	3rd	1st	2nd	3rd		1vs2	2vs3	1vs3		Start	End	D

4189 to 3531

In a total of 192 tinnitus patients who participated in the 4-week MTM trial, all three audiometric measures (Hearing Change 1, Hearing Change 2, and Descending threshold Change) improved within 4 weeks, regardless of whether or not there was a change in tinnitus. 85 people. That's 44.2% of 192 people. If 1,000

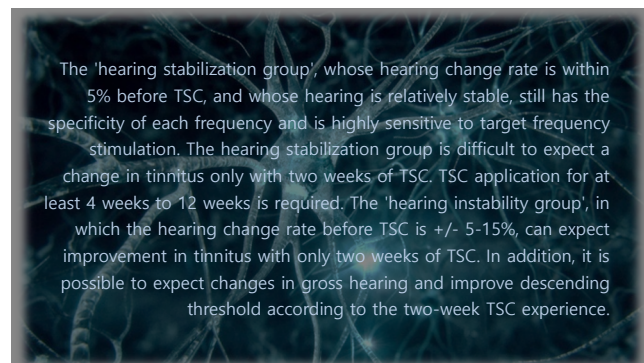
tinnitus patients participated in the 4-week MTM protocol, this means that 442 of them could reliably improve their "gross hearing capacity" or "gross hearing" within 4 weeks. These improvements were the result of listening to approximately 4.67 TSC sound signals per subject for 30 minutes, twice a day, for two weeks. But what is the level of hearing improvement? Let's take a look at the results of the statistical analysis. In the statistical analysis table below, the number of samples (N) is 85, and Var1, Var2, and Var3 are the hearing loss indices measured by the primary, secondary, and tertiary micro-audiometry, respectively. The mean of the primary hearing loss index (Var1) of 85 people was 4,189, the mean of the secondary hearing loss index (Var2) was 3,961, and the mean of the tertiary hearing loss index (Var3) was 3,531.

Variable	Mean	Std. Dev.	N	Diff.	Std. Dev. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	4189.812	1897.176	85	0.000	0.0000	0.00000	84	1.00000	0.000	0.000
Var2	3961.155	1893.888	85	0.000	0.0000	0.00000	84	1.00000	0.000	0.000
Var3	3531.706	1867.662	85	0.000	0.0000	0.00000	84	1.00000	0.000	0.000
Var1	4189.812	1897.176	85	228.647	739.2195	2.85169	84	0.005472	-388.093	-69.201
Var2	3961.155	1893.888	85	658.106	983.1342	6.17152	84	0.000000	-870.163	-446.049
Var1	4189.812	1897.176	85	-228.647	739.2195	-2.85169	84	0.005472	-388.093	-69.201
Var2	3961.155	1893.888	85	0.000	0.0000	0.00000	84	1.00000	0.000	0.000
Var3	3531.706	1867.662	85	429.459	725.6904	5.45607	84	0.000000	-595.987	-272.931
Var1	4189.812	1897.176	85	-658.106	983.1342	-6.17152	84	0.000000	-870.163	-446.049
Var2	3961.155	1893.888	85	-429.459	725.6904	-5.45607	84	0.000000	-595.987	-272.931
Var3	3531.706	1867.662	85	0.000	0.0000	0.00000	84	1.00000	0.000	0.000

There was also a significant change in hearing between Var1 and Var2 in the primary and secondary periods with TSC no-treatment ($P=0.0054$), with a hearing loss index of 228. There was a significant change in hearing between Var2 and Var3 during the secondary and tertiary periods with a 2-week TSC prescription ($P=0.0000$). The hearing improvement from the 2-week TSC trial was even more pronounced when comparing the mean of the primary hearing loss index (Var1) and the mean of the tertiary hearing loss index (Var3) across the entire 4-week MTM trial. During the 4-week MTM period, the 85 subjects improved by 658 (15.7%), from 4,189 to 3,531, a statistically significant difference ($P=0.0000$).

It is safe to understand that the improvement of all three hearing indicators in the MTM clinical trial is a 'definitely' or 'clearly' improvement in hearing. Let's note once again that the group hearing improvement of 44.2% of the subjects in the entire group of 192 tinnitus patients by the hearing index of 658 (15.7%) was the result of only two weeks of TSC in the MTM 4-week protocol. About 4.67 TSC acoustic signals per subject were listened to for two weeks in the descending threshold, how did it lead to the change in gross hearing across the entire frequency band of 250 to 12,000 Hz? How can we interpret the statistically significant improvement in the hearing index at the entire frequency even though only two to three specific

frequency bands were stimulated at the descending threshold level? To explain this in detail, Chapter 9 MTM Clinical Analysis Results 3 analyzes the MTM clinical results in more detail in the relationship between the central auditory background plate and the critical band frequency.



Analytics Based on Hearing Stability

Interesting differences were found between the clinical outcomes of the stable hearing group and the unstable hearing group when the subjects whose hearing difference in the primary and secondary period without prescription of TSC was less than +/- 5% were called the stable hearing group and the subjects whose hearing difference in the primary and secondary period was in the range of +/- 5 to 15% were called the unstable hearing group. A total of 80 subjects had relatively stable hearing with less than +/- 5% before TSC, and these subjects had no change in their hearing even after the 2-week TSC experience. In contrast, a total of 73 subjects had a somewhat unstable hearing with a hearing change of +/- 5 to 15% before TSC, and these subjects had significantly improved hearing after the 4-week MTM experience ($P=0.0029$), and the average change rate of hearing was 5.08%. 80 subjects in the stable hearing group also had no change after the 2-week TSC experience in their tinnitus scores. In contrast, 73 subjects in the unstable hearing group had statistically significant improvement in their tinnitus scores from 5.31 to 5.87 after the 2-week TSC experience ($P=0.0170$). All 153 subjects in the stable and unstable hearing groups showed statistically significant improvement in the descending threshold numerical results. 80 patients in the stable hearing group had a significant improvement in the descending threshold after 2 weeks of TSC ($P<0.0000$) and the listening volume level decreased by an

average of 2.71 within 2 weeks. For 80 patients in the stable hearing group, whose gross hearing did not change but only the descending threshold was significantly improved, microscopic hearing analysis is required for each frequency. 73 patients in the unstable hearing group also had a significant decrease in the descending threshold volume level by an average of 2.63 after 2 weeks of TSC ($P=0.0000$). The results of the stable and unstable hearing groups can be briefly summarized as follows.

Hearing change of 5% or less prior to TSC. The relatively stable 'Stable Hearing Group' has a high sensitivity to target frequency stimulation, with frequency-specificity still valid. In the stable hearing group, 2 weeks of TSC is not enough to change tinnitus. A minimum of 4 to 12 weeks of TSC is required. Hearing change rate before TSC. The 'Unstable Hearing Group' with +/- 5-15% can expect improvement in tinnitus after only 2 weeks of TSC. They also expect to see a change in gross hearing and an improvement in descending thresholds after 2 weeks of TSC.

The above descriptions are based on significant statistical differences between groups, but individual variation within groups is expected.

In addition to the stable and unstable hearing groups, there is also a 'turbulent group'. Subjects with a difference in hearing loss of +/- 15% or more during the primary and secondary periods can be categorized into the turbulent group, which included 42 of the 195 subjects. What happens to the gross hearing, descending threshold, and tinnitus resistance of subjects who already have severe hearing changes beyond the +/- 15% level without prescribing TSC after 2 weeks of TSC? The 42 subjects with a hearing difference of +/- 15% or more at Day 1 showed a significant improvement in gross hearing (hearing loss index) of 500 (15.5%) from 3,231 to 2,731 after 2 weeks of TSC ($P=0.0007$). There was also a statistically significant improvement in descending thresholds after 2 weeks of TSC, with a mean improvement of 1.80 ($P=0.0180$). Tinnitus resistance scores also improved significantly after 2 weeks of TSC, from a mean of 6.61 to 7.57 ($P<0.0081$).

The table below summarizes and compares the results of the statistical analysis of changes in gross hearing, descending threshold, and tinnitus between the three groups: 80 stable, 73 unstable, and 42 turbulent.

	1/2차 시기의 난청지수변화율(청력안정성)에 따른 분석		
	+/- 5% 미만의 안정적인 청력일 때	+/- 5~15%의 다소 불안정한 청력일 때	+/- 15% 이상의 매우 불안정한 청력일 때
TSC 2주 실시 후 난청지수 변화	X	O	O
TSC 2주 실시 후 하향역치 변화	O	O	O
TSC 2주 실시 후 이명 변화	X	O	O

Analysis by Primary Tinnitus Resistance Score

The scoring criteria for tinnitus resistance is a minimum of 3 and a maximum of 15. In the MTM study, there were a total of 166 subjects with a median tinnitus resistance score of less than 9. Approximately 85% of the 195 subjects had moderate, severe, or profound tinnitus with a Tinnitus Resistance Score of 9 or less. The number of subjects whose tinnitus resistance decreased after 2 weeks of TSC was 30. This is 18% of 166 patients with moderate, severe, or profound tinnitus. There was little change in their hearing loss index. The number of subjects who did not change their tinnitus resistance even after 2 weeks of TSC was 70. This is equivalent to 42% of 166 patients with moderate, severe, or profound tinnitus. Their hearing loss index improved. The number of subjects with improved tinnitus resistance after 2 weeks of TSC was 66. This is equivalent to 40% of 166 patients with moderate, severe, or profound tinnitus. Their hearing loss index also improved.

The mean degree of decline in the group of 30 patients (18%) with decreased tinnitus resistance after 2 weeks of TSC was 1.63 points, and the mean degree of improvement in the group of 66 patients (40%) with improved tinnitus resistance was 2.24 points. A total of 136 subjects with moderate, severe, or profound tinnitus improved their hearing loss index after 2 weeks of TSC, which is 82% of 166 subjects.

	TSC 2주 실시 기준 이명환자수 변화		
	TSC 실시 전	TSC 실시 후	비고
이명저항력 3점	56명	36명	평균 3점에서 4.45점으로 20명 개선
이명저항력 4점	42명	20명	22명 중 13명이 평균 4점에서 6.38점으로 개선
이명저항력 5점	28명	9명	19명 중 9명이 평균 5점에서 7.37점으로 개선
이명저항력 6점	15명	2명	13명 중 8명이 평균 6점에서 8.62점으로 개선
이명저항력 7점	11명	2명	9명 중 8명이 평균 7점에서 10점으로 개선
이명저항력 8점	14명	1명	13명 중 9명이 평균 8점에서 10.66점으로 개선

Analytics by Gender

Since there was no TSC prescription in the primary and secondary period, the subject's usual hearing condition can be determined through the change rate in hearing loss index in this period. The hearing loss index of the secondary and tertiary period is the result immediately before listening to the TSC sound signal and 2 weeks after listening, indicating the presence or absence of a direct effect of the 2-week TSC experience. The change in the hearing loss index of the primary and tertiary period reflects the quantitative and qualitative MTM effect obtained by faithfully performing all tasks required by the MTM 4-week protocol, such as evaluating tinnitus twice, 67-band micro-audiometry three times, and writing a 28-time listening journal.

Change in Hearing Loss Index of 105 Male Group Members

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	4503.962	1904.234								
Var1	4503.962	1904.234	105	0.000	0.00000	0.00000	104	1.000000	0.000	0.0000
Var2	4503.962	1904.234								
Var2	4503.962	1904.234	105	-28.752	569.1152	-0.51769	104	0.605775	-81.395	138.8902
Var3	4503.962	1904.234								
Var3	4503.962	1904.234	105	123.876	491.4350	2.50295	104	0.011186	-218.981	-28.7714
Var4	4503.962	1904.234								
Var4	4503.962	1904.234	105	28.752	569.1152	0.51769	104	0.605775	-81.395	138.8902
Var5	4503.962	1904.234								
Var5	4503.962	1904.234	105	0.000	0.00000	0.00000	104	1.000000	0.000	0.0000
Var6	4503.962	1904.234								
Var6	4503.962	1904.234	105	152.629	511.8308	3.05685	104	0.002843	-261.642	-53.6154
Var7	4503.962	1904.234								
Var7	4503.962	1904.234	105	-123.876	491.4350	-2.50295	104	0.011186	-218.981	-28.7714
Var8	4503.962	1904.234								
Var8	4503.962	1904.234	105	-152.629	511.8308	-3.05685	104	0.002843	-261.642	-53.6154
Var9	4503.962	1904.234								
Var9	4503.962	1904.234	105	0.000	0.00000	0.00000	104	1.000000	0.000	0.0000

Of the 195 subjects, males (105) had both a significant TSC effect ($P=0.0028$) and an MTM effect ($P=0.0111$), while females (90) had only an MTM effect ($P=0.0090$). Furthermore, the TSC effect ($P=0.0028$) was relatively higher in males compared to the TSC effect ($P=0.0588$) in females, but the MTM effect ($P=0.0111$) in males was relatively lower compared to the MTM effect ($P=0.0090$) in females.

Change in Hearing Loss Index of 90 Female Group Members

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	3987.289	2225.598								
Var1	3987.289	2225.598	90	0.000	0.00000	0.00000	89	1.000000	0.000	0.0000
Var2	3987.289	2225.598								
Var2	3987.289	2225.598	90	148.633	778.446	1.81138	89	0.073456	-311.676	14.4090
Var3	3987.289	2225.598								
Var3	3987.289	2225.598	90	314.878	1119.512	2.66830	89	0.009059	-549.395	-80.4005
Var4	3987.289	2225.598								
Var4	3987.289	2225.598	90	-148.633	778.446	-1.81138	89	0.073456	-311.676	14.4090
Var5	3987.289	2225.598								
Var5	3987.289	2225.598	90	0.000	0.00000	0.00000	89	1.000000	0.000	0.0000
Var6	3987.289	2225.598								
Var6	3987.289	2225.598	90	166.244	824.029	1.91393	89	0.058843	-338.834	6.3450
Var7	3987.289	2225.598								
Var7	3987.289	2225.598	90	-314.878	1119.512	-2.66830	89	0.009059	-549.395	-80.4005
Var8	3987.289	2225.598								
Var8	3987.289	2225.598	90	-166.244	824.029	-1.91393	89	0.058843	-338.834	6.3450
Var9	3987.289	2225.598								
Var9	3987.289	2225.598	90	0.000	0.00000	0.00000	89	1.000000	0.000	0.0000

Based on these results, it would not be a bad idea for clinicians to focus on the effects of 2 weeks of TSC for male patients and 4 weeks of MTM for female patients. Regardless of the patient's gender, it important for clinicians to know whether the patient

has stable or unstable hearing before starting TSC, so the importance of the first half of the MTM 4-week protocol without prescribing TSC should not be overlooked.

Analytics by Age

Change in Hearing Loss Index in 86 People in the Under-55 Group

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	3234.453	1954.615								
Var1	3234.453	1954.615	86	0.000	0.00000	0.00000	85	1.000000	0.000	0.0000
Var2	3234.453	1954.615								
Var2	3234.453	1954.615	86	175.174	812.9769	1.98821	85	0.048890	-349.477	-0.8722
Var3	3234.453	1954.615								
Var3	3234.453	1954.615	86	373.512	696.9617	3.86171	85	0.000219	-565.821	-181.203
Var4	3234.453	1954.615								
Var4	3234.453	1954.615	86	-175.174	812.9769	-1.98821	85	0.048890	-349.477	-0.8722
Var5	3234.453	1954.615								
Var5	3234.453	1954.615	86	0.000	0.00000	0.00000	85	1.000000	0.000	0.0000
Var6	3234.453	1954.615								
Var6	3234.453	1954.615	86	198.337	475.8292	3.86547	85	0.000216	-300.355	-96.319
Var7	3234.453	1954.615								
Var7	3234.453	1954.615	86	-373.512	696.9617	-3.86171	85	0.000219	-565.821	-181.203
Var8	3234.453	1954.615								
Var8	3234.453	1954.615	86	-198.337	475.8292	-3.86547	85	0.000216	-300.355	-96.319
Var9	3234.453	1954.615								
Var9	3234.453	1954.615	86	0.000	0.00000	0.00000	85	1.000000	0.000	0.0000

The average age of the 195 subjects in the MTM trial was 55 years old. In the under-55 group (86 patients), the TSC effect ($P=0.0002$) and MTM effect ($P=0.0002$) were both significant, whereas the 55+ group (109) the TSC effect ($P=0.0959$) and MTM effect ($P=0.2610$) were not statistically significant. Although the age value of 55 years old is not absolute, we would expect to see higher TSC and MTM effects in younger age groups. However, given that the younger the age, the better the relative hearing in the sample of tinnitus patients, it is somewhat unreasonable to use a specific age as an absolute standard to discuss the TSC effect and MTM effect. It's not that older patients don't benefit from TSC, it's that their hearing is too poor for TSC to work well. It may be that the TSC effect is immediate because they have good relative hearing, not because they are young, but because they have less damage to their hearing. Older patients with good relative hearing may benefit from TSC or MTM quickly as well, while younger patients with poor relative hearing may benefit from TSC or MTM more slowly. In the MTM trial, the mean hearing loss index for the under-55 group (86 patients) was 3,234, whereas the mean of hearing loss index in the above-55 group (109) was 5,202.

Change in Hearing Loss Index for 109 People in the 55+ Group

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	5202.835	1728.461								
Var1	5202.835	1728.461	109	0.000	0.00000	0.00000	108	1.000000	0.000	0.0000
Var2	5202.835	1728.461								
Var2	5202.835	1728.461	109	-43.183	532.9033	-0.84802	108	0.399410	-57.992	144.3593
Var3	5202.835	1728.461								
Var3	5202.835	1728.461	109	84.624	781.9216	1.12991	108	0.261018	-233.078	63.8300
Var4	5202.835	1728.461								
Var4	5202.835	1728.461	109	43.183	532.9033	0.84802	108	0.399410	-57.992	144.3593
Var5	5202.835	1728.461								
Var5	5202.835	1728.461	109	0.000	0.00000	0.00000	108	1.000000	0.000	0.0000
Var6	5202.835	1728.461								
Var6	5202.835	1728.461	109	127.807	794.5499	1.67938	108	0.095970	-278.659	23.0441
Var7	5202.835	1728.461								
Var7	5202.835	1728.461	109	-84.624	781.9216	-1.12991	108	0.261018	-233.078	63.8300
Var8	5202.835	1728.461								
Var8	5202.835	1728.461	109	-127.807	794.5499	-1.67938	108	0.095970	-278.659	23.0441
Var9	5202.835	1728.461								
Var9	5202.835	1728.461	109	0.000	0.00000	0.00000	108	1.000000	0.000	0.0000

Analysis by Hearing Loss Index

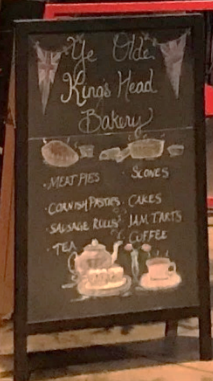
The arithmetic mean of the 195 hearing loss indices based on the primary micro-audiometry is 4,335 (845,272/195) and the geometric mean is 3,749. The median of the two is 4,042, which means that 97 subjects have better hearing than this number and 98 subjects have worse hearing than this number. There were no subjects with an audiometric index between 4,042 and 4,000, so the two groups were categorized based on an audiometric index of 4,000. Both TSC effect ($P=0.0011$) and MTM effect ($P=0.0015$) were significant in the group with a hearing loss of below 4,000 (97 patients), whereas only MTM effect ($P=0.0332$) was significant in the group above 4,000 (98 patients). It can be seen that the TSC and MTM effects are also higher in relatively healthy hearing.

Change in Hearing Loss Index for 97 People in the <4,000 Group (less than)

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	2593.536	967.189	97	0.000	0.0000	0.00000	96	1.000000	0.000	0.0000
Var1	2593.536	967.189	97	0.000	0.0000	0.00000	96	1.000000	0.000	0.0000
Var2	2547.010	1050.815	97	-46.526	510.9428	-0.89682	96	0.372056	-149.504	56.4520
Var1	2593.536	967.189	97	198.258	600.8511	3.24974	96	0.001593	-319.356	-77.1594
Var3	2395.278	1042.854	97	198.258	600.8511	3.24974	96	0.001593	-319.356	-77.1594
Var2	2547.010	1050.815	97	-46.526	510.9428	-0.89682	96	0.372056	-149.504	56.4520
Var2	2547.010	1050.815	97	0.000	0.0000	0.00000	96	1.000000	0.000	0.0000
Var2	2547.010	1050.815	97	0.000	0.0000	0.00000	96	1.000000	0.000	0.0000
Var2	2547.010	1050.815	97	151.732	445.6001	3.35365	96	0.001143	-241.540	-61.9237
Var3	2395.278	1042.854	97	151.732	445.6001	3.35365	96	0.001143	-241.540	-61.9237
Var1	2593.536	967.189	97	-198.258	600.8511	-3.24974	96	0.001593	-319.356	-77.1594
Var3	2395.278	1042.854	97	-198.258	600.8511	-3.24974	96	0.001593	-319.356	-77.1594
Var2	2547.010	1050.815	97	-151.732	445.6001	-3.35365	96	0.001143	-241.540	-61.9237
Var3	2395.278	1042.854	97	-151.732	445.6001	-3.35365	96	0.001143	-241.540	-61.9237
Var3	2395.278	1042.854	97	0.000	0.0000	0.00000	96	1.000000	0.000	0.0000

Change in Hearing Loss Index of 98 People in the >4,000 Group (more than)

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	6068.153	1292.432	98	0.000	0.0000	0.00000	97	1.000000	0.000	0.0000
Var1	6068.153	1292.432	98	0.000	0.0000	0.00000	97	1.000000	0.000	0.0000
Var2	5988.510	1450.809	98	59.643	812.729	0.72648	97	0.469292	-222.585	103.2991
Var1	6068.153	1292.432	98	225.663	1034.131	2.18022	97	0.033219	-432.983	-18.3331
Var3	5932.490	1508.651	98	225.663	1034.131	2.18022	97	0.033219	-432.983	-18.3331
Var2	5988.510	1450.809	98	59.643	812.729	0.72648	97	0.469292	-222.585	103.2991
Var2	5988.510	1450.809	98	0.000	0.0000	0.00000	97	1.000000	0.000	0.0000
Var2	5988.510	1450.809	98	0.000	0.0000	0.00000	97	1.000000	0.000	0.0000
Var3	5932.490	1508.651	98	166.020	840.925	1.95442	97	0.053531	-334.615	2.5744
Var3	5932.490	1508.651	98	166.020	840.925	1.95442	97	0.053531	-334.615	2.5744
Var1	6068.153	1292.432	98	-225.663	1034.131	-2.18022	97	0.033219	-432.983	-18.3331
Var3	5932.490	1508.651	98	-225.663	1034.131	-2.18022	97	0.033219	-432.983	-18.3331
Var2	5988.510	1450.809	98	-166.020	840.925	-1.95442	97	0.053531	-334.615	2.5744
Var3	5932.490	1508.651	98	-166.020	840.925	-1.95442	97	0.053531	-334.615	2.5744
Var3	5932.490	1508.651	98	0.000	0.0000	0.00000	97	1.000000	0.000	0.0000



Clinical Reviews 1

Mi-Sun Choi, Audiologist

AMA-PTA

AMA-PTA Micro Audiometry

When conducting the clinical study, the most important initial step we focused on was accurately understanding each participant's hearing status. Hearing patterns are influenced not only by one's congenital hearing capacity, but also by the environmental conditions to which one has been exposed throughout life. Conditions such as illness, accidents, and age-related damage to auditory cells can all result in different hearing patterns. Each participant's hearing was assessed using the AMA-PTA 67-band micro audiometry device (RCPTA). The testing duration typically ranged from 11 to 20 minutes. Prior to the test, participants were given a brief explanation of the testing procedure. One key point emphasized during this explanation was how to distinguish between test tones and tinnitus. The more severe the tinnitus, the more likely participants were to confuse tinnitus with the test tones. This confusion was especially noticeable in the latter half of the test, as the volume of the test tones gradually decreased, approaching the descending threshold, where the distinction between test tones and tinnitus became increasingly difficult. Some participants even felt that their tinnitus was louder than the test tones and were unsure whether they were hearing the tone or just their tinnitus, resulting in inaccurate responses during the test. In fact, during the early phase of the clinical study, about 10 participants, upon completing their first test, mentioned that they pressed the button incorrectly in the latter part of the test because they couldn't distinguish between the test tones and their tinnitus. Some even believed their test had not been conducted properly. To address this, we began adding a clearer explanation during the instructions: "Test tones are intermittent—tu-tu-tu-tu, beep-beep-beep-beep—whereas tinnitus is a continuous sound with no breaks." After we included this explanation, the number of participants who expressed concern or regret after the test significantly decreased. We believe that the 67-band micro-audiometry tests were conducted more accurately following this adjustment. Moreover, the fact that participants who received this clarification tended to show better treatment outcomes than the initial 10 participants suggests that such an explanation may indeed be a contributing factor to treatment effectiveness.

Targeting

One of the most important and challenging tasks during the clinical process was targeting—identifying the specific frequency points to be treated. Targeting was determined through analysis of each participant's first and second hearing test results, followed by a discussion with the participant. For participants with tinnitus, the most critical factors in targeting were "threshold fluctuation zones" and points of hearing deterioration. Threshold fluctuation refers to a sudden change in hearing sensitivity (15 dB or more) within a narrow frequency band—specifically, within one-third of an octave. In the early phase of the clinical study, we initially focused only on these fluctuations and areas of hearing loss for targeting, which sometimes caused us to overlook other important aspects of the hearing graph. As the study progressed, we recognized this issue and shifted to a broader analysis approach—starting with a macro perspective of the participant's hearing graph, then gradually narrowing down to finer details. First, we examined left-right hearing balance, then looked at frequency-specific hearing levels, and finally analyzed fluctuation zones and hearing loss points.

We categorized participants' hearing patterns into three main types:

1. Patterns showing sudden hearing deterioration in a specific frequency band (1,000–2,000 Hz) likely due to external noise exposure.
2. Patterns of hearing loss caused by internal conditions (e.g., sudden sensorineural hearing loss, Ménière's disease).
3. Patterns showing left-right hearing imbalance.

Based on these patterns, targeting points were selected according to the following criteria:

1. Target frequencies in the 30–70 dB range where threshold fluctuation is clearly observed.
2. When distinct fluctuations are present—target the areas with rapid hearing decline.
3. If neither of the above applies—target based on balancing left and right hearing differences.

As specified in the clinical manual, two primary targeting strategies were used: Isolated targeting, where specific frequencies with hearing loss are targeted individually, Proximal targeting, which focuses treatment more intensively on the affected regions. Targeting varied depending on the condition of each participant, but generally, 3 to 4 targeting points per ear were selected.

Isolated and Proximal Targeting

During the clinical period, we avoided targeting the absolute lowest thresholds of the participants' hearing. Instead, we focused on the 30–70 dB HL range, identifying fluctuation zones and targeting the lowest threshold within this range, rather than the overall lowest hearing point. In other words, 70 dB HL could serve as the minimum hearing threshold for targeting purposes. This led, often unintentionally, to the use of isolated targeting. This method aims to prevent the sudden worsening or increase in the frequency of tinnitus, but by its nature, it is less likely to yield dramatic treatment effects. However, after the four-week clinical trial ended, we began directly targeting the lowest thresholds, and shifted from isolated targeting to more frequent use of proximal targeting. Based on participant feedback during the clinical study and the subsequent ongoing treatment process, proximal targeting centered around the lowest thresholds (up to 90 dB HL) appeared to yield far more effective

results. Although not applicable to all participants, using 2 to 3 proximal targeting points centered around fluctuation zones was generally more effective than isolated targeting. Proximal targeting was especially effective for participants with hearing loss in the 8,000–12,000 Hz high-frequency range and those experiencing high-pitched tinnitus. This will be discussed in more detail later through specific participant case studies. In the beginning, we were very hesitant to target the 8,000–12,000 Hz range. Many participants showed clear threshold fluctuations or sudden drops in hearing within this frequency band. At a glance, it was evident that this range overlapped with the tinnitus frequency. The issue was that this is a high-frequency band, and even small sounds can be perceived as very loud. Moreover, since most participants had significantly worse hearing in the high-frequency range compared to other bands, a sound calibrated to their threshold with the Rev134 system could be perceived as extremely loud and even threatening to a person with normal hearing. As a result, we were cautious, even reluctant, to target this area at first. However, following the advice that “a sound that a participant cannot hear is not noise to them,” we started targeting the range carefully. Participants with hearing loss in the 8,000–12,000 Hz range often reported that the targeting tone was very similar to their tinnitus. Many had difficulty distinguishing between the targeting tone and their tinnitus. Nevertheless, when participants heard a tone that resembled their tinnitus, they seemed to gain more confidence in the treatment method and listened to the tones more diligently, which in turn brought about positive treatment outcomes. These participants also kept very detailed listening logs and showed a high treatment success rate. Some participants had normal hearing across all frequencies, in the -10 to 30 dB HL range. Even in such cases—where tinnitus was present despite normal hearing—if fluctuation or hearing loss was observed in the 8,000–12,000 Hz range, there was no need to hesitate in targeting that area. As long as clear fluctuation and hearing drops were present, treatment results were greater and faster in that frequency band compared to others. However, for participants with good hearing, targeting had to be conducted with precise accuracy. Additionally, in cases where no distinct fluctuation was observed but there was sudden hearing loss across a certain band, using 2 to 3 proximal targeting points in those areas was more effective than targeting just a single point of sharp decline. During this clinical period, frequencies below 1,000 Hz were excluded from the targeting range. However, upon reviewing participants' post-treatment hearing, we observed improvements in frequencies below 1,000 Hz even though they had not been

directly targeted, and only other frequency bands had been treated. This suggests that instead of limiting the expected outcome to the directly targeted frequencies, we should consider the broader effects of frequency-based sound therapy, and predict more extensive hearing improvements when selecting targeting points.

Descending Threshold

In the Rev134 system, targeting refers to determining the frequency, while tracking is the process of identifying the threshold volume. Though these two are described separately, it is my belief that for targeting to be effective, precise tracking is essential. The descending threshold is a crucial element in the Rev134 system for generating sound stimuli that match the subject's hearing level at a given frequency. It refers to the point at which, after starting from a clearly audible volume, the sound is gradually reduced until it can no longer be heard—that moment of disappearance is the descending threshold. While this may seem like a simple and straightforward task, the difference between capturing the threshold accurately and inaccurately resulted in significant differences in both treatment duration and effectiveness. To elaborate on the treatment sound: it consists of a frequency-modulated component, as well as a “chiki-chiki” style amplitude-modulated sound that the subject can use as an audible cue. The goal is to gradually lower this composite sound to find the point where it disappears—this is the descending threshold. However, for subjects who constantly hear tinnitus, they often struggle to distinguish between the treatment sound disappearing and the tinnitus sound persisting, making it difficult to determine the threshold accurately. For participants with complex tinnitus, the closer the treatment frequency was to their dominant tinnitus frequency, the harder it was for them to differentiate between the treatment tone and their tinnitus during targeting. In such cases, an effective targeting strategy is to first present the treatment sound at a sufficiently audible level, clearly point out the specific part of the sound to focus on (the “chiki-chiki” component), and ensure that the subject can distinguish it. This explanation must be repeated every time targeting is performed, and the more the subject confuses the tinnitus with the treatment tone, the more carefully and meticulously targeting should be conducted. When tracking for the descending threshold of the tinnitus frequency was successful in a single attempt, treatment outcomes were significantly better. Given the high correlation between accurate descending threshold identification and treatment success, it is critical to find this threshold quickly and precisely.

When comparing first-attempt captures of the descending threshold with those that required two or three tries, participants who needed multiple attempts often showed variability in the threshold volume, and their treatment outcomes were poorer. The fact that the descending threshold at the same frequency point kept changing suggests that even brief auditory stimulation can activate hair cells, which reinforces the idea that accurate identification of this sensitive threshold is key to effective sound generation and ultimately determines treatment outcome and duration. This concept was more clearly demonstrated in post-clinical treatment cases. Once participants began to clearly perceive the difference between their tinnitus and the treatment sound, we observed marked changes in their hearing threshold graphs and in their perception of tinnitus.

Listening Journal

There is much to say just from the listening journals alone. During the 2-week clinical trial period, all participants were asked to maintain a listening journal every time they listened to the sound stimulus. This included recording the date, time, and the descending threshold volume. Reading these journals, I strongly felt that the treatment is truly carried out by the participants themselves. Not every participant who showed significant improvement kept their journal diligently. However, I observed firsthand that those who did put effort into maintaining the journal—no matter how small or large—received the outcome of their treatment like a gift. Keeping a listening journal sincerely is essentially proof that the participant is engaging in sound therapy regularly and consistently. Participants, most of whom had never heard of the concept of thresholds (whether ascending or descending), followed the instructions: reducing the sound from an audible point to find the descending threshold, and then conducting sound therapy at that threshold point twice a day for 30 minutes. Even when they hadn't fully understood the logic behind it, participants started by simply listening to the sound. Many were confused at first, wondering, “How can a treatment work with a sound I can't even hear?” But the act of writing a journal helped them persist with the treatment. Although the practice of listening at the descending threshold was unfamiliar to them, keeping the journal helped develop it into a daily habit. Since we used MP3 players without built-in timers, participants' habit of noting start times in the journal even served as a sort of timer. What's most important, though, is that through this journaling process, participants began to internalize the concept of thresholds. Though the term “descending threshold”

may still have been new to them, seeing with their own eyes the numbers in their journal decrease gave them the impression that their hearing was improving. Many participants realized mid-journal that the volume they couldn't hear yesterday was now audible today, thanks to ongoing sound therapy. They often shared that, without needing any explanation from others, they came to understand on their own: "This sound therapy is doing something good for my ears, for my body—it's actually working." For many participants, the listening journal helped alleviate a great deal of doubt "Will this really work?" especially given that they were seeing a diagram of the cochlea for the first time, and had never received this type of treatment at any ENT clinic or medical facility before. Even though the term "descending threshold" was entirely new to them, the feeling that "this treatment is actually working", along with a growing sense of self-confidence, seemed to produce significant psychological effects as well. As participants recorded their descending threshold values daily, they began to notice that on days when their physical condition was poor, the thresholds were higher. Through this, they began to understand on their own that their physical condition directly influenced their tinnitus. For instance, when they saw a sudden spike in their descending threshold after drinking alcohol, they didn't need an explanation—they could see the impact clearly in their own journal, and this often prompted them to adjust their behavior. I observed many participants who, after making such behavioral changes, reported a reduction in the intensity and frequency of their tinnitus, and even experienced the added bonus of improved hearing. For those with tinnitus, finding the correct threshold is more difficult than one might expect. In the presence of constant tinnitus noise, it was not easy to distinguish between the treatment sound and the tinnitus itself, and accurately identifying the descending threshold often took considerable time. Participants with severe and complex tinnitus especially struggled to identify the moment when the "chiki-chiki" cue sound used for tracking thresholds began to overlap with the sound of their tinnitus. It often required a period of learning and adaptation. But once participants learned to distinguish the treatment sound from their tinnitus and accurately identify the descending threshold, dramatic changes began to appear in their hearing graphs. In the end, I believe true treatment begins at the point when the participant can clearly differentiate tinnitus from the treatment sound and swiftly, accurately locate the descending threshold. Sometimes I wonder—if the participants had fully understood all of this before beginning the trial, could the treatment outcomes have been even better during the limited clinical period?

Tinnitus Disappeared in 4 Weeks – Participants JYL and HSL

JYL (Male, 58 years old):

Tinnitus questionnaire score changed from 11 to 13

First visit: October 5

Second visit: October 22

Third visit: November 9

JYL was not a participant with severe tinnitus, but he did experience noticeable discomfort from it and had not found relief despite visiting other medical institutions. When he joined the MTM clinical trial, he expressed a strong desire to understand the principles behind the sound-based treatment. Since the approach was entirely unfamiliar to him and he was told it could treat tinnitus where conventional methods had failed, he was eager to understand how this treatment works. We explained the frequency specificity of the ear, and based on his hearing graph, described the regions of hearing loss and fluctuating response, and how these were targeted. After the second hearing test, we produced a personalized sound file and instructed him to listen for two weeks. Targeting was conducted in the left ear at Index 96, 120, and 128, and in the right ear at Index 130. When we compared the second and third hearing graphs to assess treatment effects, hearing changes were observed in the targeted frequency zones by the third test. The tinnitus questionnaire scores were 11 at the first visit and 13 at the third—this minor increase reflected the participant's honest reporting, but was not indicative of worsening symptoms. On the third visit, the participant brought back his thoroughly kept listening journal, reporting that he had not heard his tinnitus even once during the two weeks of sound therapy. He explained that he listened to the treatment sound at his descending threshold for 30 minutes in a quiet environment, doing absolutely nothing else during the session. While we had advised participants to conduct home therapy in as quiet an environment as possible—especially when determining the threshold—we had also told them they were free to go about their daily activities once the threshold was established. We even said watching TV or having a conversation was fine. However, this participant chose to stay still and focus solely on the sound during each session. Although the treatment involves listening, at the descending threshold level, the sound is technically inaudible, meaning the participant was actually resting in silence during therapy. We've repeatedly emphasized that difficulty in identifying the threshold at the beginning of treatment is a major factor that determines the effectiveness and duration of the therapy. In this case, the listening journal from the two-week period showed that the participant had identified the descending threshold with great accuracy. It seems likely that a quiet, focused listening environment helped him achieve this precision. The fact that a clear treatment effect appeared after just two weeks may be attributed to this.

When the participant accurately identified the descending threshold at home, he experienced clearer changes in both volume perception and tinnitus, which aligns with our broader understanding of the mechanism. Regardless of severity, the presence of tinnitus causes distress. Yet this case shows that for an early-stage tinnitus patient with a proactive attitude toward treatment, just two weeks of consistent sound therapy was enough to completely resolve the condition.

HSL (Female, 37 years old):

Tinnitus questionnaire score changed from 8 to 13

First visit: October 5

Second visit: October 19

Third visit: November 2

At the first and third visits, HSL's tinnitus questionnaire scores were 8 and 13, respectively. Although her hearing was in a good range—under 30 dBHL—there were still signs of relative hearing loss and fluctuation. As her initial score suggests, she experienced mild tinnitus, and after two weeks of listening to the treatment sound, she reported that she no longer heard the tinnitus, and thus treatment was concluded. This case demonstrates that mild tinnitus may be sufficiently treated within just two weeks. HSL had bilateral simple tinnitus, and during the targeting process, she mentioned that the targeted frequencies matched the sound of her tinnitus. When the treatment sound and the tinnitus sound were similar, accurately identifying the threshold led to a high treatment success rate. Therefore, the targeting and descending threshold detection were performed with care, and after two weeks of home-based therapy, the tinnitus was no longer perceived. In cases of mild tinnitus, it is easier to determine the descending threshold because there are fewer confusing or overlapping sounds. Though latent tinnitus may resurface after a resting period, we discussed the situation with the participant and mutually agreed to conclude both the clinical trial and the treatment.

Participants Who Recovered from Tinnitus After Continued Treatment Beyond 4 Weeks YBK, MJC, BWM, YML, MRS, KHJ

These participants did not experience dramatic improvement during the 4-week clinical period, but they began to notice changes in their hearing, the "tone" or character of the tinnitus, and the intensity of the sound. They expressed a desire to continue the sound therapy, and as a result, their treatment was extended. After completing a full 3-month program (including the initial 4 weeks of the clinical trial), their tinnitus symptoms disappeared completely.



YBK (Female, 60s): Over 10 Years of Left-Sided Tinnitus / Tinnitus score changed from 8 to 10 after 4 weeks / Continued treatment beyond clinical period, completed in December
First visit: October 5
Second visit: October 19
Third visit: November 7



This participant's audiogram revealed a clear asymmetry between the left and right ears, with significantly worse hearing in the high frequencies (8,000–12,000 Hz) on the left side. When patients with this kind of hearing pattern report high-pitched tinnitus, it typically means that frequencies in the 8,000–12,000 Hz range are part of their tinnitus frequency spectrum. This pattern was also observed in the audiograms of JYL and HSL, where hearing loss and fluctuation in this high-frequency range aligned with their tinnitus profiles. In such cases, high-frequency targeting is essential, and when applied, participants often report notable changes in their tinnitus. After conducting home-based sound therapy, YBK's tinnitus score at the third visit was 10, and she reported very noticeable changes in her tinnitus perception. Although her tinnitus was not present 24/7, she had given up on treatment after trying various therapies over the past 10 years with no success. However, as she began listening to the therapy sound, she gradually started to experience changes in the tinnitus sound. The complex, noise-mixed tinnitus began to simplify, and its intensity and frequency decreased. When asked to describe her tinnitus, she used the metaphor of entangled wires: originally like 8 twisted strands of wire, but after starting the therapy, it reduced to 5 strands, the noise component disappeared, and she felt much more comfortable—she even said it was fascinating. She also reported a significant reduction in the frequency of tinnitus occurrence. By the end of the 4-week clinical period (including 2 weeks of home sound therapy), she described her tinnitus as having been reduced from 8 strands to 5. To address the remaining tinnitus, she continued treatment, and as therapy progressed, she said it decreased to 3 strands, then 2, then 1, and by December 12, she completed the treatment. While not particularly novel, it is worth noting that although she received sound therapy only for her left ear, not only did her left ear's hearing improve, but her right ear also showed improvement. She was able to physically perceive the improvement, and this was also reflected objectively in her audiogram.



YML (female, 57):
15 years right-sided tinnitus
Tinnitus score 4

When comparing the audiograms of both ears, the right ear shows a sudden drop in hearing at specific frequencies, and the participant presents with complex tinnitus that includes high-pitched components. Targeting was performed at frequencies where hearing fluctuated and sharply declined in the high-frequency range. Initially, targeting was performed at two locations on the right ear only. By the third visit (after two weeks), no significant change was observed in the tinnitus. The 4-week clinical trial ended with no change in the questionnaire score (still 4). However, the participant wished to continue treatment, and from the fourth visit onward, the number of targeted frequencies was increased using proximity targeting. This case is comparable to that of YBK, as both are female participants of a similar age, with unilateral complex tinnitus including high-frequency components. While the overall conditions can't be perfectly matched, the difference in treatment speed appears to stem from the number of targeted frequencies and the use of proximity targeting. During the clinical period (up to the third visit), YML only had two target frequencies, which yielded no noticeable improvement. Audiogram results also showed little change. However, after increasing the number of target points from 4 to up to 6, the participant began experiencing changes in tinnitus. She reported that the complex tinnitus spectrum began to simplify, consolidating into a single dominant sound. Thus, the number of target frequencies and proximity targeting likely influence the duration and effectiveness of treatment. By December, YML had shown significant improvement, and most of the sounds in her complex tinnitus profile had been resolved.



MRS (Female, 38): Tinnitus Score Increased from 8 to 9
Left-sided tinnitus for 10 years
Hearing loss and tinnitus began after Meniere's disease diagnosis 10 years ago

The participant had unilateral tinnitus in the left ear, and the degree of hearing loss in that ear was significant enough that the presence of tinnitus could be predicted from the audiogram alone. The hearing pattern showed a sharp decline in the 8,000–12,000 Hz high-frequency range, and the tinnitus frequency spectrum included high-pitched components.

During the clinical period, isolated targeting was applied at four sharply dropped hearing points. After the 4-week clinical period, the tinnitus score increased slightly from 8 to 9, but the participant reported a reduction in tinnitus volume compared to before treatment. MRS wished to continue therapy beyond the clinical trial. As she began proximity targeting around 8,000 Hz in addition to isolated targeting, she began to experience more noticeable relief. The treatment was concluded at the end of December.



MJC (Male, 40): Bilateral Tinnitus,
Tinnitus Score Increased from 4 to 10

This participant experienced a remarkably dramatic therapeutic effect during the clinical trial. In MJC's case, the left-side tinnitus was better described as a sensation of "fullness or pressure" rather than a typical ringing or buzzing. He reported a persistent feeling of ear fullness in the left ear, similar to what one might feel when ascending to high altitudes or during airplane travel, which had remained unresolved despite seeking treatment at various medical institutions. After the second clinical visit, he began sound-based therapy, and after just three days of home sound therapy, he reported that the fullness in his left ear had disappeared. He expressed amazement that the discomfort he had endured for several years had vanished after only three days of treatment. Initially, he approached the therapy with low expectations—simply hoping for a last resort—but was stunned that sound frequency therapy alone could yield such results, and he repeatedly expressed his astonishment. Following the disappearance of the discomfort in his left ear, the participant became highly motivated and diligent about the home-based sound therapy. This case reinforced the notion that treatment is ultimately carried out by the participant themselves—not the doctor. In other words, the patient must believe in the treatment's effectiveness and also engage actively and sincerely in the self-healing process. Encouraged by the success on the left side, the participant continued to apply himself to the home therapy. He continued treatment for his right-ear tinnitus for about six more weeks after the clinical period, and this too improved significantly. The treatment was eventually concluded as his right-side tinnitus had subsided to the point where it was barely noticeable, occurring only once every few days and no longer interfering with daily life.

Subjects who did not any change during the 2-week study

DSC, GGP, YSE

These were participants who, despite listening to the sound stimuli for two weeks, did not perceive any changes in either hearing or tinnitus. These participants varied in age and duration of tinnitus experience. However, one commonality among them was that their tinnitus began after noise-induced hearing loss during military service. Another shared feature was that there were no or only minimal changes observed in their hearing thresholds across the first, second, and third audiometric tests. Participant DSC (age 33) developed tinnitus after exposure to loud noise in the military and exhibited a noise-induced hearing loss pattern with a steep drop at 2,000 Hz. Participant GGP (age 74) is a former soldier who reported having tinnitus for over 35 years, claiming to have tried nearly every available treatment. His tinnitus is also suspected to be the result of noise-induced hearing loss sustained during military service. Participant YSE (age 52) began experiencing sudden hearing loss and tinnitus in his 20s after completing military service. The common thread among these three participants is that they all had noise-induced hearing loss, and after two weeks of home-based sound therapy, neither their hearing thresholds nor tinnitus symptoms showed significant changes. While the severity of their hearing loss and their ages varied, the first, second, and third assessments revealed virtually no improvement in hearing or tinnitus. Even though participants like DSC (33) and GGP (74) continued treatment beyond the clinical trial, they reported minimal changes in hearing and no noticeable improvement in tinnitus. This contrasts with participants like GSK and SHK, whose cases are worth comparing.



GSK (Male, 57):
Tinnitus score 3

Participant GSK clearly remembered the onset and cause of his tinnitus: it began after firearm training during a university military training camp, when he began to experience a sensation of muffled and blocked ears, followed by the onset of tinnitus in both ears. In other words, he is a case of noise-induced hearing loss due to gunshot noise. His tinnitus has persisted for over 35 years, and his audiogram showed a typical noise-induced hearing loss pattern—with a steep downward slope beginning at 1,000 Hz, and thresholds ranging between 70–90 dB HL from 4,000 to 12,000 Hz. He presented with bilateral complex tinnitus, and his initial questionnaire score was 3, indicating that he was consistently suffering from loud tinnitus. After targeting was conducted on the second visit, no changes in tinnitus were reported by the third test (week 4). He continued to hear loud tinnitus constantly. At the end of the clinical period, the tinnitus questionnaire score remained unchanged at 3. This completed the 4-week clinical trial. Although GSK reported no perceived change in tinnitus, his audiogram began to show gradual changes in both ears. After discussing with the participant, it was decided to continue sound therapy after the clinical trial. While tinnitus remained unchanged, changes started to appear in the audiogram. Although there was no significant improvement during the trial, post-trial testing revealed marked improvement in the left ear, and the tinnitus became significantly softer (October 31). On the following visit, changes were also observed in the right ear, with the tinnitus also softening (November 16). As hearing improved, the intensity and volume of tinnitus also decreased. It is unclear whether the effects were due to the initial isolation targeting, which stimulated the surrounding auditory cells before targeting the lowest hearing point, or due to direct near-targeting at the hearing nadir, but audiogram improvements were observed, and with them, tinnitus changes occurred.

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 Audiologist Certification in 2018

MTM 이명의 진단과 치료

It may be that stimulating the frequencies around the damaged region activated surrounding auditory cells, and near-targeting at the point of greatest hearing loss subsequently brought improvement. Alternatively, it's possible that direct near-targeting at the lowest point from the start was effective. This question requires further study and observation. The participant is currently taking a brief break after three months of treatment. His tinnitus has softened and diminished. However, as the rate of improvement slowed, it was decided to pause treatment and resume later. The case illustrates that when tinnitus is accompanied by severe hearing loss and a long duration of symptoms, the treatment period tends to be correspondingly long.



SHK (Male, 59):

Bilateral tinnitus,
Tinnitus score 3

This participant, a career military officer and graduate of a military academy, suffered from tinnitus caused by noise-induced hearing loss. His audiogram revealed a sharp decline in hearing beginning at 1,000 Hz, with hearing thresholds between 60–90 dB HL from 3,000 Hz onward. After identifying the steep decline points, four isolated targeting zones were applied on the left ear and two on the right. After two weeks of sound therapy, changes were observed at 8,000 Hz in both ears. His tinnitus questionnaire score changed from 3 to 4 post-clinical trial. SHK stands out as a memorable participant among all who took part in the clinical trials. During the two-week treatment period, he made extraordinary efforts to identify the most accurate descending threshold, comparing treatment in quiet environments, and even testing the difference between lying down and sitting up. He was committed to finding the best settings for his therapy. He even brought detailed written reflections, such as noting that closing his eyes during threshold setting helped identify more precise values.

During the clinical period, his tinnitus reduced, and he continued sound therapy afterward. Although the tinnitus did not completely disappear, it was significantly reduced, leading to conclusion of the treatment. The previously discussed cases—DSC, YSE, GGP, GSK, and SHK—were all examples of tinnitus resulting from noise-induced hearing loss. In such cases, tinnitus treatment and hearing improvement can be more challenging than in patients whose tinnitus originates from internal medical conditions. Additionally, longer treatment durations may be required. While outcomes can vary depending on tinnitus duration and age, a comparison between participants like DSC, who developed tinnitus in his 30s and had it for 10 years, and others like YBK and YML, who developed tinnitus in their late 50s and also experienced it for 10 years, suggests that tinnitus and hearing loss caused by external trauma (e.g., traffic accidents) may be more difficult to treat and require more time than those stemming from internal conditions.

Improving Hearing Loss



EJM (Female, 47)

Unlike most participants, this individual exhibited an unusual audiometric pattern, with hearing thresholds distributed around 50–70 dB HL in the 500–3,000 Hz range and relatively better hearing—above 30 dB HL—in the high-frequency region centered around 4,000 Hz. In 2011, a health screening raised concerns about possible hearing loss, but the participant did not perceive any deficit and carried on as usual.

Only after progressive hearing difficulty led to near-total loss of audibility did the participant visit a university hospital, undergo a hearing test, and come to recognize the reality of their hearing loss. The exact onset and cause of the hearing loss remained unknown. By 2016, the participant began to experience daily inconveniences from the hearing loss and started using hearing aids. When enrolling in the clinical trial, the participant was already experiencing severe hearing loss and intense tinnitus, which caused considerable distress. Targeting was conducted at three points in the low-frequency region. By the third visit, although the tinnitus had slightly worsened, hearing at the targeted frequencies had improved. Encouraged by the lowered thresholds (indicating improved hearing) on the audiogram, the participant chose to continue treatment. By mid-December, a notable improvement of about 20 dB was observed in the 1,000–3,000 Hz range compared to the first visit. While tinnitus showed minimal change, the participant experienced clear hearing improvement.

In Conclusion of the Clinical Trial...

From observing participants who either recovered fully or concluded treatment, we have learned the following through experience: The core of MTM (Micro-Tonal Matching) therapy lies in precise micro-audiometric diagnosis, careful targeting based on damaged frequencies, and sound stimulation designed using accurate descending threshold values. While comprehensive judgment is certainly important in determining targeting points, agonizing over targeting for extended periods does not guarantee better results. Rather, based on two sets of micro-audiometric tests, one should trust their clinical intuition and decisiveness to proceed quickly with targeting. Once targeting points are selected, there should be no more hesitation. A confident decision by the hearing care specialist plays a critical role in the entire MTM treatment process for tinnitus. Another significant observation: in participants with asymmetrical hearing and unilateral tinnitus, even when treatment was provided to only one ear, improvement was often seen in the untreated ear during follow-up hearing tests. This suggests that hearing is not an entirely separate sensation between the left and right ears, but rather a bilaterally integrated perception regulated by the brain. This is strong evidence supporting the concept of central auditory integration. As a hearing care specialist participating in MTM clinical trials, one of the most puzzling phenomena was the variability in treatment outcomes among similar participants. Even when two individuals shared nearly identical backgrounds and tinnitus durations, one responded to sound therapy while the other did not. Although their ages differed, age alone could not explain the contrasting outcomes. We believe more in-depth clinical research is needed to uncover what specific factors account for such differences in therapeutic response. A more detailed investigation into these contrasting recovery patterns is something we hope will be pursued in the future.



9. MTM Clinical Results Analysis 3

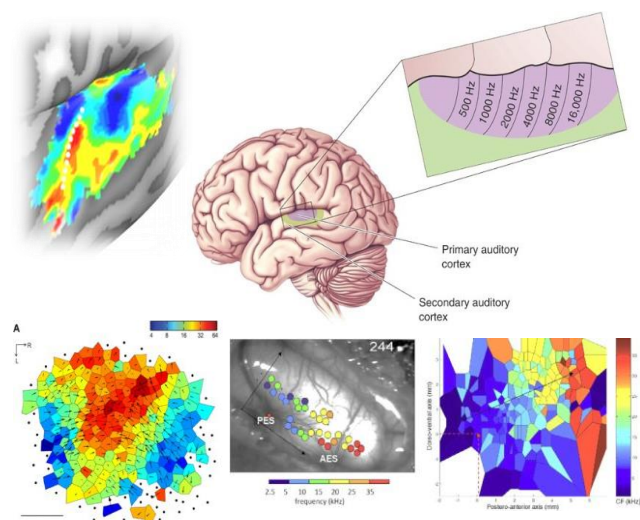
TSC acoustic cues and tonotopy

The MTM protocol uses the RCPTA 67-band algorithm to identify the tinnitus frequency of tinnitus patients. Since the frequency, intensity, and timbre of tinnitus vary as widely as the number of patients, obtaining the most objective results possible through automated algorithm testing is the core of MTM tinnitus care. When the tinnitus frequency at a given point is identified through at least two algorithm tests conducted at two-week intervals, a TSC (Threshold Sound Conditioning) acoustic signal is manually created by the medical staff to stimulate the auditory cells corresponding to that frequency. A multi-channel TSC acoustic signal, which merges multiple frequencies, can be generated using the REVE134 acoustic stimulator.

Stimulating auditory cells with the TSC acoustic signal is not solely for the improvement of the auditory cells themselves. Without stimulating the auditory cells — the gateway to the auditory nervous system — the TSC signal cannot be properly transmitted to the central auditory neurons. Thus, in order to maximize the effect of TSC, the TSC signal must precisely stimulate the specific group of auditory cells. The physical frequency resolution of the TSC acoustic signal must not be distorted or altered by biological variables before it reaches the auditory neurons. For example, if the Index 97 signal (center frequency = 4,067 Hz) from the REVE134 acoustic stimulator, due to some biological factor, ends up stimulating the auditory neurons corresponding to Index 80 (center frequency = 2,489 Hz), it would be difficult to achieve the intended TSC effect. Although it has not yet been concretely established whether such physiological variables that cause frequency distortion exist within the in vivo sound transmission pathway, it is not meaningless to 'question' whether the TSC acoustic signal truly reaches the targeted auditory neurons accurately. Out of such doubt and curiosity, Chapter 9 — MTM Clinical Results Analysis 3 — was written.

The Index 97 acoustic signal, centered at 4,067 Hz, is a modulated acoustic signal that contains all frequency components from 3,729 to 4,435 Hz. The

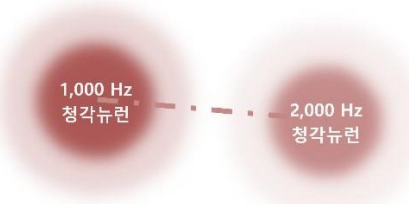
location of the auditory cell group that processes this signal is very precisely determined within the physical space of the cochlea according to a physical scale. However, the location or response area of the auditory neurons that process the same Index 97 acoustic signal cannot be identified with the same spatial precision as the auditory cell group. For example, each auditory cell group processing 1,000 Hz, 2,000 Hz, and 3,000 Hz occupies distinct, independent spaces in the physical spatial scale, but auditory neurons do not exhibit such clear spatial independence. In fact, various animal studies explaining the concept of 'tonotopy,' the frequency mapping principle of the auditory nervous system, provide evidence suggesting that in the primary auditory cortex of the temporal lobe, different spatial regions process different frequency signals, as if 1,000 Hz and 2,000 Hz auditory neurons occupy independent spaces within the auditory cortex. The images below, primarily obtained from studies based on passive auditory systems in animals, are often seen in textbooks and papers in the field of auditory neuroscience as illustrations explaining tonotopy. They show that auditory neurons at different locations respond to specific frequency signals. In the case of the passive auditory system, the concept of the frequency map of auditory neurons can be explained to some extent using a two-dimensional X, Y coordinate plane schematic.



Active Auditory System and Dynamic Frequency Maps

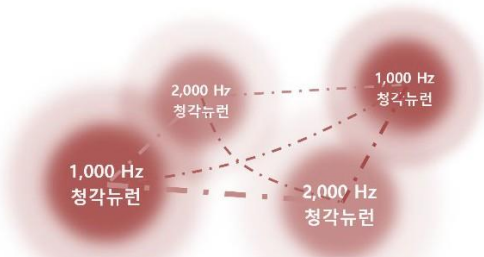
In an active auditory system environment where auditory cognitive functions are operating normally, there is no clear basis for stating that "auditory neurons processing 1,000 Hz and auditory neurons processing 2,000 Hz occupy distinct, independent spaces." Although many attempts have been made to elucidate the precise frequency mapping principle of the brain using fMRI (functional magnetic resonance imaging) in human subjects, it has been revealed that the frequency map can vary moment by moment depending on various factors such as the subject's attention, frequency preference, prior learning or prediction/expectation regarding pitch. Even if various biological variables could be controlled, a two-dimensional X, Y coordinate system alone is insufficient to explain the tonotopy principle in the active auditory system; a three-dimensional approach incorporating a Z coordinate is inevitable. Here, the Z value can essentially be interpreted as an addition of a directional concept to the planar coordinates. Alternatively, instead of direction, the concept of the temporal resolution of auditory neurons can be substituted for understanding. Because there is no evidence in the active auditory system that auditory neurons processing 1,000 Hz and those processing 2,000 Hz are distinct from each other, human auditory neurons must be understood not as a two-dimensional planar coordinate system but as a 'network' concept in three or more dimensions.

Example of a 2-dimensional frequency map of auditory neurons in a passive auditory system

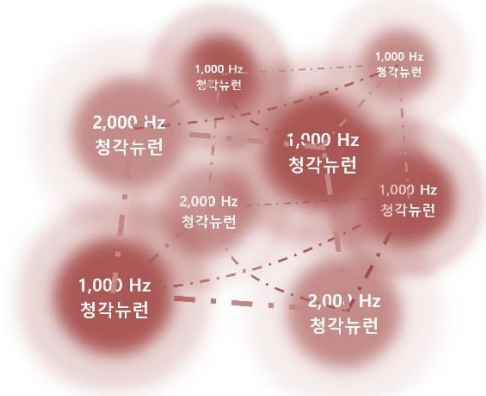


If tonotopy in a passive auditory system can be described as a "static/planar frequency map" explained by a two-dimensional coordinate system, tonotopy in an active auditory system, where auditory cognitive functions are operating normally, must be described as a "dynamic/three-dimensional frequency map" explainable only in three or more dimensions. Example of a three-dimensional frequency map of auditory neurons in an active auditory system

Example of a 3-dimensional frequency map of auditory neurons in the active auditory system



Example of a 4-dimensional frequency map of auditory neurons in the active auditory system



It is necessary to understand the auditory neurons connected to the 1,000 Hz auditory hair cells as a kind of filter or mesh that processes the 1,000 Hz range of frequencies. An auditory neuron responding to 1,000 Hz does not exclusively process only 1,000 Hz; it can also receive and process other frequencies within the 1,000 Hz range. Suppose the 1,000 Hz auditory hair cell group is stimulated using a pure tone containing only the 1,000 Hz frequency component. If the auditory neuron connected to this group processes the 1,000 Hz frequency while simultaneously exchanging information with auditory hair cell groups located in the 2,000 Hz or 3,000 Hz bands, should this phenomenon be considered a distortion of frequency processing in the auditory nervous system? The existence and role of the identical harmonic plate, the basal auditory neural network of the brain, help in understanding and explaining that such phenomena are not neurological distortions but rather natural procedures and methods of acoustic signal processing in the brain. Moreover, in the MTM clinical study analyzing frequency-specific hearing changes in 192 tinnitus patients, the role of the identical harmonic plate could be statistically observed to be deeply involved in the changes in hearing improvement. This Chapter 9 discusses in detail the specific role of the identical harmonic plate acting on hearing improvement, based on the actual hearing loss index data of 192 subjects.

Multichannel TSC and Efferent Auditory Feedback

It was mentioned earlier that, in the active auditory system, the frequency map can vary moment by moment depending on factors such as the subject's attention, frequency preference, prior learning, or prediction/expectation of pitch. The MTM clinical study notes that the hearing improvement effect based on the TSC principle is closely related to the concept of the temporal resolution of neural firing. However, in this Chapter 9 MTM Clinical Results Analysis 3, we will explore in detail, based on several statistical analyses, that the TSC hearing improvement effect is also inseparably related to the 'spectral resolution' of the identical harmonic plate, the basal auditory neural network. A normal identical harmonic plate quickly computes the fundamental frequency — the greatest common divisor of the detected cycles — within just a few tens

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of milliseconds whenever a common periodicity is detected among the firing patterns of different auditory neurons. In order to perform such computations, the temporal resolution and spectral resolution of individual auditory neurons contributing to the formation and operation of the identical harmonic plate must maintain a certain level of performance. The auditory neurons forming the identical harmonic plate also respond sensitively to various psychophysical cues such as memory, prediction, attention, and expectation. Even setting aside other cues, there is a crucial point that must be addressed regarding auditory neuron responses to 'harmonic cues' based on the hearing loss index changes in 192 subjects.

Harmonic cues are broadly referred to as spectral cues. For example, presenting a 1,000 Hz pure tone beforehand and asking the subject to memorize it, then testing their hearing ability for a 2,000 Hz tone (twice the frequency) constitutes a test where spectral cues have already been provided. The ISO8253 series of passive pure-tone audiometry (PTA), which is internationally standardized and widely used today, does not consider the actual auditory processing characteristics of auditory neurons that are sensitive to spectral cues. Testing hearing only at octave or exact multiple frequencies — 250, 500, 1,000, 2,000, 4,000, 8,000 Hz — is effectively equivalent to testing a single identical harmonic plate or a specific unitary auditory neural network fully exposed to spectral cues. However, in everyday life, human hearing is exposed to random sounds without intentional cues, not to artificially cued auditory environments. Therefore, in order to determine the true auditory abilities of the lattice-like auditory neural networks that respond to different frequencies within the active auditory system, hearing tests must be conducted in a way that is completely free from harmonic or spectral cues. The presentation timing and order of 1,000 Hz and 2,000 Hz test tones must be randomized without any cues, and the sound intensity arrangement of the presented test tones must also be randomized unpredictably.

In MTM, the hearing threshold values extracted by the RCPTA algorithm are based on biological responses obtained through such a randomized frequency presentation method, perfectly controlling to prevent the activation of the auditory neurons' spectral cue linkage mechanisms. When the singular or multiple tinnitus frequency points identified through this random frequency presentation method were stimulated using the multichannel TSC method, each subject in the MTM clinical study listened to an average of 4.67 TSC acoustic signals. For the subjects' left ears, an average of 2.34 TSC acoustic signals per person were provided, and for the right ears, an average of 2.33 signals. Even though each subject listened to only about 2.33 to 2.34 TSC acoustic signals per ear over two weeks, how could there be a statistically significant total hearing (hearing loss index) change across the entire 250–12,000 Hz frequency range? In the MTM clinical study, after two weeks of listening to an average of 4.67 TSC acoustic signals, the 192 tinnitus patients' hearing loss index dropped from an average of 4,393 to 4,169. This represents an improvement of 224 points, or 5.1%, in total hearing ability. The change in hearing loss index among the 192 tinnitus patients who experienced multichannel TSC was statistically significant according to the T-test results ($P = 0.0003$). Among the participants, 166 had a tinnitus resistance score lower than the median value of 9 points, indicating moderate, severe, or profound tinnitus. For these individuals, the average hearing loss index before multichannel TSC was 4,465, and after multichannel TSC, it improved to 4,265 — a 200-point

(4.4%) improvement in total hearing ability ($P = 0.0014$).

<Change in hearing loss index of 166 patients with moderate to severe tinnitus>

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	4465.693	1984.795	166	0.000	0.0000	0.00000	165	1.000000	0.000	0.0000
Var1	4465.693	1984.795	166	0.000	0.0000	0.00000	165	1.000000	0.000	0.0000
Var1	4265.976	1995.819	166	-199.717	793.2074	-3.24401	165	0.001427	-321.273	-78.1605
Var1	4265.976	1995.819	166	-199.717	793.2074	-3.24401	165	0.001427	-321.273	-78.1605
Var1	4465.693	1984.795	166	0.000	0.0000	0.00000	165	1.000000	0.000	0.0000
Var3	4265.976	1995.819	166	0.000	0.0000	0.00000	165	1.000000	0.000	0.0000
Var3	4265.976	1995.819	166	0.000	0.0000	0.00000	165	1.000000	0.000	0.0000

As discussed earlier in Chapter 8, among the 192 tinnitus patients who participated in the MTM clinical study over four weeks, there were a total of 85 patients who showed hearing improvement across all three hearing evaluation indices (Hearing Change 1, Hearing Change 2, and Downward Threshold Change). For these 85 patients, the average hearing loss index significantly decreased from 4,189 before the multichannel TSC procedure to 3,531 after the procedure. This represents a remarkable improvement of 658 points (15.7%) in total hearing ability, and the change was statistically significant ($P = 0.0000$).

How should we interpret the fact that even though only about 2.33 to 2.34 specific frequency bands per ear were stimulated at the downward threshold level, a statistically significant hearing improvement effect was observed across the entire frequency range? For a detailed explanation of this, Chapter 9 aims to analyze the MTM clinical results, focusing on the critical band frequency arrangement in relation to the auditory central identical harmonic plate. First, considering the action and role of the harmonic plate during TSC stimulation, it can be hypothesized that hearing improvement would be greater when identical critical bands are targeted simultaneously in both ears compared to when non-identical critical bands are targeted. This is because the central harmonic plate is expected to provide augmented feedback through the efferent auditory pathway, enhancing the downward thresholds of the fundamental frequency or its harmonically related frequencies in the contralateral ear. When identifying the patient's tinnitus frequency with the RCPTA algorithm and creating the TSC acoustic signals with the REVE134 acoustic stimulator, if the left and right frequency bands were targeted within the same critical band frequencies, it can be hypothesized that the hearing improvement would be greater than if different bands were targeted. Let us refer to this hypothesis simply as the "Same Auditory Filter Stimulation Effect Hypothesis." To stimulate the same auditory filter without causing basilar membrane interference in multichannel TSC, both ears must be stimulated separately with TSC acoustic signals within the same critical band frequency range for each ear. If multiple TSC acoustic signals occupy the same critical band on one side without being separated into both ears within the same critical band, physiological acoustic interference and distortion phenomena occur at the basilar membrane. The "Same Auditory Filter Stimulation Effect Hypothesis" is intended to explain the principle that the feedback action of the harmonic plate through the efferent auditory pathway acts in a crossed manner between the two ears. Second, to explain the fact that stimulation of only about 2.33 to 2.34 specific frequency bands per ear at the downward threshold level led to hearing improvement across the entire frequency range, a second hypothesis is also necessary: the "Same Harmonic Plate Stimulation Effect Hypothesis." This is the second hypothesis following the Same Auditory Filter

Stimulation Effect Hypothesis. Whereas the Same Auditory Filter Stimulation Effect Hypothesis specifically concerns "multichannel TSC and efferent auditory feedback" based on bilateral ear stimulation, the Same Harmonic Plate Stimulation Effect Hypothesis can be valid even with unilateral ear stimulation. The efferent auditory feedback action of the central harmonic plate is effective not only in the crossed relationship between both ears but also within the same ear. A simple example of targeting the same harmonic plate within one ear would be: if 4,000 Hz is one of the target frequencies of multichannel TSC, instead of stimulating only 4,000 Hz, simultaneously stimulating 2,000 Hz or 8,000 Hz within the same ear. Whether this results in a more enhanced hearing improvement effect or not is explained through various statistical analyses presented in the latter part of Chapter 9. To inductively prove the effect of the harmonic plate action of the central auditory nervous system on hearing improvement, we will examine the statistical significance of these two hypotheses — the Same Auditory Filter Stimulation Effect Hypothesis and the Same Harmonic Plate Stimulation Effect Hypothesis — respectively.

How the Rev134 Index Works

First, we aim to understand the frequency composition system of the REVE134 acoustic stimulator before examining the statistical significance of the Same Auditory Filter Stimulation Effect Hypothesis and the Same Harmonic Plate Stimulation Effect Hypothesis. Clinicians who adopt the MTM protocol identify the tinnitus frequency of a tinnitus patient using the RCPTA algorithm and then create a customized TSC acoustic signal for the patient using the REVE134 acoustic stimulator. The REVE134 acoustic stimulator is designed to select a total of 134 different critical band center frequencies per ear, allowing up to 20 tinnitus frequencies to be simultaneously targeted. Across both ears, a total of 268 critical band center frequencies are provided. Additionally, TSC acoustic signals can be simultaneously played across up to 40 channels. The width of a single critical band, understood as a unit of the human auditory filter, corresponds to roughly 1 mm on the cochlear basilar membrane and, in frequency terms, spans between approximately 1/3 to 1/6 of an octave. The REVE134 frequency table provided below offers the center frequency values for each of the 134 different indices (Name) and the detailed frequency ranges corresponding to the single critical bandwidths centered on those frequencies.

Name	CF	1/3 Oct.	Name	CF	1/3 Oct.	Name	CF	1/3 Oct.	Name	CF	1/3 Oct.
001	254	233-277	033	678	622-740	065	1812	1661-1976	097	4836	4435-5274
002	262	240-285	036	698	640-762	070	1865	1710-2034	101	4978	4565-5429
003	269	247-294	037	719	659-784	071	1920	1760-2093	103	5124	4699-5588
004	277	254-302	038	740	678-807	072	1976	1812-2154	106	5274	4836-5752
005	285	262-311	039	762	698-831	073	2034	1865-2117	107	5429	4978-5920
006	294	269-320	040	784	718-855	074	2093	1920-2282	108	5588	5124-6093
007	302	277-330	041	807	740-880	075	2154	1976-2349	109	5752	5274-6272
008	311	285-339	042	831	762-906	076	2217	2034-2418	110	5920	5429-6456
009	320	294-349	043	855	784-932	077	2282	2093-2489	111	6093	5588-6645
010	330	302-359	044	880	807-960	078	2349	2154-2562	112	6272	5752-6840
011	339	311-370	045	906	831-988	079	2418	2217-2637	113	6456	5920-7040
012	349	320-381	046	932	855-1017	080	2489	2282-2714	114	6645	6093-7246
013	359	330-392	047	960	880-1047	081	2562	2349-2794	115	6840	6272-7459
014	370	339-403	048	988	906-1078	082	2637	2418-2876	116	7040	6456-7677
015	381	349-415	049	1017	932-1109	083	2714	2489-2960	117	7246	6645-7302
016	392	359-427	050	1047	960-1142	084	2794	2562-3047	118	7459	6840-8134
017	403	370-440	051	1078	988-1175	085	2876	2637-3136	119	7677	7040-8372
018	415	381-453	052	1109	1017-1209	086	2960	2714-3228	120	7902	7246-8617
019	427	392-466	053	1142	1047-1245	087	3047	2794-3322	121	8134	7459-8870
020	440	403-480	054	1175	1078-1281	088	3136	2876-3420	122	8372	7677-8430
021	453	415-494	055	1209	1109-1319	089	3228	2960-3520	123	8617	7902-9397
022	466	427-508	056	1245	1142-1357	090	3322	3047-3623	124	8870	8134-9672
023	480	440-523	057	1281	1175-1397	091	3420	3136-3729	125	9130	8372-9956
024	494	453-538	058	1319	1209-1438	092	3520	3228-3838	126	9397	8617-10248
025	508	466-554	059	1357	1245-1480	093	3623	3322-3951	127	9672	8870-10548
026	523	480-570	060	1397	1281-1523	094	3729	3420-4067	128	9956	9130-10857
027	538	494-587	061	1438	1319-1568	095	3838	3520-4186	129	10248	9397-11175
028	554	508-604	062	1480	1357-1614	096	3951	3623-4309	130	10548	9672-11503
029	570	523-622	063	1523	1397-1661	097	4067	3729-4435	131	10857	9956-11840
030	587	538-640	064	1568	1438-1710	098	4186	3838-4565	132	11175	10248-12186
031	604	554-659	065	1614	1480-1760	099	4309	3951-4699	133	11503	10548-12544
032	622	570-678	066	1661	1523-1812	100	4435	4067-4836	134	11840	10857-12912
033	640	587-698	067	1710	1568-1865	101	4565	4186-4978			
034	659	604-719	068	1760	1614-1920	102	4699	4309-5124			

<Relationship of Critical Bands in the REVE134 Index>

By referring to the center frequency and the detailed frequency range corresponding to the 1/3-octave interval for each index in the REVE134 frequency table, we can find the index spacing corresponding to a single critical bandwidth. For example, the center frequency of index 50 is 1,047 Hz, and its critical bandwidth range is 960–1,142 Hz. The center frequency of index 51 is 1,078 Hz, and its critical bandwidth range is 988–1,175 Hz. Although the center frequencies of index 50 and 51 are different, their critical bandwidth frequency ranges overlap. By gradually increasing the index spacing and comparing the critical bandwidth ranges one by one, it is possible to determine the minimum index gap at which the critical bands no longer overlap. The center frequency of index 56 is 1,245 Hz, and its critical bandwidth range is 1,142–1,357 Hz. Previously, the critical bandwidth for index 50 was 960–1,142 Hz, while for index 56, it was 1,142–1,357 Hz, showing that the ending frequency of index 50's critical band and the starting frequency of index 56's critical band are the same at 1,142 Hz. Thus, across all indices of the REVE134 acoustic stimulator, it can be seen that an index gap of "6" results in only one overlapping frequency point at the boundary of specific critical bandwidths. In other words, when attempting multichannel targeting on the same ear, to prevent overlapping of adjacent critical bands on the cochlear basilar membrane, it is necessary to maintain an index spacing of at least "7" during multichannel targeting.

<1:2:3 Integer Ratio Frequency Relationships in the REVE134 Index>

To easily identify the REVE134 index values of the harmonic frequency relationships that belong to the same harmonic plate, additional organization is required by referring to the center frequencies and critical bandwidths at 1/3-octave intervals listed in the REVE134 frequency table. Among the frequency ratio relationships that elicit the most organic responses between auditory neurons within the same single harmonic plate, the representative ratio is 1:2:3. The 1:1 frequency ratio (identical frequencies) represents the closest harmonic relationship, and the 1:2 frequency ratio, corresponding to a one-octave interval, represents the next closest harmonic relationship after 1:1.

Although sequentially considering frequency relationships like 1:3, 1:4, and so on is necessary, the 2:3 frequency relationship — corresponding to the perfect fifth interval — is also a highly influential integer ratio frequency relationship that induces an organic response among auditory neurons within the same harmonic plate. To easily understand how to identify index values (or index intervals) in the REVE134 frequency table corresponding to 1:2, 1:3, and 2:3 frequency relationships, the following points should be noted:

a. 1:2 (One Octave) Frequency Relationship in the REVE134 Index:

The center frequency of REVE134 index 1 is 254 Hz. Twice that, 508 Hz, is the center frequency of REVE134 index 25. Just like the relationship between REVE134 indices 1 and 25, every "24" index gap in REVE134 represents a 1-octave (1:2) frequency relationship.

b. 1:3 Frequency Relationship in the REVE134 Index:

The center frequency of REVE134 index 1 is 254 Hz, and three times that, 762 Hz, is the center frequency of REVE134 index 39. Just like the relationship between REVE134 indices 1 and 39, every "38" index gap in REVE134 represents a 1:3 frequency relationship.

c. 2:3 Frequency Relationship in the REVE134 Index:

The 2x multiple of the center frequency 254 Hz (index 1) is 508 Hz, corresponding to REVE134 index 25. The 3x multiple is 762 Hz, corresponding to REVE134 index 39. REVE134 indices 25 and 39 share a 2:3 frequency relationship and can be understood as stimulating the same harmonic plate. Thus, just like the "14" gap between REVE134 indices 25 and 39, every "14" index gap in REVE134 represents a 2:3 frequency relationship.

Identical Filter Stimulation Effect

Let's examine whether the hypothesis of the Identical Filter Stimulation Effect can be statistically significant: "When producing TSC acoustic signals that simultaneously stimulate both ears, targeting the same critical band auditory filters in the opposite ear and stimulating them in a crossed manner can result in more enhanced TSC hearing improvement effects compared to the case where this is not done." To test this, we excluded 23 patients who only received TSC in one ear from a total of 192 tinnitus patients, and separately aggregated the hearing loss index results of the 169 patients who received TSC in both ears. These 169 patients were divided into the Identical Filter Stimulation (IFS) group and the Non-Identical Filter Stimulation (NFS) group. The IFS group refers to the group of patients who listened to IFS-TSC acoustic signals, designed such that more than half of the target frequencies in both ears stimulated the same auditory filter in the opposite ear. The NFS group refers to the group of patients who listened to NFS-TSC acoustic signals, designed such that more than half of the target frequencies in both ears stimulated different auditory filters in the opposite ear. The sample size of the IFS group was 76, and the sample size of the NFS group was 93. The average primary hearing loss index for the IFS group was 4,556, while the NFS group had an average of 4,566. The total hearing index after experiencing TSC (termed the third hearing loss index) was 4,366 for the IFS group and 4,414 for the NFS group, showing that both groups had a

reduction in their hearing loss index after TSC. The IFS group showed a reduction of 190 in the hearing loss index, indicating improved overall hearing. The NFS group showed a reduction of 152 in the hearing loss index. However, statistical analysis revealed that the enhanced TSC hearing improvement effect was statistically significant only in the IFS group (p-value = 0.0185), whereas the NFS group showed no statistically significant result (p-value = 0.0624).

<IFS (Identical Filter Stimulation) Group>

Variable	Mean	Std. Dev.	N	Diff.	Std. Dev.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	4556.763	2034.840	76	0.000	0.0000	0.00000	75	1.00000	0.000	0.0000
Var1	4556.763	2034.840	76	0.000	0.0000	0.00000	75	1.00000	0.000	0.0000
Var2	4490.645	2071.824	76	76.118	680.6747	0.97489	75	0.332747	-231.659	79.4224
Var1	4556.763	2034.840	76	190.368	688.6083	2.40657	75	0.01855	-347.951	-32.7862
Var3	4366.395	2102.440	76	-76.118	680.6747	-0.97489	75	0.332747	-231.659	79.4224
Var2	4490.645	2071.824	76	0.000	0.0000	0.00000	75	1.00000	0.000	0.0000
Var1	4556.763	2034.840	76	0.000	0.0000	0.00000	75	1.00000	0.000	0.0000
Var2	4490.645	2071.824	76	0.000	0.0000	0.00000	75	1.00000	0.000	0.0000
Var1	4556.763	2034.840	76	114.250	473.1329	2.10513	75	0.038628	-222.366	-6.1345
Var3	4366.395	2102.440	76	-190.368	688.6083	-2.40657	75	0.01855	-347.951	-32.7862
Var2	4490.645	2071.824	76	-114.250	473.1329	-2.10513	75	0.038628	-222.366	-6.1345
Var3	4366.395	2102.440	76	0.000	0.0000	0.00000	75	1.00000	0.000	0.0000

<NFS (Non-identical Filter Stimulation) Group>

Variable	Mean	Std. Dev.	N	Diff.	Std. Dev.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	4566.989	2027.306	93	0.000	0.0000	0.00000	92	1.00000	0.000	0.0000
Var1	4566.989	2027.306	93	0.000	0.0000	0.00000	92	1.00000	0.000	0.0000
Var2	4532.441	2152.000	93	34.548	671.4173	0.49622	92	0.620921	-172.825	103.7284
Var1	4566.989	2027.306	93	152.140	777.7826	1.88637	92	0.062400	-312.322	8.0426
Var2	4532.441	2152.000	93	-34.548	671.4173	-0.49622	92	0.620921	-172.825	103.7284
Var1	4566.989	2027.306	93	0.000	0.0000	0.00000	92	1.00000	0.000	0.0000
Var2	4532.441	2152.000	93	0.000	0.0000	0.00000	92	1.00000	0.000	0.0000
Var1	4566.989	2027.306	93	0.000	0.0000	0.00000	92	1.00000	0.000	0.0000
Var2	4532.441	2152.000	93	117.591	617.6864	1.89590	92	0.069003	-244.802	9.6195
Var3	4414.849	2118.154	93	-152.140	777.7826	-1.88637	92	0.062400	-312.322	8.0426
Var1	4566.989	2027.306	93	-117.591	617.6864	-1.89590	92	0.069003	-244.802	9.6195
Var3	4414.849	2118.154	93	0.000	0.0000	0.00000	92	1.00000	0.000	0.0000

The table above shows the results of the T-test analysis, focusing on the hearing loss index of the 169 tinnitus patients who received TSC in both ears, excluding the 23 patients who received TSC in only one ear. The statistical analysis was done by categorizing the patients into the IFS group and the NFS group.

Now, let's examine whether there is still a statistically significant difference between the two groups when we exclude 34 patients who received single-channel TSC (targeting one frequency in each ear) from the IFS/NFS groups. This exclusion leaves us with only the strict multi-channel (MIFS/MNFS) TSC condition, where at least two auditory filters in each ear are simultaneously stimulated. When the multi-channel IFS group is labeled as the MIFS group and the multi-channel NFS group is labeled as the MNFS group, the sample size of the MIFS group was 66, and the sample size of the MNFS group was 69. The criteria for determining the "majority" of identical and non-identical auditory filters in the MIFS and MNFS groups were as follows:

MIFS (Multi-channel Identical Auditory Filter Stimulation) Group

– Total: 66 Subjects

Subjects in the 2&2 targeting condition where both pairs had overlapping threshold frequency bands

Subjects in the 2&3 targeting condition where more than two pairs had overlapping threshold frequency bands

Subjects in the 3&3 targeting condition where all three pairs had overlapping threshold frequency bands

Subjects in the 3&4 targeting condition where more than three pairs had overlapping threshold frequency bands

Subjects in the 4&4 targeting condition where more than three pairs had overlapping threshold frequency bands

Subjects in the 4&5 targeting condition where more than three pairs had overlapping threshold frequency bands

MNFS (Multi-channel Non-identical Auditory Filter Stimulation) Group – Total: 69 Subjects

Subjects in the 2&2 targeting condition where at least one pair did not have overlapping threshold frequency bands

Subjects in the 2&3 targeting condition where at least one pair did not have overlapping threshold frequency bands

Subjects in the 3&3 targeting condition where at least one pair did not have overlapping threshold frequency bands

Subjects in the 3&4 targeting condition where at least one pair did not have overlapping threshold frequency bands

Subjects in the 4&4 targeting condition where more than two pairs did not have overlapping threshold frequency bands

Subjects in the 4&5 targeting condition where more than two pairs did not have overlapping threshold frequency bands

<MIFS (Multi-channel Identical Filter Stimulation) Group>

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	4956.068	1922.689	69	0.000	0.00000	0.00000	68	1.000000	0.000	0.0000
Var2	4956.068	1922.689	69	45.420	739.2756	0.51035	68	0.611459	-223.014	132.1731
Var3	4956.068	1922.689	69	182.971	848.6258	1.79098	68	0.077747	-386.833	20.8912
Var1	4773.087	2063.523	69	-45.420	739.2756	-0.51035	68	0.611459	-223.014	132.1731
Var2	4910.638	2144.254	69	0.000	0.00000	0.00000	68	1.000000	0.000	0.0000
Var3	4910.638	2144.254	69	137.551	687.1844	1.66220	68	0.100975	-302.630	27.5290
Var1	4773.087	2063.523	69	-182.971	848.6258	-1.79098	68	0.077747	-386.833	20.8912
Var2	4910.638	2144.254	69	-137.551	687.1844	-1.66220	68	0.100975	-302.630	27.5290
Var3	4773.087	2063.523	69	0.000	0.00000	0.00000	68	1.000000	0.000	0.0000

<MNFS (Multi-channel Non-identical Filter Stimulation) Group>

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	4612.152	1941.616	66	0.000	0.00000	0.00000	65	1.000000	0.000	0.0000
Var2	4612.152	1941.616	66	108.591	725.3578	1.21622	65	0.228238	-286.906	69.7243
Var3	4612.152	1941.616	66	235.970	672.8185	2.84925	65	0.005863	-401.369	-70.5703
Var1	4503.561	1981.694	66	-108.591	725.3578	-1.21622	65	0.228238	-286.906	69.7243
Var2	4503.561	1981.694	66	0.000	0.00000	0.00000	65	1.000000	0.000	0.0000
Var3	4376.182	1988.783	66	127.379	472.4716	2.19025	65	0.032100	-243.527	-11.2308
Var1	4376.182	1988.783	66	-127.379	472.4716	-2.19025	65	0.032100	-243.527	-11.2308
Var2	4503.561	1981.694	66	0.000	0.00000	0.00000	65	1.000000	0.000	0.0000
Var3	4376.182	1988.783	66	0.000	0.00000	0.00000	65	1.000000	0.000	0.0000

As shown in the above T-test statistical table, only the MIFS group, which stimulated identical auditory filters in the opposite ear with multi-channel TSC, showed a statistically significant change in the hearing loss index. The MIFS group's initial hearing loss index average of 4,612 dropped to 4,376 after multi-channel TSC, a decrease of 236, which was statistically significant (P = 0.0058). In contrast, the MNFS group, which stimulated non-identical auditory filters in the opposite ear with multi-channel TSC, showed an improvement of 183 from a 1st/3rd hearing loss index of 4,956/4,773, but the change was not statistically significant (P = 0.0777). Through comparisons between the IFS/NFS and MIFS/MNFS groups, we confirmed that stimulating identical auditory filters in the opposite ear leads to a more enhanced TSC hearing improvement effect.

Identical Harmonic Template Stimulation Effect

To confirm whether a more enhanced TSC hearing improvement effect occurs when TSC sound signals stimulate the same harmonic template in the same ear or the opposite ear, we selected a sample of hearing loss indices from patients among the 192 tinnitus patients who received TSC sound signals with frequency compositions in the ratios of 1:1, 1:2, 1:3, and 2:3. The selection was made according to the following conditions:

1:1 Group: A group of subjects whose left and right targeting threshold frequency bands were identical (or overlapping)

1:2 Group: A group of subjects whose REVE134 targeting indices included an interval of "24," regardless of left or right side

1:3 Group: A group of subjects whose REVE134 targeting indices included an interval of "38," regardless of left or right side

2:3 Group: A group of subjects whose REVE134 targeting indices included an interval of "14," regardless of left or right side

The group stimulating the same harmonic template with the frequency relationships of 1:1, 1:2, 1:3, and 2:3 was classified as the Identical Harmonic Template Stimulation (IHS) group, while the group not stimulating the same harmonic template was classified as the Non-identical Harmonic Template Stimulation (NHS) group. Any pair of target frequencies that fit the 1:1, 1:2, 1:3, or 2:3 ratio was classified into the IHS group, while any other combinations were considered as the NHS group.

The sample size of the IHS group, which performed identical harmonic template stimulation, was 108, and the sample size of the NHS group, which performed non-identical harmonic template stimulation, was 84.

<IHS (Identical Harmonic Template Stimulation) Group>

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	4453.176	2058.710	108	0.000	0.00000	0.00000	107	1.000000	0.000	0.000
Var2	4453.176	2058.710	108	132.963	758.3157	1.82219	107	0.071220	-277.615	11.689
Var3	4453.176	2058.710	108	318.889	917.6831	3.61126	107	0.000466	-493.941	-143.836
Var1	4330.213	2122.901	108	-132.963	758.3157	-1.82219	107	0.071220	-277.615	11.689
Var2	4330.213	2122.901	108	0.000	0.00000	0.00000	107	1.000000	0.000	0.000
Var3	4330.213	2122.901	108	185.926	700.1488	2.75970	107	0.006808	-319.483	-52.369
Var1	4134.287	2159.584	108	-185.926	700.1488	-2.75970	107	0.006808	-319.483	-52.369
Var2	4134.287	2159.584	108	0.000	0.00000	0.00000	107	1.000000	0.000	0.000
Var3	4134.287	2159.584	108	0.000	0.00000	0.00000	107	1.000000	0.000	0.000

<NHS (Non-identical Harmonic Template stimulation) Group>

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	4318.548	2022.759	84	0.000	0.00000	0.00000	83	1.000000	0.000	0.0000
Var2	4318.548	2022.759	84	39.881	557.2367	0.65594	83	0.513676	-81.047	160.8087
Var3	4318.548	2022.759	84	102.500	729.9587	1.28696	83	0.201686	-260.911	55.9108
Var1	4214.048	2124.847	84	-39.881	557.2367	-0.65594	83	0.513676	-81.047	160.8087
Var2	4214.048	2124.847	84	0.000	0.00000	0.00000	83	1.000000	0.000	0.0000
Var3	4214.048	2124.847	84	142.381	642.3395	2.03155	83	0.045399	-281.777	-2.9847
Var1	4214.048	2124.847	84	-102.500	729.9587	-1.28696	83	0.201686	-260.911	55.9108
Var2	4214.048	2124.847	84	-142.381	642.3395	-2.03155	83	0.045399	-281.777	-2.9847
Var3	4214.048	2124.847	84	0.000	0.00000	0.00000	83	1.000000	0.000	0.0000

The IHS group had an initial hearing loss index average of 4,453, while the NHS group had an initial hearing loss index average of 4,316. After experiencing TSC, the total hearing loss index (3rd hearing loss index) for the IHS group was 4,134, and for the NHS group, it was 4,214, indicating that the hearing loss index decreased for both groups after the TSC session. The IHS group saw a 319 point decrease in their hearing loss index after TSC, showing an improvement in total hearing. The NHS group experienced a decrease of 102 points in their hearing loss index after TSC. However, statistical analysis revealed that the enhanced TSC hearing improvement effect was statistically significant only in the IHS group (P-value for the IHS group was 0.0004, and for the NHS group it was 0.2016).

To reiterate the classification criteria for the IHS/NHS groups: If any pair of frequencies in the multiple TSC sound signals, regardless of left or right ear, fit the frequency ratios of 1:1, 1:2, 1:3, or 2:3, they were classified into the IHS group. If not, they were classified into the NHS group.

What happens when we compare cases where there are multiple pairs instead of just one pair? To explore this, we selected 75 participants for the Enhanced Identical Harmonic Template Stimulation (EIHS) group based on the criterion of stronger stimulation of the identical harmonic template, regardless of left or right ear frequencies.

- Subjects with 2 targetings who stimulated an identical harmonic plate
- Subjects with 3 targetings where at least one pair stimulated an identical harmonic plate
- Subjects with 4 targetings where at least one pair stimulated an identical harmonic plate
- Subjects with 5 targetings where at least two pairs stimulated an identical harmonic plate
- Subjects with 6 targetings where at least two pairs stimulated an identical harmonic plate
- Subjects with 7 targetings where at least two pairs stimulated an identical harmonic plate
- Subjects with 8 targetings where at least two pairs stimulated an identical harmonic plate
- Subjects with 9 targetings where at least three pairs stimulated an identical harmonic plate

To compare with the EIHS group, the original NHS group was further refined into the Completely Non-identical Harmonic Template Stimulation (CNHS) group. From the original 84 participants in the NHS group, we strictly excluded 8 participants whose critical band start/end frequencies overlapped, leaving 76 participants for the CNHS group.

<EIHS (Enhanced Identical Harmonic Plate Stimulation)

Group>

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	4339.000	2108.587	75	0.000	0.00000	0.00000	74	1.000000	0.000	0.0000
Var2	4339.000	2108.587	75	0.000	0.00000	0.00000	74	1.000000	0.000	0.0000
Var3	4339.000	2108.587	75	84.213	730.6705	0.99814	74	0.321466	-252.325	83.8987
Var4	4339.000	2108.587	75	308.693	941.9985	2.83797	74	0.005856	-525.428	-91.9592
Var5	4339.000	2108.587	75	-84.213	730.6705	-0.99814	74	0.321466	-252.325	83.8987
Var6	4339.000	2108.587	75	0.000	0.00000	0.00000	74	1.000000	0.000	0.0000
Var7	4339.000	2108.587	75	0.000	0.00000	0.00000	74	1.000000	0.000	0.0000
Var8	4339.000	2108.587	75	224.480	767.5578	2.53278	74	0.013435	-401.079	-47.8810
Var9	4339.000	2108.587	75	-308.693	941.9985	-2.83797	74	0.005856	-525.428	-91.9592
Var10	4339.000	2108.587	75	-224.480	767.5578	-2.53278	74	0.013435	-401.079	-47.8810
Var11	4339.000	2108.587	75	0.000	0.00000	0.00000	74	1.000000	0.000	0.0000

<CNHS (completely non-identical harmonic template

stimulation) Group>

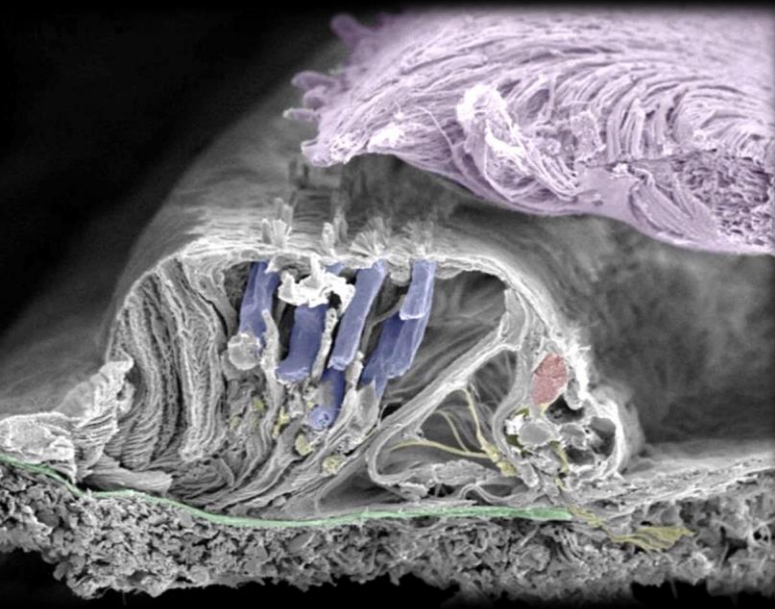
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	4149.789	1954.245	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.0000
Var2	4149.789	1954.245	76	-5.724	532.5992	-0.08369	75	0.925607	-115.980	127.4278
Var3	4149.789	1954.245	76	116.895	760.1967	1.34053	75	0.184120	-290.607	56.8176
Var4	4149.789	1954.245	76	5.724	532.5992	0.08369	75	0.925607	-115.980	127.4278
Var5	4149.789	1954.245	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.0000
Var6	4149.789	1954.245	76	122.618	631.3581	1.69312	75	0.094583	-265.890	21.6531
Var7	4149.789	1954.245	76	-116.895	760.1967	-1.34053	75	0.184120	-290.607	56.8176
Var8	4149.789	1954.245	76	-122.618	631.3581	-1.69312	75	0.094583	-265.890	21.6531
Var9	4149.789	1954.245	76	0.000	0.00000	0.00000	75	1.000000	0.000	0.0000

The EIHS group had an initial hearing loss index average of 4,339, while the CNHS group had an initial hearing loss index average of 4,149. After experiencing TSC, the total hearing loss index (3rd hearing loss index) for the EIHS group was 4,030, and for the CNHS group, it was 4,032, indicating a decrease in the hearing loss index for both groups. The EIHS group experienced a 309 point decrease in hearing loss after TSC, showing an improvement in total hearing. The CNHS group experienced a 117 point decrease, but the enhanced TSC hearing improvement effect was statistically significant only in the EIHS group (P-value for the EIHS group was 0.0058, and for the CNHS group it was 0.1841). Through the comparison of IHS/NHS and EIHS/CNHS groups, it was confirmed that stimulating the identical harmonic template, regardless of the left or right ear, leads to a more enhanced TSC hearing improvement effect.

G	N	D	P
IFS	76	190	0.0185
NFS	93	152	0.0624
MIFS	66	236	0.0058
MNFS	69	183	0.0777
IHS	108	319	0.0004
NHS	84	102	0.2016
EIHS	75	309	0.0058
CNHS	76	117	0.1841

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10. Tinnitus Index and Hearing Loss Index

Within the group with better hearing than 4,000 as the standard, the tinnitus symptoms are weaker as the hearing is better, and the tinnitus symptoms are severe as the hearing is worse. On the other hand, in the group with worse hearing than 4,000, it cannot be said that tinnitus symptoms are necessarily weaker just because the hearing is good, and it cannot be said that tinnitus symptoms are necessarily severe as the hearing is worse.

Tinnitus Index

There is an auditory theory explaining the correlation between tinnitus and hearing loss called the Gaussian function of subjective tinnitus loudness (dBSL) theory. Using the results of a regression analysis of tinnitus and hearing loss indices from 192 participants (excluding 3 with SOAE) out of 195 MTM clinical subjects, we will explore whether a Gaussian function relationship between tinnitus intensity and hearing loss index actually holds. This will be discussed in detail in Chapter 13 of this textbook, which covers the Gaussian effect of tinnitus. The Gaussian function of tinnitus explains that there is roughly the following relationship between the degree of hearing loss and the subjective intensity of tinnitus. The numerical values provided here are the most idealized examples to explain the theory of the Gaussian function of tinnitus, and the relative values may vary depending on various factors within the subjects.

Threshold 0 dBHL	= Tinnitus 0 dBSL
Threshold 10 dBHL	= Tinnitus 0.9 dBSL
Threshold 20 dBHL	= Tinnitus 8 dBSL
Threshold 30 dBHL	= Tinnitus 21 dBSL
Threshold 40 dBHL	= Tinnitus 24 dBSL
Threshold 50 dBHL	= Tinnitus 25 dBSL
Threshold 60 dBHL	= Tinnitus 24 dBSL
Threshold 70 dBHL	= Tinnitus 21 dBSL
Threshold 80 dBHL	= Tinnitus 8 dBSL
Threshold 90 dBHL	= Tinnitus 0.9 dBSL
Threshold 100 dBHL	= Tinnitus 0 dBSL

To analyze the correlation between tinnitus and hearing loss, the 13-step tinnitus resistance scores (3-15) for the 192 participants were converted into a 6-step Tinnitus Index (1-6). The reason for converting the tinnitus resistance score into a tinnitus index is that the arithmetic progression scale of 1-point units in the tinnitus resistance score and the psychological logarithmic scale of tinnitus loudness differ from each other. When performing statistical analysis on the tinnitus resistance score itself, each 1-point interval of the 13-step scale was considered equivalent in sequence. For example, whether the score changed from 3 to 4, from 7 to 8, or from 12 to 13, all were considered as improvements of "1" in tinnitus resistance. However, in the psychological perception of tinnitus loudness, the difference between scores 3 and 4 in tinnitus resistance is much greater in terms of relative loudness than the difference between scores 12 and 13. The arithmetic tinnitus resistance scores are converted into a logarithmic psychological loudness scale considering the subjective dBSL (dB Sensation Level) loudness level. This converted scale is referred to as the Tinnitus Loudness Index or Tinnitus Index. When the tinnitus index is set from 1 to 6, a tinnitus index of 1 refers to the absence of tinnitus or the weakest intensity, and a tinnitus index of 6 refers to the most severe intensity of tinnitus. The 13-step tinnitus resistance evaluation scores (3-15) of the 192 participants were converted into a total of 6 tinnitus indices, ranging from 1 to 6.

6
5
4
3
2
1

The method of converting each tinnitus resistance score follows the rules outlined in the table of the 6-Step Tinnitus Index and Tinnitus Resistance Relationship. For the 192 subjects' tinnitus resistance evaluation scores (3–15), a score of 3 corresponds to a tinnitus index of 6, a score of 4 corresponds to a tinnitus index of 5, a score of 5 corresponds to a tinnitus index of 4, scores between 6 and 7 correspond to a tinnitus index of 3, scores between 8 and 10 correspond to a tinnitus index of 2, and scores between 11 and 15 correspond to a tinnitus index of 1. If the tinnitus resistance score improves from 3 to 4, the tinnitus index decreases from 6 to 5. If the tinnitus resistance score changes between 11 and 15, it is considered to remain in the same tinnitus index category (index 1). The psychological loudness difference between scores 3 and 4 in tinnitus resistance is considered equivalent to the loudness differences between scores 6 and 8, 7 and 10, and 10 and 15.

<Step 6 Relationship between Tinnitus Index and Tinnitus Resistance>

6	Tinnitus Resistance 3 = Tinnitus Index 6
5	Tinnitus Resistance 4 = Tinnitus Index 5
4	Tinnitus Resistance 5 = Tinnitus Index 4
3	Tinnitus Resistance 6~7 = Tinnitus Index 3
2	Tinnitus Resistance 8~10 = Tinnitus Index 2
1	Tinnitus Resistance 11~15 = Tinnitus Index 1

The 192 tinnitus resistance evaluation scores were collected from the results of the first and second questionnaires. Each subject has two tinnitus resistance scores. On the first and second tinnitus resistance evaluation days, the first and third hearing tests were conducted simultaneously, so the first tinnitus resistance evaluation relates to the first hearing loss index obtained from the first hearing test, while the second tinnitus resistance evaluation relates to the third hearing loss index obtained from the third hearing test. Therefore, from 192 subjects, 384 tinnitus index samples and 384 hearing loss index samples were obtained. The frequency distribution of hearing loss indices for each tinnitus index is as follows.

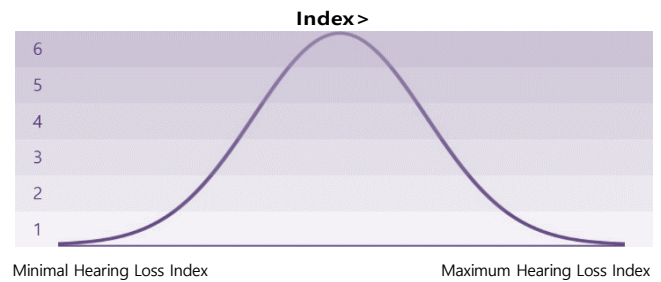
<Distribution of hearing loss index by tinnitus index>

6	107 (27.9%)
5	88 (22.9%)
4	49 (12.8%)
3	45 (11.7%)
2	60 (15.6%)
1	

There are 107 hearing loss indices distributed in tinnitus index 6. The average hearing loss index for these 107 samples is 5,139. While the average for tinnitus index 6 is 5,139, this average alone does not reveal

the detailed distribution pattern of the 107 hearing loss indices in tinnitus index 6. To understand the distribution pattern of samples in each tinnitus index group, the standard deviation for each group must be known. By calculating the ratio between the upper and lower means based on the mean of a specific group, the distribution pattern of that group can be analyzed. Let tinnitus index 6 be denoted as T6, and the average hearing loss index of T6 (5,139) be denoted as A. The average hearing loss indices greater than A will be denoted as A + a, and the average hearing loss indices smaller than A will be denoted as A - a. If the standard deviation of hearing loss indices in the T6 group is large, the ratio of the difference between A + a and A - a, denoted as Da, will also be larger. Conversely, if the standard deviation is small, the Da value will be smaller.

<Relationship between Tinnitus Index and Hearing Loss Index>



Let the tinnitus indices 6, 5, 4, 3, 2, 1 be denoted as T6, T5, T4, T3, T2, T1, respectively. The upper and lower hearing loss index averages for the T6, T5, T4, T3, T2, and T1 groups will be denoted as A + a, A - a, B + b, B - b, C + c, C - c, D + d, D - d, E + e, E - e, F + f, F - f. Additionally, the ratio between A + a and A - a is denoted as Da, the ratio between B + b and B - b as Db, the ratio between C + c and C - c as Dc, the ratio between D + d and D - d as Dd, the ratio between E + e and E - e as De, and the ratio between F + f and F - f as Df. If a Gaussian function relationship between subjective tinnitus intensity and the severity of hearing loss actually holds, the distribution pattern of hearing loss index samples in the 6 tinnitus index groups (T6 through T1) should differ. This pattern should follow the outline of a Gaussian curve. Moreover, if the Gaussian function theory for tinnitus is correct, the following propositions must also hold true:

The standard deviation of hearing loss indices in the T6 group should be smaller than that in the T1 group.

The Da value for T6 should be smaller than the Df value for T1.

The values of Da, Db, Dc, Dd, De, and Df should follow a Gaussian distribution.

Standard deviation of hearing loss index by tinnitus index

A total of 384 hearing loss indices in each of the six tinnitus index groups were examined. As shown in the distribution of tinnitus indexes by tinnitus index, there were 107 tinnitus indexes in tinnitus index group 6 (T6).

3	6109	3	7532	3	4307	3	6860	3	4852
3	3025	3	5664	3	5312	3	2647	3	2979
3	9292	3	5295	3	4590	3	5032	3	3777
3	6027	3	3462	3	3927	3	8982	3	7617
3	5520	3	2937	3	5475	3	7992	3	4510
3	1600	3	2757	3	3307	3	3682	3	6442
3	7039	3	2347	3	7192	3	3462	3	5062
3	4917	3	6215	3	6002	3	3062	3	3525
3	6292	3	5932	3	4407	3	6317	3	3824
3	4660	3	6364	3	6912	3	3992	3	4074
3	7494	3	2917	3	7314	3	5117	3	3472
3	4800	3	4925	3	5609	3	7027	3	5497
3	4517	3	6512	3	1627	3	5305	3	5789
3	7999	3	3794	3	6670	3	5382	3	7164
3	3924	3	3899	3	3029	3	3362	3	7622
3	3535	3	6252	3	9352	3	2379	3	4567
3	3532	3	3767	3	5325	3	2385	3	7102
3	3099	3	7157	3	6762	3	2374	3	6477
3	6534	3	8590	3	6552	3	7017	3	5392
3	3977	3	2672	3	4932	3	3510		
3	4687	3	7180	3	5632	3	3615		
3	6435	3	8229	3	4030	3	3004		

The number of hearing loss indexes in the tinnitus index group 5 (T5) was 88.

4	2685	4	1992	4	4290	4	4560	4	6440
4	2750	4	2304	4	3870	4	4712	4	4472
4	5807	4	7092	4	4802	4	7370	4	8310
4	5372	4	3959	4	4714	4	3564	4	2094
4	2702	4	3430	4	6517	4	2735	4	5067
4	3422	4	2304	4	5209	4	1997	4	4652
4	4549	4	782	4	2385	4	7742	4	4312
4	2182	4	2047	4	4984	4	2112	4	2147
4	8924	4	7157	4	1097	4	4602	4	3270
4	6159	4	5367	4	3244	4	4297	4	7425
4	3234	4	5419	4	4675	4	6340	4	4397
4	3284	4	5567	4	3182	4	5474	4	6580
4	3789	4	4315	4	4319	4	5802	4	4735
4	4662	4	3622	4	2915	4	6029	4	1717
4	4792	4	4554	4	622	4	4207	4	7167
4	7887	4	1325	4	3164	4	3924	4	4742
4	3287	4	4667	4	5937	4	6787		
4	2642	4	2212	4	2990	4	6295		

The Tinnitus Index Group 4 (T4) had a hearing loss index of 49.

5	2164	5	3989	5	2850	5	3032	5	3590
5	6899	5	2209	5	3714	5	3617	5	7274
5	4674	5	6834	5	2337	5	2812	5	2090
5	2187	5	3182	5	3700	5	3649	5	2262
5	5390	5	3839	5	1152	5	3740	5	1039
5	3087	5	3917	5	6442	5	4237	5	4765
5	3332	5	5607	5	7604	5	6750	5	3744
5	4699	5	3430	5	8544	5	3157	5	9190
5	3379	5	4309	5	2145	5	3044	5	4580
5	5017	5	6767	5	6017	5	5582		

The number of hearing loss indexes in the tinnitus index group 3 (T3) was 45.

6	1307	6	3240	6	4922	7	2860	7	882
6	5349	6	5150	6	1237	7	3635	7	4752
6	1517	6	2655	6	1340	7	7394	7	567
6	5907	6	8124	6	1657	7	7082	7	4560
6	5650	6	3662	6	4460	7	1189	7	1442
6	952	6	4745	6	3222	7	6522	7	3535
6	6257	6	4822	6	3889	7	7677	7	5509
6	1479	6	5752	6	3047	7	5649	7	3374
6	5672	6	4747	7	5575	7	3225	7	2482

The Tinnitus Index Group 2 (T2) had a hearing loss index of 60.

8	2380	8	2027	9	1724	9	2237	10	7785
8	4750	8	3574	9	4074	9	895	10	1762
8	1972	8	1357	9	1930	9	4425	10	2442
8	1067	8	5852	9	2745	9	5112	10	4127
8	2065	8	662	9	3307	9	-98	10	6237
8	5869	8	1069	9	3580	10	5774	10	1634
8	1515	8	8175	9	3085	10	1335	10	7732
8	6224	8	6220	9	2295	10	1999	10	2742
8	3415	8	2107	9	2065	10	1570	10	9945
8	3002	8	6474	9	1584	10	1317	10	2840
8	1962	9	7442	9	5779	10	1069	10	2380
8	2204	9	6764	9	3372	10	4052	10	6532

The number of hearing loss indexes in the Tinnitus Index Group 1 (T1) was 35.

11	2570	11	2080	12	6805	13	6197	13	4495
11	2377	11	1922	12	8542	13	1114	13	2187
11	2272	11	1502	12	2005	13	2764	14	5222
11	955	12	1917	12	2405	13	2362	14	1272
11	790	12	5625	13	1817	13	2684	14	1087
11	9577	12	3402	13	6522	13	-389	14	1169
11	6892	12	6107	13	622	13	1054	15	9154

The standard deviation (SD) of hearing loss indices in each tinnitus index group is as follows:

T6 SD = 1,792

T5 SD = 1,820

T4 SD = 1,874

T3 SD = 2,043

T2 SD = 2,263

T1 SD = 2,644

For each tinnitus index group, the upper and lower mean values of hearing loss indices (the average of values greater than and smaller than the group's mean hearing loss index) are as follows:

Upper Mean / Lower Mean

T6: 6,687 / 3,675

T5: 5,784 / 2,880

T4: 6,059 / 2,978

T3: 5,739 / 2,278

T2: 5,934 / 1,973

T1: 6,545 / 1,675

If a Gaussian function relationship exists between subjective tinnitus intensity and the severity of hearing loss, the distribution pattern of hearing loss index samples in the 6 tinnitus index groups (T6 through T1) should follow the outline of a Gaussian curve. Furthermore, if the Gaussian function theory for tinnitus is correct, the following propositions must hold true, as mentioned previously:

The standard deviation of hearing loss indices in the T6 group must be smaller than that in the T1 group.

The Da value for T6 must be smaller than the Df value for T1.

The values of Da, Db, Dc, Dd, De, and Df must follow a Gaussian distribution.

The values of Da, Db, Dc, Dd, De, and Df, which represent the difference ratio between the upper mean and lower mean hearing loss indices for the six tinnitus index groups (T6 through T1), were calculated as follows:

Da: The ratio of the upper mean of 6,687 to the lower mean of 3,675 in the T6 group gives a Da value of 1.82.

Db: The ratio of the upper mean of 5,784 to the lower mean of 2,880 in the T5 group gives a Db value of 2.00.

Dc: The ratio of the upper mean of 6,059 to the lower mean of 2,978 in the T4 group gives a Dc value of 2.03.

Dd: The ratio of the upper mean of 5,739 to the lower mean of 2,278 in the T3 group gives a Dd value of 2.52.

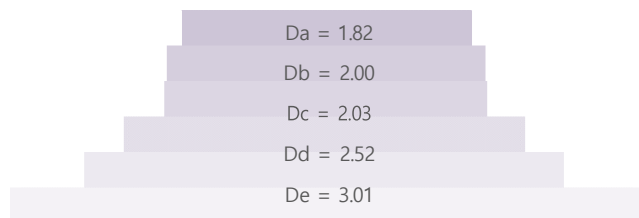
De: The ratio of the upper mean of 5,934 to the lower mean of 1,973 in the T2 group gives a De value of 3.01.

Df: The ratio of the upper mean of 6,545 to the lower mean of 1,675 in the T1 group gives a Df value of 3.91.

Now, to summarize all of these results into a single table:

이명지수	T1	T2	T3	T4	T5	T6
난청지수 표준편차	2,644	2,263	2,043	1,874	1,820	1,792
난청지수 평균값	3,345	3,492	3,970	4,236	4,332	5,139
난청지수 상위평균/하위평균값	6,545/1,675	5,934/1,973	5,739/2,278	6,059/2,978	5,784/2,880	6,687/3,675
상위평균/하위평균값 차이비율	3.91	3.01	2.52	2.03	2.00	1.82
분석표본수(N)	35	60	45	49	88	107

Difference ratio (D) between the upper and lower mean hearing loss indices for the six groups:



Using the results of the 384 tinnitus resistance scores and 384 hearing loss indices from the MTM clinical study participants (192 participants), we examined the relationship between tinnitus and hearing loss. The results showed that in the T6 group (the group with the most severe tinnitus), the standard deviation of the hearing loss index was the smallest, and the difference ratio (D) between the upper and lower means was the smallest as well. On the other hand, in the T1 group (the group with the mildest tinnitus), the standard deviation of the hearing loss index was the largest, and the difference ratio (D) was the largest. Additionally, when listing the D values from the T6 group to the T1 group, the result followed the outline of a Gaussian distribution.

Correlation Analysis between Tinnitus and Hearing Loss

It appears that there is a Gaussian function relationship between the subjective intensity of tinnitus and the progression of hearing loss. The statistical test results of the various figures mentioned earlier also support the theory of a Gaussian function for tinnitus. To inductively prove the Gaussian function theory between the tinnitus index and the hearing loss index, we conducted a regression analysis, which is one of the most widely

used methods in correlation analysis. In regression analysis, if the slope (b-value) of the regression equation is negative, it indicates an inverse relationship between the two variables, and if the b-value is positive, it suggests a direct proportional relationship. For a theory to assert that two variables are 'proportional' or 'inversely proportional,' the regression analysis result's R-value must be close to 1. The closer the R-value is to 1, the higher the probability that the theory is correct.

To examine the correlation between the tinnitus index and hearing loss index, we first performed a regression analysis on the reduction in standard deviation of the hearing loss index as the tinnitus index increased. The result showed a strong inverse relationship with a correlation coefficient (R) of 0.93 between the six tinnitus index ranks and the magnitude of the hearing loss index standard deviation.

Regression Summary for Dependent Variable: Var2 (Spreadsheet1)							1	2
R= .93171041 R²= .86808429 Adjusted R²= .83510537							Var1	Var2
F(1,4)=26.322 p<.00684 Std.Error of estimate: 134.14							1	2544
							2	2263
							3	2043
							4	1874
							5	1820
							6	1792
N=6	b*	Std.Err. of b*	b	Std.Err. of b	t(4)	p-value		
Intercept			2648.467	124.8780	21.20843	0.000029		
Var1	-0.931710	0.181601	-164.514	32.0657	-5.13054	0.006836		

This inverse relationship was also observed when comparing the difference ratio (D) between the upper and lower mean hearing loss indices and the six tinnitus index ranks (R=0.94).

Regression Summary for Dependent Variable: Var2 (Spreadsheet1)							1	2
R= .93812951 R²= .88008697 Adjusted R²= .85010872							Var1	Var2
F(1,4)=23.358 p<.00662 Std.Error of estimate: 3081.7							1	3.91
							2	3.01
							3	2.52
							4	2.03
							5	2
							6	1.82
N=6	b*	Std.Err. of b*	b	Std.Err. of b	t(4)	p-value		
Intercept			3,945,333	0.286889	13,75213	0.000162		
Var1	-0.938130	0.173142	-0.399143	0.073656	-5.41826	0.005624		

Based on these findings, the following conclusions can be made:

In the group with mild tinnitus, there are both groups with good hearing and groups with poor hearing, but the hearing gap between the two groups is large.

In the group with severe tinnitus, there can also be both groups with good hearing and groups with poor hearing, but the hearing gap between the two groups is small.

There is an important consideration when conducting correlation analysis between tinnitus and hearing loss. One should not make the claim "the more severe the tinnitus, the worse the hearing" based solely on the trend of the representative average values of the hearing loss indices in the six tinnitus index groups. The most commonly cited statistic in statistics is the 'mean value,' and in statistical analysis, the 'error of averaging' or 'error of generalization' is often pointed out. When analyzing the correlation between the tinnitus and hearing loss indices, attempting to interpret the phenomenon using only the representative average values of the hearing loss indices could lead to incorrect conclusions. In the correlation analysis between tinnitus and hearing loss, making a claim like "the more severe the tinnitus, the worse the hearing" or "the worse the hearing, the louder the tinnitus" based solely on the trend of the representative average values for each tinnitus index group is an overly hasty conclusion that is not free from the "error of averaging."

이명지수	T1	T2	T3	T4	T5	T6
난청지수 평균값	3,345	3,492	3,970	4,236	4,332	5,139

Based on the trends of the six representative average values above, one might claim that "the worse the hearing, the louder the tinnitus." However,

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If we break down the trends of these six representative average values by distinguishing between the upper and lower mean values and analyzing them in more detail, different interpretations and conclusions emerge.

이명지수	T1	T2	T3	T4	T5	T6
난청지수 상위평균/하위평균값	6,545/1,675	5,934/1,973	5,739/2,278	6,059/2,978	5,784/2,880	6,687/3,675
상위평균/하위평균값 차이비율	3.91	3.01	2.52	2.03	2.00	1.82

First, when analyzing the correlation between the six tinnitus index ranks and the lower mean values of the hearing loss index, a strong proportional relationship was established when using the lower mean values of the hearing loss index as the reference ($R=0.97$). From the perspective of the group with relatively good hearing, mild tinnitus symptoms indicate relatively good hearing, and severe tinnitus symptoms suggest poor hearing.

Regression Summary for Dependent Variable: Var2 (Spreadsheet1)							1	2
R= .97156142 R²= .94333160 Adjusted R²= .92991450							Var1	Var2
F(1,4)=67.341 p<.00120 Std.Error of estimate: 195.48							1	1675
b=	Std.Err. of b=	b	Std.Err. of b	t(4)	p-value		2	1973
Intercept		1234.400	181.9788	6.783209	0.002466		3	2278
Var1	0.971561	0.118394	383.457	46.7278	8.206182	0.001202	4	2978
							5	2880
							6	3675

Next, when analyzing the correlation between the six tinnitus index ranks and the upper mean values of the hearing loss index, there was no correlation between the tinnitus index and the hearing loss index when using the upper mean values of the hearing loss index as the reference ($R=0.07$). From the perspective of the group with relatively poor hearing, the severity of tinnitus symptoms and the hearing status appear to have little correlation.

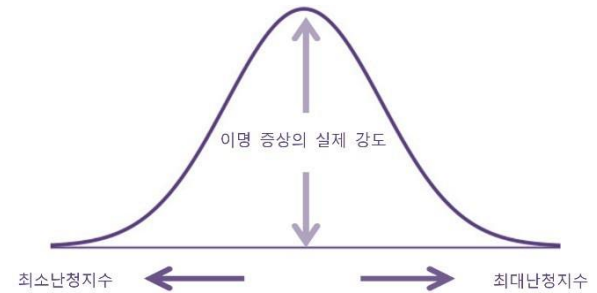
Regression Summary for Dependent Variable: Var2 (Spreadsheet1)							1	2
R= .07758546 R²= .00601950 Adjusted R²= -----							Var1	Var2
F(1,4)=.02422 p<.88386 Std.Error of estimate: 445.41							1	6545
b=	Std.Err. of b=	b	Std.Err. of b	t(4)	p-value		2	5934
Intercept		6066.667	414.6519	14.63075	0.000127		3	5739
Var1	0.077585	0.498493	16.571	106.4728	0.15564	0.883855	4	6059
							5	5784
							6	6687

What is clear is that, based on the distribution of the six standard deviation values and the six upper-lower mean difference ratio (D) values, which have a strong inverse relationship with the tinnitus index ranks, the following general conclusion can be drawn:

For groups with better hearing than a hearing loss index of 4,000, the milder the tinnitus, the better the hearing, and the more severe the tinnitus, the worse the hearing ($R=0.97$). On the other hand, for groups with worse hearing than a hearing loss index of 4,000, better hearing does not necessarily indicate mild tinnitus, nor does worse hearing necessarily indicate more severe tinnitus.

To summarize the correlation analysis results based on the 384 tinnitus resistance scores and 384 hearing loss index results obtained from the 192 MTM clinical subjects, the standard deviation of the hearing loss index and the difference ratio (D) values between the upper and lower means exhibit a Gaussian function relationship with the six-step tinnitus index ranks. In the group with relatively good hearing, there is a tendency for more severe hearing loss to correlate with more severe tinnitus and mild hearing loss to correlate with mild tinnitus. However, in the group with relatively

poor hearing, there is no clear relationship between the subjective intensity of tinnitus and the progression of hearing loss. In the group with poor hearing, more severe hearing loss does not necessarily mean more severe tinnitus. With intervention from Threshold Sound Conditioning (TSC), hearing loss improvement could lead to an increase in tinnitus severity, but this is not always the case.



The theory of the Gaussian function relationship between tinnitus and hearing loss will be discussed in detail in Chapter 13.

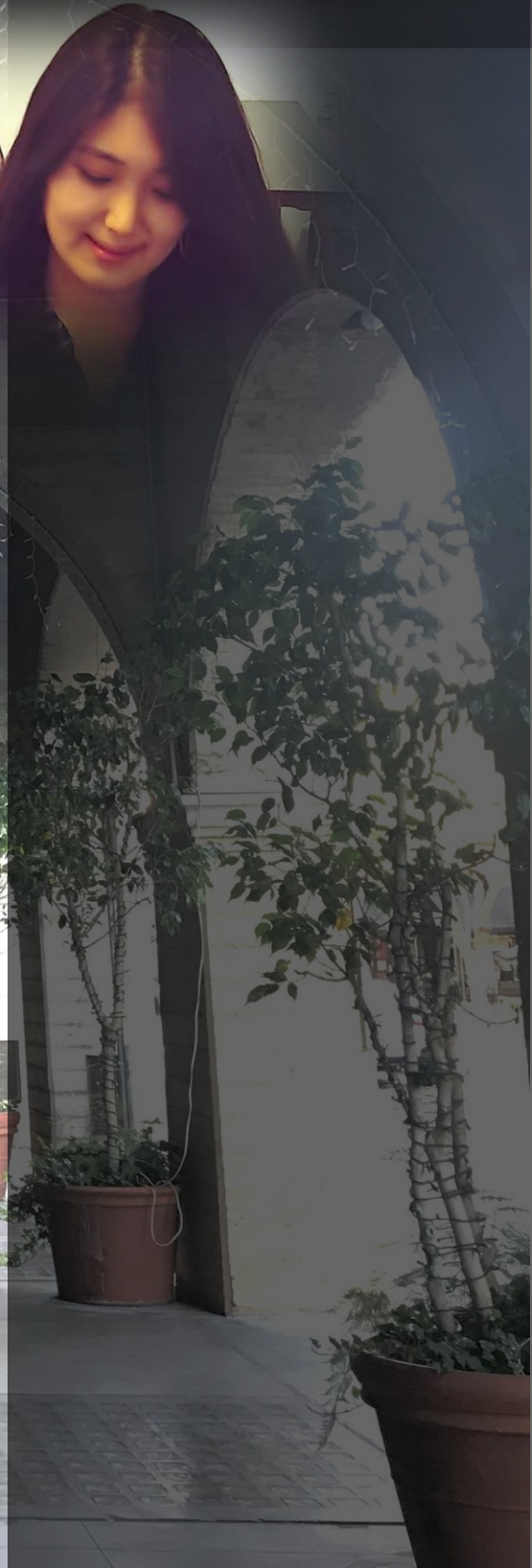


Clinical Reviews 2

Songhwa Kim, Audiologist

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Tinnitus is defined as "the perception of sound in the absence of external auditory stimuli" in the dictionary. The dictionary definition of tinnitus is very broad, and its causes are highly varied. A small number of people may mistakenly interpret sounds originating from within the body as tinnitus, but in most cases, tinnitus is sensorineural, caused by abnormal issues along the auditory nerve pathway, which includes the inner ear, auditory nerve, and auditory cortex in the brain. Tinnitus, such as bodily sounds, could potentially be heard by others if amplified in a very quiet environment, so it's difficult to call it tinnitus. Almost everyone has experienced tinnitus at some point. In my own case, I've occasionally heard a high-pitched "beep" sound for about a second after staying up all night or experienced brief tinnitus associated with anemia. Such temporary tinnitus often goes unnoticed or is easily masked by other sounds. However, if tinnitus does not resolve and continues persistently, it can make a person hyper-sensitive due to excessive stress, causing significant difficulties in daily life. According to multiple studies, 1-2% of adults face difficulties in normal activities due to tinnitus. As a hearing management specialist, I often hear stories from people with tinnitus. I had no idea before, but I later discovered that a close relative of mine suffers from severe tinnitus. I also heard from a stranger I met on a train about their struggles with tinnitus. Patients with severe tinnitus whom I met during my career as a hearing management specialist shared that they had spent enormous amounts of money traveling across the country for treatments. These stories allowed me to indirectly feel the pain they endure and the challenges they face in seeking treatment for their tinnitus.

Tinnitus sounds are not audible to others. Therefore, when people with tinnitus are asked to describe the sound, they are often unable to accurately express it, and even if they try, it can be difficult for others to understand. According to those who experience tinnitus, the sounds they hear can range from the sound of cicadas, wind, water, machinery, heartbeats, frogs, crickets, and more. Additionally, they often struggle to distinguish whether the sound comes from the left ear or the right ear. Since tinnitus cannot be heard by hearing management specialists, a great deal of time is invested in identifying it as an objective sound. This includes various tests such as the Minimum Masking Level test to assess the intensity of the tinnitus, as well as a self-tinnitus-finding program using 134-band frequency signals to help individuals find a sound most similar to their tinnitus. The pain of tinnitus is difficult to fully empathize with from family and friends, so the efforts of hearing management specialists go beyond just treatment, offering significant assistance. I have provided education to hearing management specialists and people with tinnitus about "self-tinnitus-finding." By using descriptions of the tinnitus sound and results from fine hearing tests, individuals can find the most similar tinnitus sound out of 432 options. However, the majority of people do not have a clear understanding of frequency and intensity, and they find it difficult to distinguish pure tones from complex tones composed of multiple pure tones. Noises with random frequency components also make it hard to differentiate timbres. The way people describe similar tinnitus sounds is individual and unique to each person. Therefore, finding an accurate match for the diverse forms of tinnitus within a short period is practically challenging.

Hearing loss and tinnitus can arise from damaged auditory hair cells. Tinnitus is most often accompanied by hearing loss, and even if the patient does not perceive it, there may be underlying hearing issues. In

other words, the frequency of tinnitus often closely matches the frequency of hearing loss, making it essential to conduct a fine hearing test within the audible frequency range of 20–20,000 Hz. Furthermore, improvements in hearing and tinnitus can be expected through the recovery of damaged auditory hair cells. The MTM clinical protocol aims to demonstrate the effectiveness of tinnitus treatment through hearing improvement, providing a quick diagnosis and objective treatment outcomes for tinnitus patients. Since tinnitus can be caused by various factors such as medications, noise, stress, environment, and chronic diseases, a method that objectively treats tinnitus without focusing on the cause by displaying hearing status through numerical values or graphs can be very innovative and effective. To ensure a swift diagnosis, information about the tinnitus symptoms or sound characteristics is not shared with the participants. Instead, a three-item questionnaire is used to assess the participant's current tinnitus condition, followed by a 67-band high-resolution automatic fine hearing test to quickly and accurately evaluate hearing status. In MTM clinical practice, if treatment is effective within about 30 minutes per patient, it brings great joy to the medical staff.

On September 17, 2018, MTM clinical trials began with voluntary participation from patients with tinnitus who visited 17 clinical medical institutions across the country. Over a two-week period, excluding the Chuseok holiday, more than 250 participants expressed a desire to voluntarily participate and underwent the first fine hearing test. In a previous clinical trial conducted at Stanford University's Department of Neurology in the U.S., 96 participants were supported with transportation expenses to participate, but despite no advertising or financial support for participants in this trial, a significantly larger number of participants were recruited. This highlighted how many people need treatment for tinnitus. On the fourth week of the trial, October 15, the first completed clinical data set was received. The original data from the participants' first, second, and third fine hearing tests, along with the first and second tinnitus questionnaires, TSC listening logs, and clinical logs from the medical institutions, were reviewed. Next, approximately 2,000 sets of participant data were integrated and organized for easier analysis. This resulted in the creation of 195 MTM clinical trial baseline analysis data sets, based on the original data from 195 participants. The number of participants is substantial, and the fact that all 195 participants followed the clinical protocol correctly and that all the data were collected without major issues is undoubtedly a result of the dedication of the medical staff and the participants' earnestness.

Not all 195 tinnitus patients in the study had sensorineural tinnitus alone. Occasionally, among those with good hearing, there are individuals who hear spontaneous otoacoustic emissions (SOAE). Spontaneous otoacoustic emissions are body sounds that can be heard by others if amplified, and they are not considered tinnitus. However, just because someone with good hearing experiences tinnitus, it cannot automatically be classified as spontaneous otoacoustic emission, so distinguishing between the two has been challenging. Traditional hearing tests had limitations in defining "good hearing," but the establishment of the concept of "hearing loss index" allowed for the establishment of a "good hearing" concept to differentiate spontaneous otoacoustic emissions. If the hearing loss index is below 500, it can be reasonably understood as "good hearing." Therefore, for tinnitus patients with a hearing loss index below 500, spontaneous otoacoustic emissions can be considered. If the center

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frequency of the spontaneous otoacoustic emission in individuals with hearing thresholds below 0 dBHL matches the test tone frequency, a positive (or induced) phenomenon can occur, which serves as a clue. Additionally, if periodic induced phenomena occur at 0 dBHL or lower, spontaneous otoacoustic emissions should be considered. Though not many, there are some tinnitus patients who confuse the sound of spontaneous otoacoustic emissions with tinnitus, and this cannot be disregarded. To distinguish between spontaneous otoacoustic emissions and tinnitus, a fine hearing test with at least 67 bands is essential. Among the 195 tinnitus patients who participated in the MTM clinical trial, three patients were excluded from the analysis data because they were considered to have spontaneous otoacoustic emissions.



The participants visited the clinical institution three times over four weeks, completing two tinnitus questionnaires and undergoing three micro-hearing tests. During the first two weeks, based on the second micro-hearing test, there was no diagnosis or prescription, allowing the participants' baseline hearing status to be assessed through normal daily life. The following two weeks were dedicated to active tinnitus treatment, with TSC prescriptions being administered. At the first and final visits, participants completed the tinnitus questionnaires, which helped track changes in their tinnitus symptoms. Once the clinical trial was completed for each participant, the data from the clinical institution were received and immediately integrated. This marked the beginning of observing the participants' data. Over the course of a month, an average of 5-6 participants per day, with a maximum of 16, were reviewed for any data errors. During the process of data integration for each participant, the most scrutinized data were the improvements in tinnitus symptoms and changes in hearing status. The results from the micro-hearing tests were determined based on the RCPTA algorithm for each of the 67 frequency bands in both ears, yielding a total of 134 threshold values for the first, second, and third tests, and thus a total of 402 threshold values. The MTM tinnitus treatment signal maximizes the treatment effect by targeting the individual's tinnitus frequency across multiple channels, as determined through objective testing. Initially, the focus was on observing changes in hearing status based on the participants' data, with a microscopic analysis comparing their tinnitus frequencies. However, interestingly, changes in frequency bands that were not targeted by treatment were found in nearly all participants, prompting a shift to observing the macroscopic hearing changes first. As a result, the concept of the "hearing loss index," which

reflects the total hearing value that can only be derived from the 67-band micro-hearing test, was introduced. The hearing loss index is the sum of the 134 threshold values from both ears, and because the computer's random frequency presentation algorithm minimizes the test duration, it provides a measurable figure. The results from the MTM clinical trial, interpreted through the hearing loss index, were surprising. Comparing the results from the second and third micro-hearing tests showed that participants with a reduced hearing loss index could be understood as having experienced hearing improvement from the TSC treatment signals. Similarly, comparing the results of the first and third tests indicated that participants with a reduced hearing loss index had experienced hearing improvement throughout the entire MTM process, including the TSC treatment sound. Lastly, the decrease in volume values recorded by participants as they identified the downward threshold volume of the TSC treatment sound also served as an indicator of hearing improvement from the treatment. Participants who showed hearing improvement across all three indicators—TSC effect, MTM effect, and downward threshold volume—could be considered as "definitively improved hearing" participants. Of the 192 participants in the MTM tinnitus clinical trial, 44.2%, or 85 participants, were definitively improved. A statistical analysis of only the hearing loss index changes in these 85 participants revealed that, through the 4-week MTM tinnitus treatment protocol, participants' total hearing and hearing loss index improved by 15.7%, with an astonishingly low statistical error rate approaching 0%. Hearing loss, often considered an incurable condition, showed significant improvement even from a macroscopic perspective—comparing overall hearing values rather than focusing on individual frequency changes. This result holds great significance.

For audiologists and researchers, hearing improvement may hold significant meaning, but for the participants in the tinnitus treatment trial and the medical staff committed to treating tinnitus, changes in tinnitus symptoms are undoubtedly the most important aspect. In the MTM clinical trial, the only data available to assess changes in tinnitus symptoms as perceived by the participants are the tinnitus questionnaires. The questionnaire contains only three questions. It is considered to be the most objective tool for assessing subjective tinnitus symptoms. The content of the first tinnitus questionnaire, completed during the first visit, and the second tinnitus questionnaire, completed during the final visit, is the same. However, most participants are unlikely to remember how they filled out the first questionnaire. This is because participants focus on the present moment when filling out the questionnaire, making it possible to objectively assess changes in their tinnitus symptoms. In fact, one participant thought their tinnitus symptoms had improved, but their tinnitus questionnaire score decreased. Conversely, some participants felt that their tinnitus had not changed or had worsened, but their questionnaire scores showed improvement. Information regarding how the tinnitus was experienced, what sounds were heard, and how the timbre of the sound changed, aside from the intensity and frequency, cannot be derived from the MTM tinnitus questionnaire. The more attempts a participant has made to treat their tinnitus in the past, the more information they may want to convey due to their previous experiences. In reality, some participants included additional subjective details about their tinnitus in the questionnaire, while others felt their tinnitus had improved but the questionnaire score did not reflect this, leading the medical staff to add notes of their own out of frustration.

1804-09 14 선영

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연구 참여 신청서

본인은 귀 의뢰기관에 실시하는 <이명 진단 및 치료 연구> 참가를 희망합니다.

성명: 선영

나이: 28

전화번호: 010-6511-6996

2018. 04. 14

연구 참여 신청서

이명 진단 및 치료 일정

이명 진단 및 치료 일정

이명 진단 및 치료 일정

There were instances of contradictory answers in the tinnitus questionnaires. For example, on the fourth day of completing the MTM clinical trial, a participant answered "Always heard" to the question about tinnitus during the past three days, but answered "Not heard at all" regarding the current tinnitus volume. Then, they answered "Consistently present" for the current tinnitus experience. On their first visit, the participant had filled out the initial tinnitus questionnaire and answered "Always heard" to the same question about the past three days, "Moderately heard" to the question about the current volume, and "Consistently present" to the question about today's tinnitus. They had also written a note saying "At night or in quiet places." This suggests that the tinnitus persisted during the night or in quiet places, and at the time of completing the first questionnaire, it was noticeable at a moderate level. However, after completing the 4-week clinical trial, the tinnitus was not heard at all. By reviewing the note that mentioned "at night or in quiet places," the contradictory answers could be understood. In other words, while the tinnitus questionnaire had simple questions, it seems that additional explanations from medical staff might be needed for accurate diagnosis.

The answers from the participants' tinnitus questionnaires could be used to analyze the effectiveness of the MTM clinical trial's tinnitus treatment. Initially, when receiving tinnitus questionnaires randomly from clinical institutions, the improvement in tinnitus was not clearly evident. However, after completing the trial and analyzing the answers from all participants together, the effects began to emerge. Remarkably, in all questions of the tinnitus questionnaire, the results showed a decrease in the intensity and frequency of tinnitus after the MTM trial. The scores derived from the tinnitus questionnaires reflect tinnitus resistance, with the lowest score being 3 and the highest score being 15. A tinnitus resistance score of 3 indicates the most severe tinnitus symptoms, while a score of 15 indicates no tinnitus. After analyzing the tinnitus questionnaires, it was found that the tinnitus resistance improved in 38% of the 192 participants, amounting to 74 individuals, and the results were statistically significant with an error rate of 0.0003%. Furthermore, changes in hearing were observed in 42 participants whose tinnitus resistance score had decreased after completing the MTM clinical trial. Among these 42 participants, 16 showed complete hearing improvement, and 2 showed complete hearing deterioration. Additionally, in the 76 participants whose tinnitus resistance score remained unchanged, 37 showed complete hearing improvement, which was statistically significant. According to Gaussian theory, hearing improvement or deterioration can lower the tinnitus resistance score, which means further microscopic frequency analysis is necessary. What is

clear is that a 2-week TSC treatment resulted in changes in hearing improvement, and with prolonged treatment, tinnitus treatment could also be feasible.

The MTM clinical trial has demonstrated the tinnitus treatment effects associated with hearing improvement. Now, the next step is to explore methods to achieve higher treatment efficacy. Based on the basic analysis data from the 192 participants in the MTM clinical trial, approximately 200 additional classification/integration data points were created. Thanks to the sufficient amount of data, various treatment methods, specifically various targeting methods, were collected. This MTM clinical trial utilized multi-channel targeting to maximize the tinnitus treatment effect. Therefore, we first decided to observe the changes in the hearing loss index based on the number of targetings. Targeting could be conducted using both proximity and isolation methods, allowing a maximum of five targetings in one ear. Combining the number of targetings in both ears, the participants had a minimum of 1 targeting and a maximum of 9 targetings. By categorizing the participants into two groups based on whether they had fewer than five targetings or more than five targetings, we observed if any statistically significant results emerged. If statistically significant results were found in the group with more than five targetings, we could recommend conducting at least five targetings for higher TSC effects. Unfortunately, both the group with fewer than five targetings and the group with more than five targetings exhibited statistically significant TSC effects, and no significant differences were observed between the two groups. To observe the effect of multi-channel targeting, additional classification data and microscopic and detailed analyses are required.



Next, we attempted to observe the changes in the hearing loss index based on the targeting method. We analyzed whether higher hearing improvement could be observed when stimulating the same frequency band in both ears simultaneously. By classifying participants who had both ears targeted with the same threshold band into two groups—those whose majority of the frequencies were in the same threshold band and those whose majority were not—we found that the TSC effect was statistically significant in the group where the majority of frequencies were in the same threshold band, but not in the group where the frequencies did not overlap. In other words, when targeting so that the threshold bands overlap in both ears, higher hearing improvement can be expected. Furthermore, we analyzed whether targeting frequencies that stimulate the

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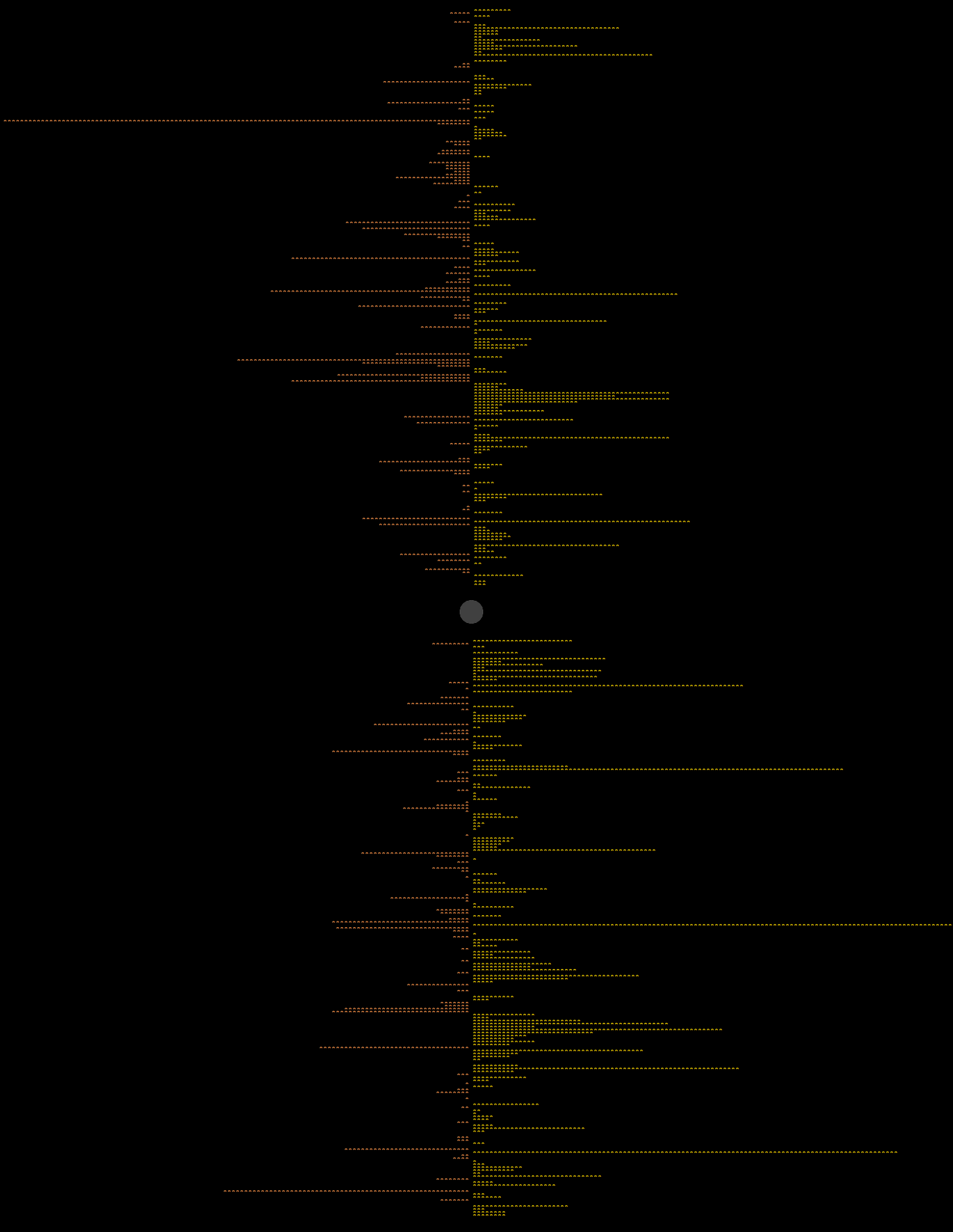
same harmonic plate would result in better hearing improvement. The closely related frequency ratio in the same harmonic plate is 1:2:3. Specifically, the most closely related ratio is 1:1, followed by 1:2, then 2:3, and finally 1:3. When classifying participants into two groups—those whose left and right targeting frequency ratio corresponded to 1:2:3, and those whose ratio did not—the group that targeted the same harmonic plate exhibited a statistically significant TSC effect, whereas the group that did not show significant effects. This suggests that targeting in a way that stimulates the same harmonic plate can lead to better hearing improvement. In order to target in such a way that the threshold bands overlap or stimulate the same harmonic plate, one would need to find and calculate the center frequency and the frequency range of the threshold bands based on the REVE134 index number used for targeting. However, using the formula for the threshold band and harmonic multiplication relations of the REVE134 index, the process can be quick and useful when creating the TSC treatment sounds. When targeting to overlap the left and right threshold bands, it is important to remember the number '6'. If the left and right targeting index numbers differ by 6 or less, higher hearing improvement effects can be expected. Similarly, for the 1:2 multiplication relationship, the formula is '24'; for the 1:3 multiplication relationship, it is '38'; and for the 2:3 multiplication relationship, it is '14'.

I remember the emotional experience during the seminar in April 2018, where I presented the seminar on The Gaussian Theory and Formula on the Correlation between Tinnitus Intensity and Hearing. As I interacted with people who had suffered from tinnitus for a long time and had very poor hearing, I always made sure to remind them as an audiologist that "improving hearing may increase the volume of tinnitus." Often, I would receive feedback that the tinnitus had indeed become louder. I also asked people who had significant hearing loss, to the point of almost no hearing, if they had experienced tinnitus before. More often than not, they would reply that they had had tinnitus, but it was no longer present. People with deafness or those with nearly complete hearing loss either don't have tinnitus now or it hasn't gotten any worse. Many of them reported feeling changes in their tinnitus while listening to TSC sound sources. On the other hand, for those with less hearing loss, tinnitus would often diminish or disappear in a short period. The Gaussian Theory and Formula on Tinnitus Intensity posits that hearing loss and tinnitus intensity do not have a proportional relationship but rather a Gaussian function relationship. It was a significant day for me when this theoretical connection between tinnitus intensity and hearing, which I had only vaguely sensed through experience, was diagrammed and could be better understood in terms of the process of tinnitus generation. However, the model of the Gaussian Theory on Tinnitus Intensity is a schematic study of the process of tinnitus generation within a single threshold band in the cochlea, involving auditory cells, auditory neurons, and the central system. The fact that the inductive proof of the Gaussian Theory on Tinnitus Intensity can now be derived from the macro-level analysis data of the MTM clinical trial indicates that this theory extends beyond the single auditory filter concept and is reflected in total human hearing. In other words, the theory suggests that when an individual's overall hearing loss is moderate, the subjective intensity of tinnitus is the strongest, and when hearing is either very good or completely lost, the subjective intensity of tinnitus can be zero. This has been proven by the hearing loss index data from this MTM clinical trial. In the group with good hearing, the severity of tinnitus symptoms was weaker the better the hearing, and the worse the

hearing, the more severe the tinnitus symptoms. In contrast, in the group with poor hearing, the severity of tinnitus symptoms was not necessarily stronger as hearing loss increased. This indicates that within the group with poor hearing, tinnitus symptoms could either be weak or strong, depending on the severity of hearing loss. Therefore, the hypothesis that "the intensity of tinnitus correlates proportionally with the degree of hearing loss" could be an overgeneralization. Through this MTM clinical trial, I have witnessed the reflection of the Gaussian Theory on Tinnitus Intensity in total human hearing, extending beyond the concept of a single auditory filter. Within the uncertain relationship between hearing loss and tinnitus, the Gaussian Theory on Tinnitus Intensity presents a critical tool for improving existing tinnitus treatment methods. It is expected to serve as the starting point for groundbreaking tinnitus treatments in the future.







The "temporal resolution of firing rate" at the level of the auditory cell group is an important clue that allows the auditory neurons in the central nervous system to differentiate between various intensities. The TSC effect arises from the phenomenon where abnormally excessive, intermittent firing at different stages of auditory processing, including auditory cells, the auditory nerve, and auditory neurons, is transformed into normal, continuous firing. The reason for adjusting the intensity of the modulated acoustic signal to the descending threshold (rather than the ascending threshold) during TSC implementation is that more intermittent firing occurs at the descending threshold than at the ascending threshold. When, at a specific descending threshold level, the total amount of intermittent firing decreases and the total amount of continuous firing increases due to TSC, the intensity that is perceived by the individual increases. This results in an improvement in hearing.



11. Reinterpretation of MTM Results

Temporal Resolution of Firing Rate

In electrophysiology, when studying a single response pattern of various event-related potentials (ERPs) hidden in the brainwave (EEG), the stimulus signal is often repeated hundreds, or even thousands, of times. The more high-quality ERP signal samples that can be obtained within a given measurement time, the better. By repeatedly presenting the stimulus, the amplitude information of very small electrical responses in the body is expressed as numerical data or coordinates in a time series. Each ERP signal amplitude sample is synchronized with the timing of each stimulus presentation and undergoes an accumulation averaging process. The reason for accumulating and averaging thousands of ERP amplitude values to obtain a single bio-signal result is to remove various noise (artifacts) that enters the brainwave. This allows for a better signal-to-noise ratio (SNR). Artifacts generated by various body factors and electrical environmental factors often mix with the subject's brainwave, so by artificially averaging, the random noise occurring at different time points can be canceled out. This results in high-quality bio-signal data. In auditory systems, evoked potentials are referred to as AEPs (auditory evoked potentials). AEPs are the electrical responses generated in the body by auditory stimuli. These responses are produced by the firing of auditory cells or auditory neurons. When looking at the time series information of firing, intermittent firing and sustained firing constantly cross each other in a random manner, even if the moment is very short. The firing time series pattern is similar to the random time series pattern of brainwave artifacts.

At the level of a single auditory cell, the firing cycle is governed by the absolute refractory period law. However, the absolute starting time of firing in different individual auditory cells is not governed by this law. The start time of firing is influenced by the physical environment, not the electrical environment within the body. When considering only the absolute starting times of firing in different auditory cells or auditory neurons, the time difference between the firing start times can range from a few millionths of a second to several hundred thousandths of a second. While the auditory center cannot individually perceive the time difference between each firing start time, the total amount of absolute time

difference between the start times of different firings forms the clue to the "intensity" of the sound. The auditory center distinguishes between different intensities by analyzing the total amount of time difference between the firing start times collected from the periphery. The firing cycles of the A-1 cell and A-2 cell that process an A frequency are governed by the absolute refractory period law. However, the different starting points of firing in the A-1 and A-2 cells are not governed by this law. Within a single A-1 cell, continuous firing cannot occur with a time difference shorter than one-thousandth of a second (1 msec). However, when the A-1 and A-2 cells react together, cross-firing can occur with a temporal resolution within 1 msec. At the level of an auditory cell group, the "temporal resolution of firing rate" is an important clue that enables the auditory neurons in the central system to distinguish between different intensities.

Let's consider a group of approximately 500–600 auditory cells within the same critical frequency band as a single unit and think about how these cells produce firing when exposed to a specific frequency stimulus. The image below is a 90-degree rotation of the 192 hearing change rate results from the 1st and 2nd phase of the previous page's hearing loss index graph. Let's assume that the 192 points arranged along the horizontal axis correspond to an ideal time grid of 1 msec. Additionally, let's assume that the height of each of the 192 lines represents the total firing rate of the auditory cell group at each msec time point. The total firing rate refers to the amount of sustained firing minus the amount of intermittent firing within each 1 msec time grid.



MTM 이명의 진단과 치료



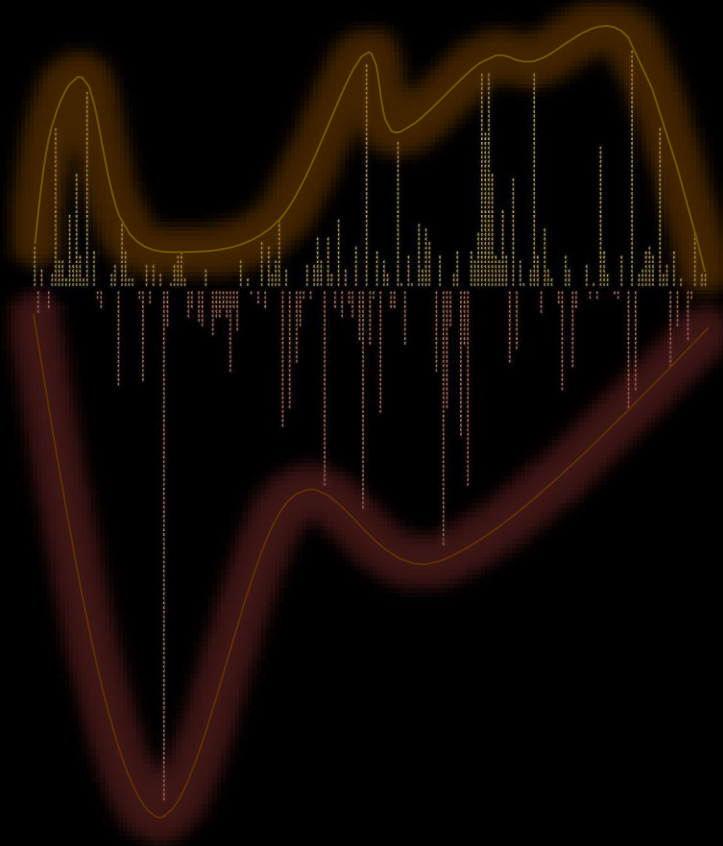
The 192 lines are interpreted as the time series of the total firing rate of the auditory cell group within a single critical frequency band over 192 msec. These lines can also be understood as representing an individual's "gross hearing" within a specific time window. The concept of gross hearing includes both the "spectral resolution" and "temporal resolution" concepts that are formed between the actual physical space elements, such as the cochlea or auditory cortex, and the time element of sound. As

shown in the image below, the total of the 192 lines can be interpreted as symbolizing an individual's total hearing at the 2-week and 4-week MTM marks within the 192 msec time window.

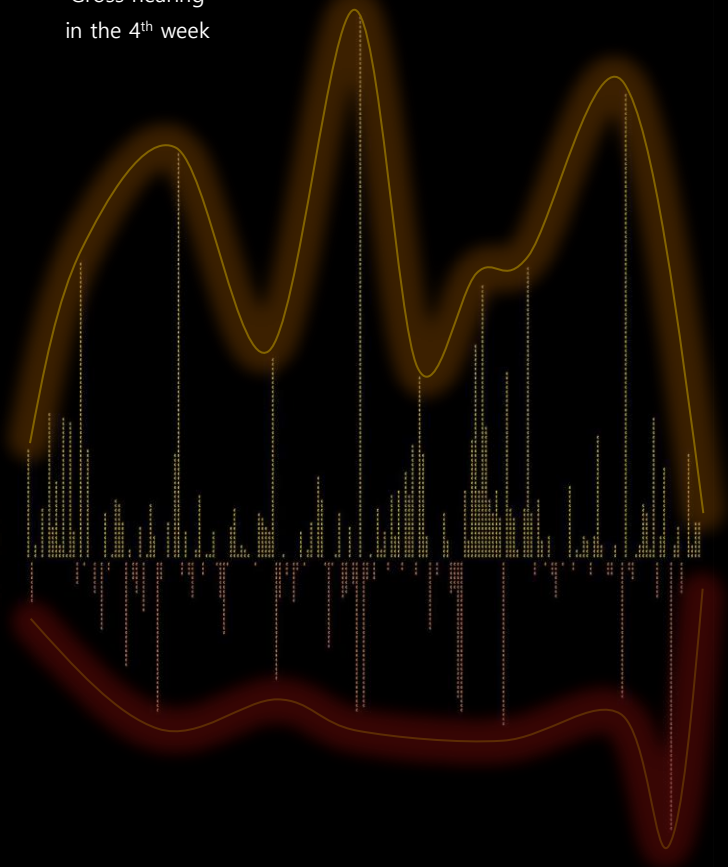
Healthy Hearing

As I attempt to reinterpret the MTM results, many questions come to mind. The most representative one concerns the instability of hearing. Could the act of completing the tinnitus questionnaire itself have had an impact on hearing? What factors, aside from TSC intervention, led to the change in gross hearing during the MTM clinical trial? Of the 195 subjects, 59%, or 115 individuals, showed a change in gross hearing of more than $\pm 5\%$ during the 1st and 2nd phases. What might be the reason for such unstable hearing, even without TSC intervention, when only the RCPTA and tinnitus questionnaire were administered? Could the random arrangement

Gross hearing
in the 2nd week



Gross hearing
in the 4th week



of the 67 sine wave tones in the RCPTA listening test have caused temporary fluctuations in the auditory nervous system of the subjects, who were encountering it for the first time? Could there have been spatial or environmental factors unrelated to hearing that contributed to the temporary "hearing deterioration" or "hearing improvement" observed over the two weeks without TSC intervention? It is worth noting that the observed +/- 5% change in total hearing instability in 59% of the subjects occurred after they voluntarily visited the clinic where the clinical trial was conducted. In the MTM 4-week clinical study, conducted primarily with patients visiting the clinic, the subjects completed their first fine hearing test and the initial tinnitus questionnaire in an unfamiliar clinic environment. Additionally, the expectation that they would return to the same location in two weeks introduced a psychophysical variable. This special experience, initiated in the clinical setting (not only an unfamiliar auditory experience but a new spatial environment itself), may have had a positive or negative impact on the temporary total hearing observed over the next two weeks.

MTM is a diagnostic and treatment procedure for tinnitus based on the RCPTA and TSC technologies. The goal of MTM is the fundamental improvement of total hearing. A fundamental improvement in total hearing means a hearing state that is healthier than the previous one. How should we specifically understand the expression "healthier hearing"? To explore this, let's first consider what unhealthy hearing might be. Unhealthy hearing is hearing that is often accompanied by sudden firing or neural synchronization responses. Even in fine hearing tests, traces of sudden firing or neural synchronization are often reflected. Unhealthy hearing deteriorates quickly. The rate at which frequency specificity deteriorates is also rapid. Unhealthy hearing is characterized by the fast progress of reorganization, where the boundaries of critical frequency bands become increasingly unclear. The characteristics of unhealthy hearing become apparent in quiet sound environments. Since the attenuation performance is degraded, the person reacts sensitively to certain sounds even though they are not loud. They may not hear faint sounds at all. There is a severe mismatch in auditory function in response to slight environmental noise. The characteristics of unhealthy hearing also appear in noisy sound environments. Due to the reduced attenuation function, the defense against loud sounds is weak. The person reacts irritably to loud sounds. In a noisy environment, their voice becomes excessively loud. They are startled by even a slight increase in loudness. They perceive differences in sound intensity as much larger than normal individuals. Unhealthy hearing is often easily assumed to be "hearing loss" itself, but this is not the case. Unhealthy hearing can be present in normal individuals as well and can exist at various thresholds of hearing. For example, even if two people have the same 1,000 Hz hearing threshold at 30 dBHL, the actual health of their hearing at this 30 dBHL level could differ. Both individuals may currently have a 30 dBHL hearing threshold, but the speed and degree to which their hearing at this level will either deteriorate, improve, or remain the same can be different. Even if two people with profound hearing loss both show a 70 dBHL hearing threshold, their responses to a 10 dB increase to 80 dBHL can vary significantly. When two individuals with a 70 dBHL hearing threshold are presented with a sound at 80 dBHL, one may perceive it as an increase of only 10 dBSL, while the other might perceive it as an increase of 50 dBSL.

From a microscopic perspective of intermittent/sustained firing, healthy hearing can be defined as follows: Healthy hearing refers to a hearing state that possesses qualitatively superior spontaneous firing patterns at the level of single auditory cells and single auditory neurons. A qualitatively superior spontaneous firing pattern must exhibit a non-periodic distribution of auditory cell firing points along the time axis. A healthy firing pattern maintains its inherent non-periodic firing characteristics without interference from the frequency spectrum of blood flow noise or the periodic heartbeat sounds. From the perspective of intermittent/sustained firing, healthy hearing refers to a hearing state in which the quality of non-periodic firing patterns at the level of single auditory cells/single auditory neurons is reflected in the firing patterns between auditory cell groups or auditory neuron groups within the same critical frequency band. In an active auditory system, the more the firing patterns between 500-600 auditory cells within a single critical frequency band do not synchronize and instead interlace, the healthier the hearing. The interlaced firing pattern itself must also exhibit non-periodic characteristics.

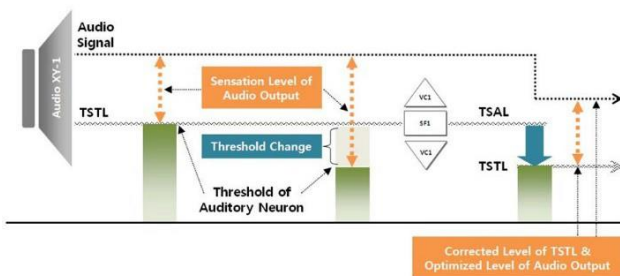


To define healthy hearing, let us broaden the scope to include the entire cochlea or the entire auditory nervous system. The high-quality non-periodic spontaneous firing pattern that appears at the level of a healthy single auditory cell should also be evident in the spontaneous firing patterns of auditory neurons processing complex tones such as speech or music. When the non-periodicity of the firing pattern is well-maintained, not only in the random interlaced patterns between auditory cell groups within the same critical frequency band but also across the entire audible frequency range, including the harmonic bands and tonotopic neural network, this can be considered healthy hearing.

Schematic Understanding of TSC Acoustic Technology

The TSC acoustic technology introduced by the MTM clinical protocol is not only used for medical purposes to treat sensorineural hearing loss but also for self-hearing management by the general public to maintain their hearing health in daily life. To integrate TSC acoustic technology with medical practices or medical technologies, a high-resolution diagnostic result concerning the hearing state of sensorineural hearing loss patients is required. In order to accurately track spontaneous firing or neural synchronization phenomena in a single auditory filter under uncontrolled or random conditions in a behavioral response experiment environment, a high-resolution audiometric test result with a frequency specification that exceeds at least three times the average resolution of the critical frequency band is necessary. This means that the hearing results must be derived from presenting at least three different frequencies at random points within the same critical frequency band. An example that meets this specification is the 67-band RCPTA algorithm used in the diagnostic section of the MTM protocol. Let's examine a simple schematic example of the TSC acoustic technology, which is used for hearing management by the general public, not for medical purposes. This will help in understanding the general principles of TSC technology.

Improvements in hearing or tinnitus symptoms are observed as a result of medical practices in various medical institutions that have implemented the MTM clinical protocol. On the other hand, improvements in hearing or alleviation of tinnitus symptoms are often seen as a result of self-conducted frequency-specific hearing management by the general public. In this case, although no medical diagnostic procedures are involved at the high-resolution level of 67 bands or more, even non-hearing-impaired individuals can roughly identify their vulnerable frequencies and experience improvements in hearing or alleviation of tinnitus symptoms by applying TSC at those frequencies or related frequencies. This TSC acoustic technology can be applied in daily life based on the principle shown in the schematic below.



The diagram above shows an example of the integration of TSC acoustic technology into a popular music streaming service known in English-speaking countries. Users of content platforms such as Apple Music, Spotify, and YouTube, while listening to audio content like music or speech, can click the TSC button to attempt hearing improvement along with the consumption of that audio signal content. In the diagram, the speaker image represents the stereo headphones/earphones used by the audio signal listener. The device must be a stereo headphone/earphone

capable of independently delivering the audio signal to each ear, with left and right signals separated. When people generally listen to sound, they adjust the volume to a level that is "audible." No one would typically listen to a sound by setting the volume below their hearing threshold, making it "inaudible." According to the diagram, while the audio signal listener adjusts the volume to a level higher than their hearing threshold, a subtle trigger signal (TSC acoustic signal) appears at the level just near their hearing threshold, a signal that is barely audible. This subtle trigger signal is essentially the TSC acoustic signal, similar to the modulated acoustic signals used in MTM. When the auditory trigger signal occurs at the hearing threshold level (TSTL), it causes changes in the listener's auditory neuron response range. The threshold can be divided into the ascending threshold and descending threshold. For TSTL to work more effectively, it is better to adjust the volume to the descending threshold rather than the ascending threshold. When the TSTL is adjusted to the descending threshold, it induces a reduction in the auditory neuron response range, increasing the volume level of the audio signal that was previously at the "audible level." Furthermore, the TSTL is no longer at the "threshold level" but instead at the "audible level." When TSTL reaches the audible level, it becomes TSAL (trigger signal at audible level), which has minimal effect on causing changes in the auditory neuron response range. Therefore, TSAL needs to be recalibrated back to the descending threshold level of TSTL. The algorithm applied in the TSC diagram automatically reduces the volume of the audio signal in accordance with the recalibrated TSTL of the audio signal listener.

Homeostasis and Non-Homeostasis of Hearing

In traditional neurophysiology or audiology, human hearing or hearing ability is fundamentally considered a homeostatic biological phenomenon. To discuss whether something is "homeostatic" or "non-homeostatic," the grid size must first be defined. If a phenomenon is observed to be homeostatic within a specific category, region, or grid unit, it raises the question: would it still be observed as a homeostatic phenomenon if the grid unit were changed? Another essential topic in the discussion of the homeostasis (or non-homeostasis) of hearing is the concept of "general factors" and "specific factors" that influence everyday hearing. These factors will be discussed shortly. However, to understand the precise meaning of "homeostasis" in the auditory system, let us briefly look at the example of a 100-meter sprint.

Let's assume that a professional sprinter measures their speed for the 100-meter sprint once a day over the course of a week. The recorded times are 11.43 seconds, 11.65 seconds, 11.23 seconds, 11.02 seconds, 11.78 seconds, 10.91 seconds, and 11.10 seconds. If these results are viewed within the "1-second" time grid unit, the sprinter's speed appears homeostatic. However, if viewed within a time grid unit of "0.1 seconds" or less, the times vary each time. The athlete's motor-sensory ability, which controls the 100-meter sprint, is homeostatic at the "1-second" time grid level but non-homeostatic at the "0.1-second" or smaller time grid level. How about a non-professional individual's 100-meter sprint speed? If the sprinting speed is measured once a day over the course of a week, the results might be 16.53 seconds, 17.18 seconds, 16.04 seconds, 15.45 seconds, 16.25 seconds, 17.07 seconds, and 16.34 seconds. This individual's 100-meter sprinting ability is non-homeostatic at the "1-second" time grid level but homeostatic at the "5-second" time grid level.

In international standard pure-tone audiometry (PTA) conducted on human subjects, the intensity grid unit for testing sounds is 5 dB. The reason this unit is not subdivided into finer increments is that, although finer increments could be used, the testing time would increase exponentially. Additionally, at the typical "hearing threshold" level for most subjects, a 5 dB difference in volume is not easily perceptible. To explain why a 5 dB difference is not easily perceived at threshold levels:

Human hearing can maintain homeostasis at a 5 dB intensity grid unit under "static hearing" conditions.

For this statement to hold true, there must be no external factors causing changes to the static hearing state. Only then does the concept of "5 dB unit homeostasis" make sense. Humans are constantly exposed to a wide spectrum of sounds in daily life, and non-auditory health variables also continuously affect hearing. In such an unstable auditory environment and conditions, it is almost impossible to maintain homeostasis at a 5 dB grid unit. This does not mean that daily exposure to noise will lead to a consistent 5 dB decrease in hearing each day. If hearing were to decrease by exactly 5 dB every day, this would be considered a "homeostatic change." However, such consistent and predictable changes in hearing do not occur. Human hearing is routinely exposed to unstable conditions and environments.

In these situations, maintaining "5 dB unit homeostasis" is nearly impossible, and hearing will fluctuate randomly at any given moment within the 5 dB intensity grid. For example, hearing may fluctuate from 10 dB to 15 dB or from 30 dB to 25 dB at any time. To summarize the above:

Hearing can maintain homeostasis at a 5 dB intensity grid unit under "static hearing" conditions. However, human hearing is subject to the influence of unstable internal and external general factors, so hearing becomes non-homeostatic at a 5 dB intensity grid unit.

The internal and external general factors mentioned above include daily noise, diet, health conditions, stress, rest, etc. What happens to the homeostasis or non-homeostasis of hearing when specific factors intervene?

In an ideal static hearing state, hearing at a 5 dB intensity grid unit may appear to be homeostatic. However, due to internal and external general factors, this homeostasis manifests as non-homeostatic characteristics at the 5 dB intensity grid unit. This non-homeostasis at the 5 dB grid unit may appear homeostatic when viewed at a new intensity grid unit of 10 dB or 15 dB. But what specific factors could induce non-homeostasis of hearing at the 10 dB or 15 dB intensity grid units? In modern neurophysiology and audiology, when asked what specific factors could cause hearing changes of 10-15 dB or more, the following factors would be identified: Loud noise, Intense stress, Severe deterioration of health, Overwork, Side effects of medication, Surgical complications. All these specific factors can cause non-homeostasis of hearing at the 10-15 dB intensity grid unit, and interestingly, they are all factors that worsen hearing. However, non-homeostasis of hearing is not just a concept viewed from the perspective of deterioration in the function of auditory cells, auditory nerves, or auditory neurons. From the perspective of improving the overall function of the auditory nervous system, what factors could indeed induce non-homeostasis of hearing at the 10 dB or 15 dB intensity grid unit? The only factor that can systematically induce a positive change in hearing—leading to positive non-homeostasis at the 10-15 dB intensity grid unit as of 2019—is TSC (Threshold Sound Conditioning) technology.



12. Tinnitus care

In this MTM clinical study, no detailed classification of tinnitus types among patients with tinnitus symptoms was attempted. To achieve the primary goal of MTM treatment, which is "maximum effect in the shortest time," efforts to classify various tinnitus symptoms were postponed to future research. The tinnitus diagnosis method in this MTM clinical study relied solely on the RCPTA algorithm test and a three-item tinnitus questionnaire. This approach aimed to meet both the study's objectives: ensuring an objective assessment of the patient's hearing and capturing the patient's subjective tinnitus descriptions in a simple and efficient manner. Therefore, common aspects typically assessed during tinnitus treatment—such as the tonal characteristics of tinnitus, its causes, duration, medication intake, and health management habits—were not inquired about in this study. However, in general tinnitus treatment settings, various questions and discussions may be necessary to meet the diverse needs of patients. In particular, procedures involving a frequency generator may be required to determine the detailed tonal characteristics of tinnitus or to analyze the tinnitus frequency spectrum. This chapter will examine the most widely

used tinnitus diagnosis method in general clinical practice: the "tinnitus diagnosis using a frequency generator." Additionally, it will provide a detailed understanding of the limitations of this method and propose several alternatives to overcome them. Furthermore, it will explore tinnitus treatment approaches based on ten different tinnitus classification methods.

Frequency Generator

The manual use of a frequency generator to identify the tinnitus frequency of a patient has been a tinnitus testing method for decades. The most commonly used frequency generator in medical institutions for diagnosing and treating tinnitus is the pure tone audiometer. Let's consider a tinnitus patient, Mr. P, who perceives a high-pitched "beep~~~" sound as his tinnitus. To determine the characteristics of Mr. P's tinnitus, medical professionals use a pure tone audiometer to generate a series of comparison tones at different frequencies and

present them sequentially to Mr. P. The patient is then asked to identify the tone that best matches or closely resembles his tinnitus. Suppose Mr. P's tinnitus frequency is 4,000 Hz. The medical professional plays comparison tones at 1,000 Hz, 2,000 Hz, 4,000 Hz, and 8,000 Hz, repeatedly asking questions such as, "Does this sound match your tinnitus?" or "Is this sound more similar to your tinnitus?" To accurately determine Mr. P's 4,000 Hz tinnitus frequency, at least four different frequencies must be presented multiple times (at least three comparisons each), while closely observing Mr. P's responses. However, in many cases, tinnitus patients are unable to quickly and accurately identify their tinnitus frequency. It is common for patients to mistakenly perceive comparison tones at other frequencies as resembling their tinnitus frequency. Due to time constraints in clinical settings, audiometers typically present only four standard pure tones: 1,000 Hz, 2,000 Hz, 4,000 Hz, and 8,000 Hz. This raises the question: Can a patient's tinnitus frequency be accurately identified using only these four comparison tones? Some clinicians include additional tones at 3,000 Hz and 6,000 Hz, but even then, the chance that a tinnitus patient's actual frequency matches exactly one of these six options is limited. Now, consider a scenario where a clinician presents Mr. P with two comparison tones: 2,000 Hz and 8,000 Hz. How would Mr. P perceive them in relation to his 4,000 Hz tinnitus? This situation frequently leads to misidentification. Most tinnitus patients find it easier to match the intensity of a tone rather than its frequency or timbre. When asked to find a sound similar to their tinnitus, many patients tend to select a tone that is similar in loudness, rather than one that matches the actual frequency. For example, if Mr. P has a 4,000 Hz tonal tinnitus, but he is given a 2,000 Hz tone at a slightly lower intensity and a 4,000 Hz tone at a much higher intensity, many patients mistakenly perceive the 2,000 Hz tone as being more similar to their tinnitus. The difficulty increases when a patient's tinnitus is not a pure tone but a complex tinnitus, consisting of multiple frequencies (e.g., 2,000 Hz, 4,000 Hz, and 8,000 Hz mixed together). In such cases, can a frequency generator truly pinpoint the exact tinnitus frequency? The challenge of accurately identifying the tinnitus frequency through this method remains a significant limitation in clinical practice.

Another common misidentification encountered when using a frequency generator for tinnitus identification is as follows. According to the harmonic mapping principle of the auditory nervous system, 3,000 Hz and 6,000 Hz are processed within the same harmonic map. As a result, while they may seem different in tone, they are actually very similar in timbre. For example, consider the case of Mr. G, who has tinnitus with a 3,000 Hz frequency component. When presented with comparison tones by medical staff, he may perceive 6,000 Hz as being closer in timbre to his tinnitus than 4,000 Hz. This is analogous to a musical perception test: if a reference note, G1 (Sol), is played first, followed by C2 (Do) and G2 (Sol, one octave above G1), and a listener is asked which of the two sounds more similar in timbre to the reference note, at least 50% of listeners tend to find G2 more similar to G1 than C2. Similarly, a tinnitus

patient with 3,000 Hz tinnitus may mistakenly perceive 6,000 Hz as more similar to their tinnitus than 4,000 Hz. Accurately identifying tinnitus frequency using a manual pure tone audiometer is extremely difficult. Even when a match seems to be found, misidentifications are frequent. This challenge is not limited to pure-tone tinnitus, where distinguishing frequencies is already complex, but becomes even more pronounced with complex tinnitus, which consists of multiple frequencies. Furthermore, if a tinnitus patient perceives broadband noise rather than distinct tonal components, attempting to pinpoint their tinnitus frequency using a manual pure tone audiometer—by presenting comparison tones one by one—becomes an even more challenging task.

Minimum Masking Level (MML)

Most tinnitus patients find it easier to perform loudness discrimination tasks—which involve comparing the intensity of their tinnitus—than spectral discrimination tasks that require distinguishing tinnitus frequency and timbre. Conversely, this means that the error rate is higher when identifying tinnitus frequency or timbre compared to tracking tinnitus loudness. One of the primary methods for tracking tinnitus loudness is the Minimum Masking Level (MML) test. The MML test estimates the approximate intensity of the dominant tinnitus—the frequency component that is currently perceived as the loudest by the patient. During the MML test, white noise, which stimulates auditory cells across the entire audible frequency range, is presented to the affected ear. The volume of the white noise is gradually increased until the dominant tinnitus becomes completely masked and is no longer perceptible to the patient. Since the MML test only tracks the loudness of the dominant tinnitus, it does not effectively measure the intensity of secondary or tertiary tinnitus components that may be present at lower levels. This limitation is not due to technical constraints of the test itself, but rather because tinnitus patients struggle to perceptually distinguish these additional tinnitus components. As a result, MML testing can provide a relatively accurate measure of tinnitus intensity only in cases of pure-tone tinnitus with a single dominant frequency. For complex tinnitus, where multiple tinnitus components occur across different critical frequency bands, the MML test is insufficient for accurately tracking the overall tinnitus intensity.

Tinnitus Care by Type

The 10 types of tinnitus classification were briefly introduced in Chapter 2: Understanding Tinnitus. Tinnitus can be broadly categorized into simple tinnitus and complex tinnitus, and further classified into pure tone, noise, complex tone, and combined tinnitus, which is a mixture of pure tone and noise. In the MTM treatment protocol, neither tinnitus frequency matching using a frequency generator nor MML (Minimum

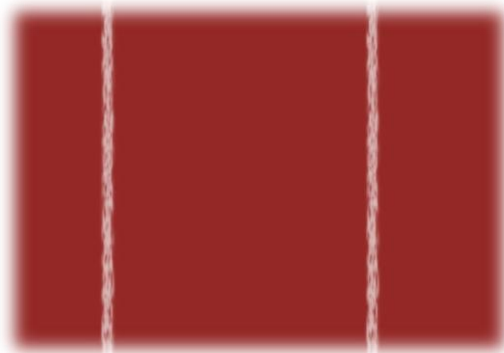
Masking Level) testing is performed. Instead, the protocol analyzes the fine structure of hearing thresholds observed in the RCPTA 67-band audiogram to track one or multiple tinnitus frequencies and their intensity levels.

Unilateral simple tone



Pure-tone simple tinnitus is the most common type of tinnitus in early-stage patients. When a “beep”-like simple tone tinnitus occurs in only one ear, as shown in the image, and the hearing level at the tinnitus frequency band is better than 50 dBHL, there is a very high probability that the tinnitus will completely disappear or become barely noticeable after 2 to 4 weeks of TSC (Tinnitus Sound Conditioning) treatment. However, if pure-tone simple tinnitus occurs in both ears simultaneously or if the hearing level at the tinnitus frequency band is worse than 50 dBHL, at least 4 weeks of TSC treatment is recommended. Since pure-tone simple tinnitus often does not cause significant discomfort, many patients tend to ignore it. However, both healthcare professionals and patients should recognize that the accuracy of diagnosis and the likelihood of a full recovery are highest at this stage.

Bilateral simple tone



When simple tone tinnitus occurs in both ears simultaneously, the situation becomes more complex than when it occurs in only one ear.

This can be categorized into cases where the tinnitus frequencies in both ears are identical or different.

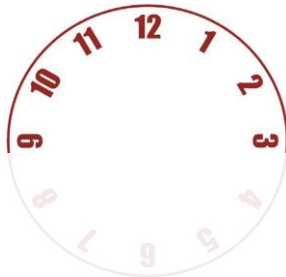
<When the Tinnitus Frequencies and Intensities Are Identical in Both Ears>

If a patient has bilateral pure-tone simple tinnitus with the same frequency and intensity in both ears, they often describe their experience as “my head is ringing” or “the sound is coming from my brain.” This is due to a phenomenon called binaural fusion, where identical sounds from both ears merge, causing a loss of auditory localization—the ability to determine whether a sound is coming from the left or right ear. As a result, the brain cannot accurately perceive the lateral origin of the tinnitus. Among healthcare professionals, this type of tinnitus is often referred to as “head tinnitus” or “brain tinnitus.” It is crucial for medical professionals to explain to patients why their tinnitus seems to originate from the center of their head. Additionally, before starting TSC (Tinnitus Sound Conditioning) therapy, patients should be informed that as their tinnitus improves, they may regain auditory localization and start perceiving the tinnitus as coming from a specific ear rather than the center of the head. This means that the tinnitus currently perceived at the 12 o’clock position (the top of the head) is actually the result of the fusion of bilateral tinnitus. During TSC, if the intensity of tinnitus in one ear decreases, the perceived location of the tinnitus will shift toward the stronger side. Patients may feel as if the tinnitus in one ear has become louder, even though the overall intensity has actually decreased. For example, if a patient originally perceives their tinnitus at 60 dBHL in both ears, they will experience it as coming from the center of the brain. However, after TSC, if the tinnitus in the left ear remains at 60 dBHL while the right ear decreases to 50 dBHL, the patient will perceive the tinnitus as coming from the left ear or being louder in the left ear rather than recognizing that the right-side tinnitus has weakened. Although the tinnitus in the right ear has actually reduced in intensity, the patient does not perceive it as weaker. Instead, they regain their ability to localize the tinnitus, which was previously lost due to binaural fusion.

<When the tinnitus frequencies are identical but the intensities differ>

Let’s examine cases where pure-tone simple tinnitus occurs in both ears at the same frequency but with different intensities. When pure-tone simple tinnitus occurs in the same frequency range in both ears but at different intensities, medical professionals can improve diagnostic accuracy by communicating with patients using “time expressions.” Expressions such as the 10 o’clock direction, 1 o’clock direction, or 3 o’clock direction should be used to facilitate detailed communication regarding the left-right volume balance of the tinnitus. If the patient’s tinnitus occurs only in the left ear, it can be understood as being heard from the 9 o’clock direction. If the tinnitus occurs only in the right ear, it

corresponds to the 3 o'clock direction. If the patient says, 'The tinnitus in the left ear is louder,' it is recommended to ask whether it feels more like the 10 o'clock or 11 o'clock direction and record this in the medical chart. It is also a good method to draw a semicircular clock from 9 o'clock to 3 o'clock and ask the patient to directly indicate their left-right tinnitus balance.

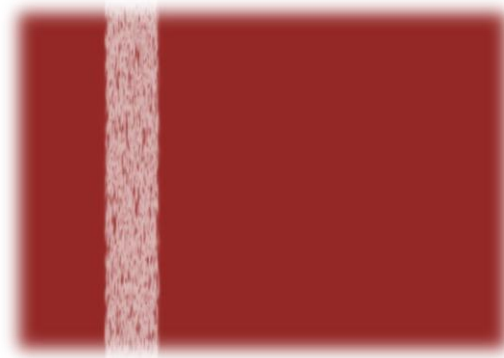


If tinnitus in the 10 o'clock direction shifts to the 11 o'clock direction after TSC treatment, it means that the intensity of the left-sided tinnitus has decreased compared to before. A decrease in tinnitus intensity does not necessarily mean that the hearing threshold must have changed at that moment. Conversely, a change in the hearing threshold does not necessarily mean that tinnitus intensity must have changed at that moment either. Generally, when tinnitus is alleviated, it is often accompanied by an improvement (lowering) of the hearing threshold, with approximately 50 dBHL as the reference point. However, it is important to note that this is not the case for all patients. The auditory nervous system undergoes long-term reorganization, and during the process of restoration, the patient's subjective auditory response timing may not always align with the timing of hearing threshold changes. By observing changes in the directional perception of tinnitus through TSC treatment, medical professionals should encourage patients with bilateral pure-tone simple tinnitus to regularly assess the balance of their tinnitus between the left and right sides. This approach is highly effective in helping patients dispel their vague fears about tinnitus.

<When the Tinnitus Frequency and Intensity Differ in Both Ears>

When the frequency and intensity of pure-tone simple tinnitus differ between both ears, patients with this type of bilateral simple tinnitus accurately describe it as "hearing tinnitus in both ears." In such cases, the treatment approach is not significantly different from that for patients with complex-tone complex tinnitus, where two pure-tone simple tinnitus sounds occur in one ear. When different tinnitus sounds are present in each ear, the best approach is to follow the standard manual of the MTM protocol. However, if the patient's compliance is high and a strong relationship of trust has been established with the healthcare provider, it is also possible to explore the enhanced TSC effects introduced in Chapter 9 (pages 81–83) of this textbook, which occur when stimulating the same auditory filter and the same harmonic plate. This would require a strategy focused on targeting the same auditory filter or the same harmonic plate.

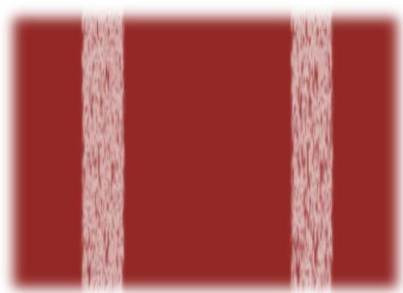
unilateral simple noise



If pure-tone simple tinnitus is left untreated for an extended period, it can develop into noise-type simple tinnitus. This occurs when tinnitus that initially had clear frequency specificity loses this characteristic, resulting in a more diffuse, noise-like perception. Exposure to extremely loud noise or occupational noise-induced hearing loss can also directly lead to noise-type simple tinnitus. This type of tinnitus is commonly observed in professional musicians who use headphones or earphones for extended periods, as well as individuals working in aviation, construction, civil engineering, and telemarketing. Many affected individuals tend to ignore or tolerate their tinnitus, as it is often only noticeable in quiet environments and does not significantly interfere with their professional activities. Unlike simple tone tinnitus, which presents a distinct high-pitched "beep" sound, noise-type tinnitus is perceived as a "shhh" or "hiss," making it sound softer and less sharp. People with noise-type unilateral simple tinnitus are generally aware of their condition but often make little effort to address it. However, leaving it untreated almost inevitably leads to the development of complex tinnitus. Additionally, as neural reorganization progresses, the condition may spread to the opposite ear, evolving into noise-type bilateral simple tinnitus, which requires more extensive treatment and time for management. A critical concern with noise-type unilateral simple tinnitus is that while patients often underestimate their tinnitus, advanced 67-band fine audiometry frequently reveals that they actually have complex tinnitus rather than a single tinnitus sound. Patients may perceive only one tinnitus sound and dismiss it as insignificant, but in reality, secondary or even tertiary tinnitus sounds may be present. It is essential not to take noise-type unilateral simple tinnitus lightly. Some patients report that their tinnitus sound has weakened after 2 to 4 weeks of TSC treatment, while others describe hearing a "new tinnitus sound." In most cases, patients who report new tinnitus after TSC were initially classified as having simple tinnitus. However, these patients should have been diagnosed as having complex tinnitus from the beginning. If TSC is conducted based solely on the patient's verbal statements and focuses only on the dominant tinnitus, it is common for secondary or tertiary tinnitus to become recognized once the dominant tinnitus decreases. To anticipate and prepare for such situations, the only

current approach is to carefully examine the fine structure of hearing thresholds using 67-band fine audiometry results based on the RCPTA algorithm. Regardless of the type of tinnitus, traditional "white noise therapy" that alleviates tinnitus by worsening fundamental hearing is not aware of what terms like "dominant tinnitus" or "latent secondary and tertiary tinnitus" mean. One major issue with most traditional tinnitus treatments is that both the pre- and post-hearing tests are conducted by the same audiologist. The physician relies on results that are manually conducted by the same tester, whose biased judgment or recording may influence the determination of the patient's hearing changes (in fact, traditional tinnitus treatments often ignore changes in the patient's hearing altogether). To ensure accurate pre- and post-hearing test results, algorithmic testing is essential to eliminate any bias or artificial judgment from the audiologist. If algorithmic testing is unavoidably difficult to implement, at the very least, the pre- and post-hearing tests should be conducted by different audiologists to implement a double-blind approach to the testing process.

bilateral simple noise



If pure-tone bilateral simple tinnitus is left untreated for a long time, it can progress into noise-induced bilateral simple tinnitus. To alleviate this type of tinnitus, at least 4 to 8 weeks of TSC treatment is required. In the fine audiometry results of noise-induced bilateral simple tinnitus patients, the hearing in the frequency range where tinnitus occurs is usually impaired to the level of moderate hearing loss or worse. Therefore, the probability of experiencing the Gaussian effect of tinnitus during the treatment process is very high. It is advisable for healthcare providers to share this information with patients before starting treatment. Even if the frequency of noise-induced tinnitus is the same in both ears, the likelihood of binaural fusion occurring is very low. The noise in noise-induced tinnitus is mostly narrowband noise, and it is rare for the frequency bandwidth of the tinnitus in both ears to match exactly. Even when the tinnitus frequency bandwidths of the narrowband noise components match, it is even rarer for synchronized neural firing to occur in both ears at the same time on the time axis. If a patient with noise-induced bilateral simple tinnitus reports that they hear tinnitus at the "12 o'clock" position (in the brain), despite their fine audiometry

results indicating they belong to the noise-induced bilateral simple tinnitus type, this patient is most likely suffering from noise-induced bilateral complex tinnitus or mixed-type bilateral complex tinnitus. In the case of noise-induced bilateral complex tinnitus, some of the narrowband noise components may meet the criteria for binaural fusion. In the case of mixed-type bilateral complex tinnitus, some of the simple tone tinnitus components may precisely fulfill the binaural fusion requirements, leading to the sensation of tinnitus at the "12 o'clock" position.

unilateral complex tone

The most common type of tinnitus in early-stage patients is pure-tone unilateral simple tinnitus. The high-pitched "beep~~~" sound is the most frequently reported tinnitus tone. However, if a tinnitus patient perceives their tinnitus sound to be more similar to "wing~~~" or "doo~~~" rather than "beep~~~," this indicates complex-tone complex tinnitus rather than pure-tone simple tinnitus. Patients with complex-tone complex tinnitus often perceive their tinnitus frequency as a single component. However, a 67-band micro-hearing test typically reveals hearing threshold damage across multiple frequency bands. There are two types of complex-tone unilateral complex tinnitus, which can be categorized based on whether they occur within the same harmonic series or different harmonic series.

<Unilateral Complex-Tone Tinnitus Occurring in the Same Harmonic Series>

When multiple simple tone tinnitus components occur simultaneously at varying intensities within one ear, this is classified as complex-tone unilateral complex tinnitus. A complex tone is created from the combination of two or more pure tones. If the frequency ratio between these tones follows an integer ratio of 1:2:3, the tinnitus is considered to arise from the same harmonic series. The timbre of same harmonic series complex-tone tinnitus is closer to "wing~~~" rather than "doo~~~." The pronunciation of "doo" is formed by a combination of a non-integer ratio consonant ("tt") and a vowel ("ㄊ") that primarily exists in the low-frequency range, making it unsuitable for describing same harmonic series complex-tone tinnitus. On the other hand, the "wing" sound is produced by the vowel " | ", which is typically formed in the mid-frequency range above 1 kHz. Because this vowel follows a 1:2:3 integer ratio in its frequency composition, it aligns with the characteristics of same harmonic series tinnitus. Notably, all sonorous sounds inherently follow the same harmonic series frequency composition. Therefore, the "wing" sound is a more accurate representation of same harmonic series complex-tone tinnitus than the "doo" sound. For cases of same harmonic series unilateral complex-tone

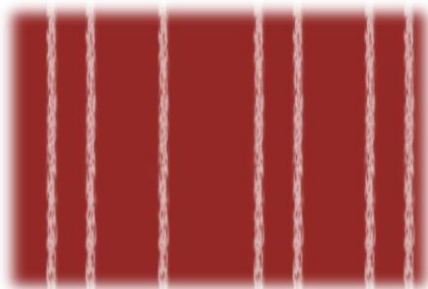
tinnitus, following the MTM protocol and performing TSC (Targeted Sound Conditioning) for 4 to 8 weeks can yield positive treatment outcomes.



<Unilateral Complex-Tone Tinnitus Occurring from Different Harmonic Plates>

When the frequency components of two or more simple tone tinnitus sound in one ear do not conform to a 1:2:3 integer ratio, this is classified as unilateral complex-tone tinnitus occurring from different harmonic plates. Compared to unilateral complex-tone tinnitus occurring from the same harmonic plate, this type of tinnitus is considered to have a more complex cause. Since the term "different harmonic plates" itself implies multiple, distinct harmonic structures, unilateral complex-tone tinnitus occurring from different harmonic plates often requires a longer treatment period than unilateral complex-tone tinnitus occurring from the same harmonic plate. The perceived sound of this type of tinnitus is closer to "too~~~" rather than "wing~~~". During TSC (Tinnitus Suppression Conditioning), some patients report that their tinnitus tone has become "thinner" compared to before. This occurs when the number or intensity of distinct simple tone tinnitus components across multiple frequency bands decreases, causing the "thicker" sensation of unilateral complex-tone tinnitus occurring from different harmonic plates to shift toward a "thinner" perception.

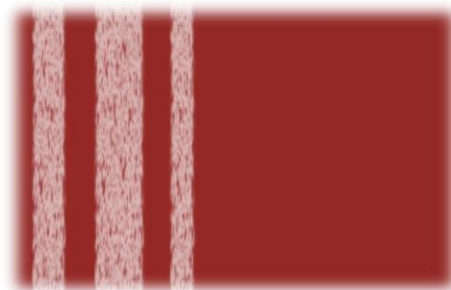
bilateral complex tone



Bilateral complex-tone tinnitus falls into the category of profound tinnitus among the ten types of tinnitus. In some cases, hearing loss in one ear can promote reorganization in the opposite ear, leading to the transition from unilateral complex tinnitus to bilateral complex-tone

tinnitus. If a person has been repeatedly exposed to extremely loud noise over several years or has had tinnitus for a long time without any intervention, both their hearing threshold and tinnitus intensity are highly likely to become fixed. Patients with bilateral complex-tone tinnitus generally have very poor hearing. Many of them exhibit hearing thresholds worse than 50 dBHL, and their hearing often fluctuates significantly. It is common to observe distinct threshold fluctuation zones across multiple specific frequency bands, and these fluctuation zones frequently change. Patients with bilateral complex-tone tinnitus belong to the group that experiences the most severe variations in tinnitus perception. During the TSC process or after its implementation, they may experience significant improvement in their tinnitus or, conversely, an aggravation of symptoms. When experiencing tinnitus aggravation, it is essential to understand the Gaussian effect of tinnitus to avoid resistance to continuing TSC. The compliance rate with TSC differs significantly between tinnitus patients who understand the Gaussian effect and those who do not. After repeating the MTM 4-week protocol approximately three times, most patients with bilateral complex-tone tinnitus fully understand and internalize the methods and principles of MTM. If financial circumstances permit, many patients wish to continue using TSC consistently, regardless of whether it alleviates their tinnitus.

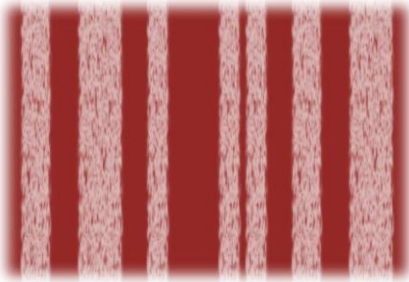
unilateral complex noise



If unilateral complex tone is left untreated for a long period, it can develop into unilateral complex noise. Unilateral noise-type complex tinnitus is classified as profound tinnitus. This transition occurs when complex-tone tinnitus, which initially has frequency specificity, loses this specificity and becomes noise-type complex tinnitus. Additionally, prolonged and repeated exposure to extremely loud noise significantly increases the likelihood of developing noise-type complex tinnitus. Compared to unilateral complex-tone tinnitus, unilateral noise-type complex tinnitus has a significantly diminished frequency specificity. As a result, it is perceived with a completely different sound quality—rather than the tonal "whi~~~" or "beep~~~" sounds characteristic of complex-tone tinnitus, it manifests as a "shhh~~~" or "whoosh~~~" noise. It has a stronger auditory presence than simple noise-type tinnitus, which is often described as a "hiss~~~" or "chhh~~~" sound.

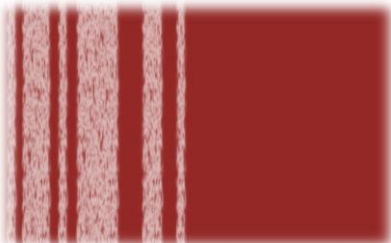
The occurrence of unilateral noise-type complex tinnitus suggests a relatively large difference in hearing thresholds between both ears. Furthermore, in most cases, the affected ear exhibits moderate hearing loss or worse across a wide frequency range. To achieve noticeable relief from tinnitus symptoms through TSC sound technology, patients with unilateral noise-type complex tinnitus typically need to undergo at least three intensive repetitions of the MTM 4-week protocol.

bilateral complex noise



Just as untreated pure-tone bilateral simple tinnitus can worsen into noise-type bilateral simple tinnitus over time, noise-type bilateral complex tinnitus often develops as a progression from bilateral complex-tone tinnitus. Noise-type bilateral complex tinnitus is one of the most common types of tinnitus experienced by patients with profound tinnitus, and it may take a long time to achieve significant relief. With 4 to 8 weeks of TSC implementation, the perception of tinnitus intensity is likely to change only slightly. While some patients may experience dramatic improvements within 2 to 4 weeks, such exceptional cases should not be used as a standard for designing treatment schedules for other patients. Since patients with unilateral noise-type simple tinnitus typically need to undergo at least three intensive repetitions of the MTM 4-week protocol to perceive noticeable symptom relief, those with bilateral noise-type simple tinnitus may require at least 4 to 5 repetitions of the MTM 4-week protocol. It is advisable to inform patients of this in advance and establish a treatment plan accordingly.

unilateral combination of tone and noise

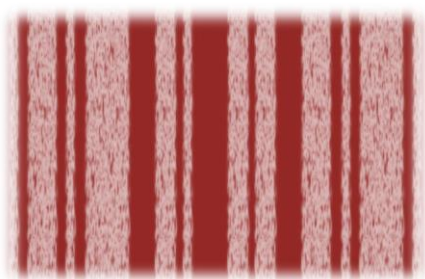


To provide a precise understanding of unilateral mixed-tone complex tinnitus, we introduce an interview case of a tinnitus patient who experienced TSC. This patient is a musician. Since high school, he had been actively involved in a music band club and spent long hours wearing headphones, analyzing, and creating music. He was already aware of tinnitus in his right ear during high school but chose to ignore it. Upon entering university and becoming more engaged in musical activities, he began to experience a persistent "beep~~~" pure-tone simple tinnitus in his right ear. While the tinnitus was intermittent during high school, it became a daily burden during his university years. Several years after graduating, he made an intriguing discovery: if he listened to music at maximum volume through headphones for a few minutes, the tinnitus in his right ear would temporarily disappear. In particular, when he played sounds at a frequency similar to his "beep~~~" tinnitus at a high volume, he often found that his tinnitus vanished within seconds rather than minutes. He knew precisely that his tinnitus frequency was 6,272 Hz, having identified it himself using a pure-tone generator. At the time of encountering TSC for the first time, he had been experiencing pure-tone unilateral simple tinnitus at 6,272 Hz for approximately 15 years. The hearing threshold at this frequency fluctuated between 50 and 75 dBHL in repeated 67-band micro-audiometry tests. Surprisingly, after just five days of TSC treatment centered on the 6,272 Hz frequency band, his tinnitus disappeared. He described the experience as "anticlimactic," having endured 15 years of tinnitus only to have it vanish in a mere five days. Perhaps due to his background as a musician, he seemed almost disappointed by the sudden disappearance of a sound he had lived with for so long. However, after his 6,272 Hz tinnitus vanished, he realized that it had not been his only tinnitus. For 15 years, he had been aware of only this "salient" tinnitus, but once it was gone, he began to perceive two or three additional tinnitus sounds. At that point, he decided to discontinue his TSC experience—not out of dissatisfaction, but out of amazement. Having already experienced the disappearance of his 6,272 Hz tinnitus, he seemed unconcerned about eliminating the remaining sounds. After the disappearance of his primary tinnitus, the newly perceived tinnitus in his right ear consisted of a pure-tone tinnitus around 3,500 Hz and a noise-type tinnitus spanning the 10,000–12,000 Hz range. The 3,500 Hz pure-tone tinnitus was intermittent, while the 10,000–12,000 Hz noise-type tinnitus was constant. This case represents a typical unilateral mixed-tone simple tinnitus patient—one who had two pure-tone tinnitus sounds and one narrow-band noise-type tinnitus in the right ear. For a long time, he had only perceived his primary tinnitus, but once it disappeared, he became aware of the others. His right ear's hearing level was classified as mild hearing loss.

The total hearing threshold (hearing loss index) sum across the 67 frequency bands in both ears is approximately 3,000. The severity of the tinnitus in the right ear can be classified as "mild" unilateral mixed-tone complex tinnitus. Mixed-tone unilateral complex tinnitus itself can be categorized into three severity levels: mild, moderate, and severe (or

profound). When mixed-tone unilateral complex tinnitus is at a mild level, the total hearing threshold (hearing loss index) typically falls between 1,500 and 3,000. If the condition is at a moderate level, the index usually ranges between 3,000 and 5,000. When mixed-tone unilateral complex tinnitus reaches a severe or profound level, the index is most likely between 5,000 and 7,500. Regardless of whether mixed-tone complex tinnitus affects one ear or both, some degree of tinnitus relief can be expected through hearing improvement. However, it is extremely rare for mixed-tone complex tinnitus to completely disappear without any deterioration in hearing. Most individuals with mixed-tone unilateral complex tinnitus have been experiencing tinnitus for over 10 years.

bilateral combination of tone and noise



Mixed-tone bilateral complex tinnitus has the most intricate tinnitus spectrum among the ten major tinnitus types. Various tones of tinnitus can be heard from different directions at unpredictable times, making it difficult to distinguish between individual components due to the highly complex spectrum. Those with mixed-tone bilateral complex tinnitus often experience a profound fear of their tinnitus. The psychological distress caused by this condition can be severe, and many patients find it nearly impossible to maintain a normal lifestyle. The sound characteristics of mixed-tone bilateral complex tinnitus are not at a level where one can simply ignore or endure them. The overwhelming noise often leads to a sense of despair, making daily life extremely challenging. Many patients wonder in fear, "Is there truly no escape from this deafening sound?" In extreme cases, patients may even contemplate drastic actions. From a medical perspective, treating mixed-tone bilateral complex tinnitus presents one of the most challenging dilemmas. Establishing a treatment plan for these patients is complex, and difficulties often increase after initiating the MTM protocol rather than before. During the treatment process, some patients experience uncontrollable changes in tinnitus sound characteristics, while others show no improvement even after undergoing TSC (Tinnitus Sound Conditioning) for more than two to three months. Is there a way to wisely overcome these challenges? The most powerful tool for making this possible is trust between the medical team and the patient. The trust built between them can surpass the effectiveness of medication or

TSC. However, while it is assumed that the medical team trusts their patients, the real question is: How can patients be encouraged to trust their medical team? If a patient undergoing more than two to three months of TSC exhibits no hope or expectations, the most effective way for medical professionals to gain their trust is through a structured and educational approach.

In the four-week MTM protocol, the medical team meets with the patient three times: on the first day of treatment, during the second week, and at the final week of the protocol. During these interactions, the medical team should dedicate at least 10–15 minutes to studying the patient's condition together. Approaching these sessions as a shared learning experience can create a reservoir of trust over time. If the medical team assumes the role of a teacher and the patient as a student, they must provide enough knowledge so that the patient can gradually reach a similar level of understanding. One way to achieve this is by reviewing the 67-band micro-audiometry test results at every visit, explaining how to interpret the hearing data, and discussing the patient's insights. Although repeating the same explanations three times within a month may feel tedious for medical professionals, it can be profoundly enlightening for patients. Repeated exposure to this information helps patients internalize details about their hearing health. Over time, some patients may even be able to interpret their RCPTA (Refined Clinical Pure Tone Audiometry) results independently, gaining a more precise understanding of their hearing thresholds. As long as TSC is in progress, patients' curiosity about their micro-level hearing changes will grow in proportion to their understanding of RCPTA techniques. Even after completing the full MTM treatment cycle, patients often continue seeking solutions based on the knowledge and insights they gained from their medical team. At some point, they may want to reassess their subtle hearing changes or tinnitus details and will need to revisit a medical facility capable of conducting RCPTA algorithm-based tests. This is why the trust built between medical professionals and patients holds lifelong value. Thanks to the shared study sessions with their doctors, patients will recognize that the conventional six-band audiometry test lacks sufficient detail. Medical professionals should share valuable information with patients suffering from mixed-tone bilateral complex tinnitus, helping them better understand their condition and participate actively in their treatment. By incorporating these elements into patient interactions, medical professionals can foster trust, which in turn enhances treatment adherence and improves outcomes for those suffering from mixed-tone bilateral complex tinnitus.

<Localized Targeting Strategy and Comprehensive Targeting Strategy>

To define the terms in advance, the "Localized Targeting Strategy" refers to "single/multiple proximal targeting," while the "Comprehensive Targeting Strategy" refers to "multiple proximal targeting/isolation targeting across a broad frequency range." When scheduling the MTM

treatment protocol for patients with mixed-tone bilateral complex tinnitus, a "long-term battle" must be taken into account. It is recommended to plan a treatment schedule that repeats the MTM 4-week basic protocol at least six times. During each repetition of the MTM 4-week protocol, the 2-week TSC non-prescription period (rest period) can be shortened to 1 week by mutual agreement between the medical professionals and the patient. Additionally, the 2-week TSC implementation period may be extended to 3 weeks. However, it is strongly advised to strictly follow the standard schedule outlined in the MTM protocol for at least the first cycle, which includes the first 2-week TSC non-prescription period (rest period), the subsequent 2-week TSC prescription period, and the first 2-week TSC non-prescription period (rest period) of the second MTM 4-week protocol cycle. The first six weeks are a critical phase for adjusting the "distance" and "trust" between medical professionals and patients, preparing them for the "long-term battle" ahead. If this period is successfully endured, it can be considered that at least 75% of the trust between medical professionals and patients has been established, and they are ready to embark on the "long-term battle" together. If a mixed-tone bilateral complex tinnitus patient fails to endure and persist through the 42-day (6-week) period and chooses to "drop out" midway, it indicates through their actions that they have lost interest in acquiring information about RCPTA and their 67-band micro-audiometry results. It also serves as an implicit declaration that they no longer wish to engage in the "long-term battle" with their medical professionals to conquer the "fearsome tinnitus." Medical professionals should be able to filter out such patients within 42 days while leaving room for future possibilities. Even if a patient gives up midway, if they have engaged in multiple study sessions with medical professionals and reached a level where they understand how to interpret their RCPTA results, this is already a meaningful achievement from the medical perspective. By providing RCPTA, which acts as both a "magnifying glass and a telescope" to allow patients with mixed-tone bilateral complex tinnitus to examine and comprehend their micro-hearing structure, medical professionals must always convey that they are ready for the "long-term battle." For patients reaching the second cycle (on the 43rd day since the start of MTM), the TSC prescription period of the MTM protocol is approaching, and they have only experienced two weeks of TSC implementation so far. From the perspective of TSC, they are still in the very early stages. The TSC implementation strategy directly corresponds to the REVE134 targeting strategy. The "long-term battle" requires the parallel or alternating application of "localized warfare" and "comprehensive warfare" strategies. By explaining and helping patients understand the Localized Targeting Strategy and the Comprehensive Targeting Strategy, medical professionals must guide them to independently observe the effects of localized warfare and comprehensive warfare. Furthermore, mixed-tone bilateral complex tinnitus patients must be educated and guided to decide for themselves—based on their own experience of enduring "painful, roaring noise"—whether they expect greater tinnitus changes

from the Localized Targeting Strategy or the Comprehensive Targeting Strategy. Patients with good adherence should, by the time they complete six cycles of the MTM protocol, have a deeper understanding of MTM than the audiologists working in medical institutions.

<Tinnitus Intensity and White Noise>

For patients with simple tinnitus, the improvement of symptoms can be measured to some extent using the Minimum Masking Level (MML) test. However, for patients with complex tinnitus, tracking changes in tinnitus intensity through MML testing is difficult. Conducting an MML test to track tinnitus intensity in patients with mixed-tone bilateral complex tinnitus, where multiple tinnitus sounds coexist simultaneously, is a waste of time. For example, if a patient has complex tinnitus consisting of two frequency components, f1 and f2, even if one of these frequency components disappears or decreases in intensity, the MML test results will show no change in tinnitus intensity. If the two tinnitus sounds, f1 and f2, occupy different critical bands, even a reduction in the loudness of one of them will not reflect any change in tinnitus intensity in an MML test that is based on white noise. However, in an exceptional case where all tinnitus frequency components improve simultaneously, the tinnitus intensity measured by the MML test may significantly decrease. For patients with mixed-tone bilateral complex tinnitus, who constantly hear a "painful roaring noise," the white noise used in MML testing can have both positive and negative effects, similar to a "medical narcotic." While this text does not cover in detail the possible uses of white noise for patients with mixed-tone bilateral complex tinnitus, those experiencing severe symptoms may consider using the concept of tinnitus intensity and white noise as an experiential learning tool. One possible reference is the residual inhibition (RI) technique, which is one of the existing emergency treatments for tinnitus. Residual inhibition (RI) refers to the phenomenon where white noise is presented at approximately 10–15 dB above the patient's MML for about 60 seconds and then suddenly stopped. Due to the temporary threshold shift (TTS) effect in auditory perception, the patient may experience a period ranging from a few seconds to several minutes, or even hours or days, during which tinnitus is no longer perceived.

<Tinnitus Intensity Tracking Method>

Is it possible to track multiple intensity values of tinnitus simultaneously, regardless of the number of frequency components of the tinnitus? Currently, the only method available is RCPTA. Using the RCPTA 67-band algorithm, a total of 134 hearing thresholds (67 for each ear) are extracted, which takes an average of 15 minutes and 35 seconds per person. This average value was derived from conducting 585 RCPTA tests on 195 participants in the MTM clinical trial. By using the RCPTA

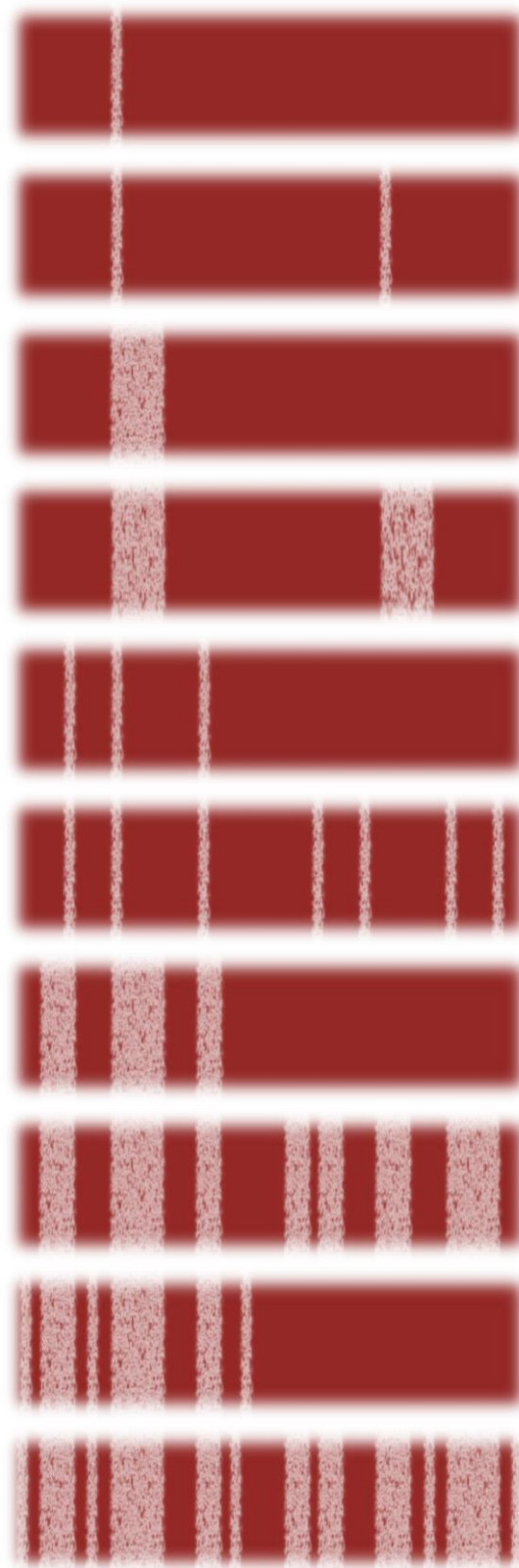
algorithm, it is possible to identify key details such as the acute onset frequency band, neural synchronization frequency band, and frequency-specific hearing loss band in real-time, all within approximately 15 minutes, allowing for objective tracking of tinnitus intensity. During the RCPTA examination process for tracking multiple intensities of tinnitus, there can be no subjective judgment or conscious intervention from the patient regarding the intensity of the tinnitus itself.

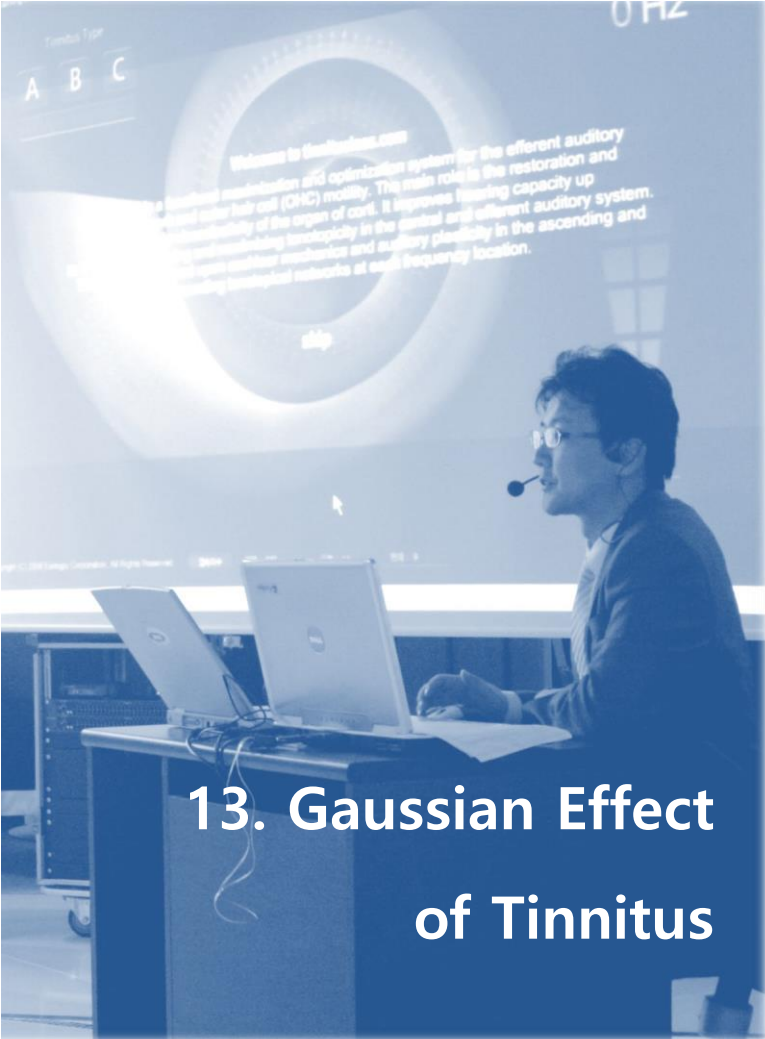
<Tinnitus Spectrum Changes>

In physics, the three elements of sound are explained as frequency, intensity, and spectrum. Understanding the spectrum of sound, excluding the frequency and intensity elements, is not easy. When defining the third element of sound, the spectrum, terms such as time or phase are often used. Excluding the frequency and intensity elements, the spectrum of sound can be defined as the third property of sound, arising from the temporal dimension. What are the representative elements that form the spectrum in the temporal dimension of sound? The subjective sensory aspect of the spectrum, called "timbre," depends on the modulation pattern of the sound over time. For example, let's assume we record the same consonant "ch" pronounced twice by the same person, and then compare the timbre of the two recordings under identical conditions: both recordings are 0.3 seconds long and have the same intensity of 70 dB. Despite the same "ch" consonant frequency components originating from the same person, and the identical intensity and time conditions of 70 dB and 0.3 seconds, the element that makes these two sounds perceived differently is the spectrum. The most general definition of the spectrum of sound is as follows:

The spectrum of sound is the physical factor or property that makes two sounds, which have the same frequency and intensity, sound different from each other.

During the MTM period, patients with mixed-tone complex tinnitus almost always experience changes in the tinnitus spectrum. When the tinnitus spectrum changes, it is perceived as a change in the timbre of the tinnitus. While there are changes in the intensity of the complex tinnitus itself, the most frequent change is in the timbre of the tinnitus. The reason that changes in the tinnitus spectrum are relatively frequent in patients with mixed-tone bilateral complex tinnitus during the MTM period is that the number of component tinnitus tones that make up a mixed-tone complex tinnitus is relatively higher compared to other types of tinnitus. The phenomenon of a change in timbre occurs when the intensity of one of the tinnitus components that make up the complex tinnitus changes. The change in intensity of some tinnitus components during TSC is believed to result from the modification of the sum of continuous/intermittent firing quantities needed for the auditory nervous system's intensity processing in the frequency band of the specific tinnitus component, which is adjusted by TSC.





13. Gaussian Effect of Tinnitus

Generally, the intensity of tinnitus is felt more strongly when there is moderate hearing loss compared to severe hearing loss. The relationship between tinnitus intensity and the degree of hearing loss is proportional up to a certain point, but beyond that, it can become inversely proportional. In fact, among the 195 participants in the MTM clinical study, the average total hearing (hearing loss index) of the 42 participants with a tinnitus resistance score of 4, who had very severe tinnitus symptoms, was 4,182. In comparison, the 52 participants with tinnitus resistance scores of 5, 6, or 7, who experienced less severe tinnitus, had an average total hearing of 4,342. Despite the 4-point group having more severe tinnitus symptoms, their overall hearing was relatively better. There is further evidence that the relationship between tinnitus intensity and the degree of hearing loss may not be proportional. Among the 24 participants with total hearing between 4,300 and 5,200, the average tinnitus resistance score was 4.12. Meanwhile, another group of 24 participants with total hearing between 5,200 and 5,900 had worse hearing, yet their average tinnitus resistance score was 5.58, higher than the previous group's. The difference between the two groups was statistically significant ($P < 0.0150$). These results show that severe tinnitus symptoms do not necessarily correlate with worse hearing, and conversely, mild tinnitus symptoms do not necessarily indicate better hearing.

As briefly discussed in Section 6, the 4:4:2 item of the MTM effects, during the 4-week MTM clinical period, the tinnitus weighting group, in which both the intensity and frequency of tinnitus increased, consisted of 42 participants. The average tinnitus resistance score for these participants decreased from 7 points on the first test day to 5.3 points on the third test day, indicating an increase in subjective tinnitus intensity or frequency. As shown in the T-test statistical table below for these 42 participants, although the difference between the first total hearing average of 4,725 and the third total hearing average of 4,622 is not statistically significant, it is evident that the total hearing score improved by 103 on the hearing loss index. This suggests that while the subjective intensity of tinnitus was exacerbated, their hearing did not worsen.

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	4725.929	2305.630	42	0.000	0.0000	0.00000	41	1.000000	0.000	0.0000
Var1	4725.929	2305.630	42	-39.429	529.3234	-0.48274	41	0.631847	-204.377	125.5202
Var2	4686.500	2501.264	42	0.000	0.0000	0.00000	41	1.000000	0.000	0.0000
Var1	4725.929	2305.630	42	103.714	631.3010	1.06470	41	0.293243	-300.442	93.0130
Var3	4622.214	2347.578	42	0.000	0.0000	0.00000	41	1.000000	0.000	0.0000
Var2	4686.500	2501.264	42	-39.429	529.3234	-0.48274	41	0.631847	-204.377	125.5202
Var1	4725.929	2305.630	42	0.000	0.0000	0.00000	41	1.000000	0.000	0.0000
Var2	4686.500	2501.264	42	0.000	0.0000	0.00000	41	1.000000	0.000	0.0000
Var2	4686.500	2501.264	42	64.286	684.7705	0.60841	41	0.546274	-277.675	149.1038
Var3	4622.214	2347.578	42	-103.714	631.3010	-1.06470	41	0.293243	-300.442	93.0130
Var1	4725.929	2305.630	42	-64.286	684.7705	-0.60841	41	0.546274	-277.675	149.1038
Var2	4686.500	2501.264	42	0.000	0.0000	0.00000	41	1.000000	0.000	0.0000
Var3	4622.214	2347.578	42	0.000	0.0000	0.00000	41	1.000000	0.000	0.0000
Var3	4622.214	2347.578	42	0.000	0.0000	0.00000	41	1.000000	0.000	0.0000

Tinnitus in the passive auditory system

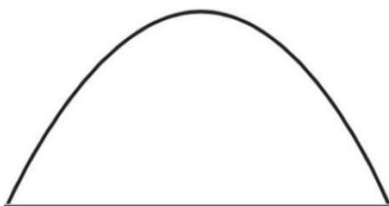
Auditory neurons in the brain's harmonic region, responsible for extracting pitch from physical frequencies, can modulate neural firing rate information based on various psychophysical cues. When attention, memory, expectation, and prediction are activated by harmonic or spectral cues, the frequency processing location in the tonotopic map can shift. Various internal and external factors can also affect the unique temporal resolution of auditory neurons. In this regard, animal auditory research is much easier to control for variables compared to human auditory research. Auditory brain activity responding to specific cue conditions tends to be more consistent in animals than in humans. While similar areas in the auditory cortex of animals and humans have been found under pure tone experimental conditions involving harmonic regions or tonotopy, significant differences are often observed in complex sound experiments that layer pure tones or in music stimulus experiments where those complex sounds are arranged along a time axis. Animal hearing is almost invariably classified as a passive auditory system. Although some animals may communicate through "musical" signals, their "music" is rudimentary compared to human music. Even in recognizing speech, the auditory system of animals has more limitations compared to that of humans.

Let's explore the principle of tinnitus occurrence in the passive auditory system based on Sam Kwak's Welch curve theory on tinnitus intensity. The following diagrams illustrate the mechanism of tinnitus occurrence in the passive auditory system by using the concept of "family" to

represent the auditory cells within a single critical band and the auditory neurons connected to them. The auditory cells within a single critical band are grouped into 10 groups, each of which is likened to a "family member" in a "family of 10." The auditory cells are compared to the physical reality of family members, while the auditory neurons are compared to the psychophysical reality of family members. In the passive auditory system, a single critical band is considered as a "family," and the 10 groups of auditory cells within a single critical band are considered the "10 family members." It is important to note that this attempt to represent the single critical band as a family and the 10 auditory cell groups as family members is solely for the purpose of explaining the mechanism of tinnitus occurrence in the simplest and clearest way possible. To properly understand the Welch curve theory on tinnitus intensity, let's first introduce the key terms.

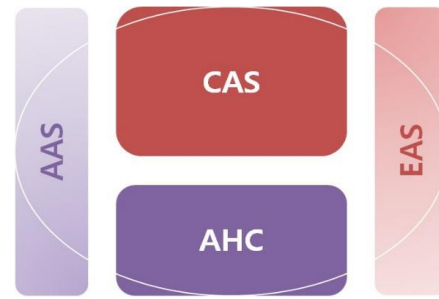
AC	Auditory Capacity in a Single Auditory Filter, the hearing level based on a single auditory filter.
100% AC	The Most Perfect Hearing Condition in a Single Auditory Filter
0% AC	Complete Hearing Loss in a Single Auditory Filter
AAS	Afferent Auditory System within a Single Auditory Filter
AHC	Auditory Hair Cells within a Single Auditory Filter
CAS	Central Auditory System Governing a Single Auditory Filter
EAP	Excitatory Action Potential in the Afferent Auditory System of a Single Auditory Filter
EAS	Efferent Auditory System in a Single Auditory Filter
IAP	Inhibitory Action Potential in the Efferent Auditory System of a Single Auditory Filter
LT	Loudness Level of Tinnitus in a Single Auditory Filter
α	Current Loudness Level of Tinnitus in a Single Auditory Filter
β	Inhibitory Action Potential Value Transmitted through the Efferent Auditory System in a Single Auditory Filter
γ	Action Potential Constant (or δ value) at the Most Ideal Hearing State in a Single Auditory Filter
δ	Number of Auditory Hair Cell Groups Currently Functioning Normally in a Single Auditory Filter

The basic shape of a Welch curve looks like this.



The anatomical structure of the passive auditory system can be briefly illustrated using a simple schematic. The auditory system, extending from the peripheral to the central structures, is often compared to an "I/O electric circuit." However, when processing acoustic information, a circulatory circuit following the pattern of "periphery $\Rightarrow$ central $\Rightarrow$ periphery $\Rightarrow$ central" is more useful in explaining the principles of the

auditory system than a one-way circuit of "periphery $\Rightarrow$ central."



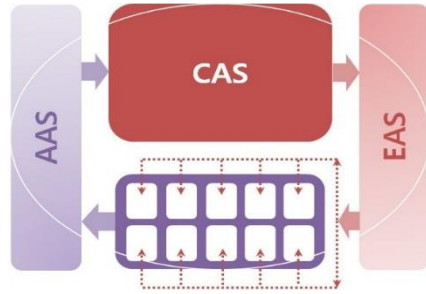
Acoustic energy is converted into electrical energy by the auditory hair cells (AHC) in the peripheral auditory system. This electrical energy is then transmitted to the central auditory system (CAS) via the afferent auditory system (AAS). Before decoding the electrical energy received through the afferent auditory nerves, the central auditory system sends a portion of this energy back to the auditory hair cells (AHC) through the efferent auditory system (EAS). For the physical acoustic energy to be ultimately decoded in the brain, both functions of the peripheral auditory system must operate properly. The peripheral auditory system not only converts acoustic energy into electrical energy for transmission to the brain but also receives specific information from the brain and generates additional electrical energy accordingly. Based on the AHC $\Rightarrow$ AAS $\Rightarrow$ CAS $\Rightarrow$ EAS $\Rightarrow$ AHC auditory system circulatory circuit schematic, let's examine Sam Kwak's tinnitus intensity function.

$$\alpha_{LT} = \delta (\gamma - \beta) EAP$$

α = Loudness level of the tinnitus currently occurring in the single auditory filter β =loudness level of the tinnitus transmitted through the centrifugal auditory system in the single auditory filter Inhibitory action potential value γ = Action potential constant or the value of δ in the most hearing state in a single auditory filter δ = Number of currently auditory hair cell groups in a single auditory filter.

LT = Loudness Level of Tinnitus EAP= Excitatory Action Potential

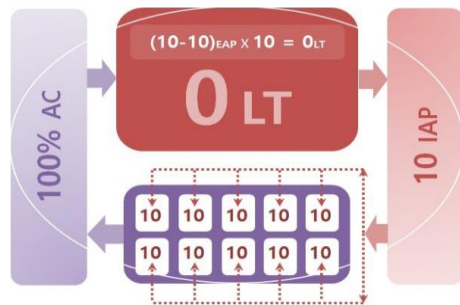
In a passive auditory system, the loudness level of tinnitus (LT) in the central auditory system (CAS) is proportional to the magnitude of excitatory action potentials (EAP). The tinnitus loudness level in a single critical band of the passive auditory system follows a Welch curve relationship with the number of normally functioning hair cell groups (δ) in that critical band. The inhibitory action potential quantity (β) is determined by the number of normal hair cell groups. In Sam Kwak's tinnitus intensity function, the constant γ represents the intrinsic action potential value corresponding to the most optimal hearing state within a single critical band. This is equivalent to the δ value in the most perfect hearing condition.



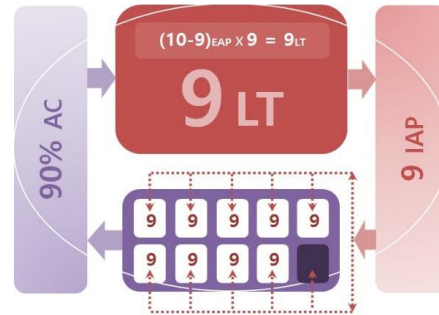
In the auditory system circuit diagram $AHC \Rightarrow AAS \Rightarrow CAS \Rightarrow EAS \Rightarrow AHC$, the Auditory Hair Cells (AHC) are represented as a "family of 10 members," referring to the 10 auditory hair cell groups. By applying the tinnitus intensity function—which uses the four variables α , β , γ , and δ —to the mechanism of tinnitus generation in the passive auditory system, we can explore the theory of the Welch Curve of Tinnitus Intensity through the following 11 conceptual diagrams.

The Mechanism of Tinnitus Generation in the Passive Auditory System

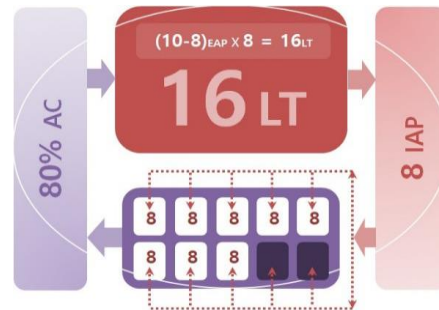
Imagine a large family of ten members living together in a harmonious household. One night, while everyone is asleep, a tragic event occurs—a fire (firing) breaks out in the home. This incident brings unprecedented sorrow to the family. Now, consider a situation where no sound of crying is heard from any of the ten family members. This silence could result from one of two scenarios: None of the ten members feels sad enough to cry out loud. All ten members are so overwhelmed or impaired that they are no longer capable of crying out at all.



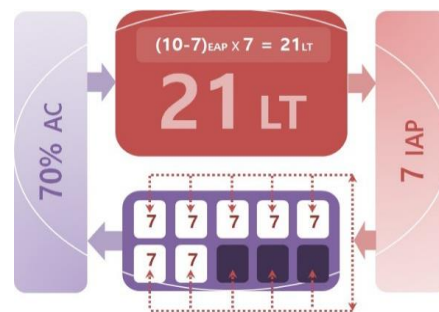
The first diagram represents a situation where the fire has not yet occurred. Under these conditions, the loudness level of crying (tinnitus) is zero.



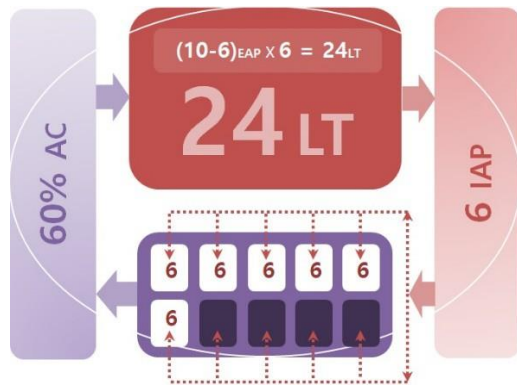
The second diagram represents a situation where one family member has fallen into a coma due to the fire last night. The remaining nine family members, overwhelmed with grief, produce a crying (tinnitus) loudness level of 9. Now, let's assume that instead of one, two family members have fallen into a coma due to the fire. In this case, the crying (tinnitus) loudness level of the remaining eight family members increases to 16, which is greater than when only one was in a coma.



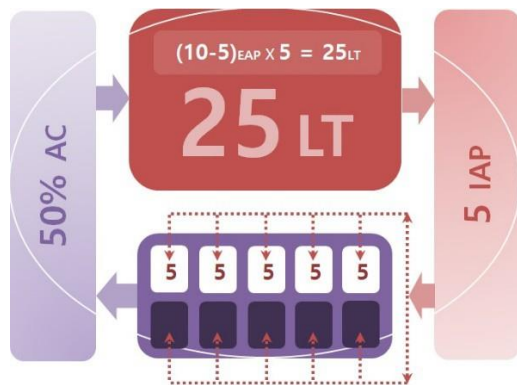
Now, let's assume that not one or two, but three family members have fallen into a coma due to the fire last night. In this case, the crying (tinnitus) loudness level of the remaining seven family members would be 21, which is greater than when one or two were in a coma.



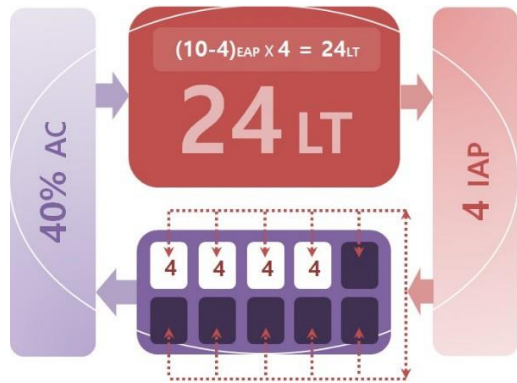
Now, let's assume that a total of four family members have fallen into a coma due to the fire last night. In this case, the crying (tinnitus) loudness level of the remaining six family members would be 24, which would be very loud.



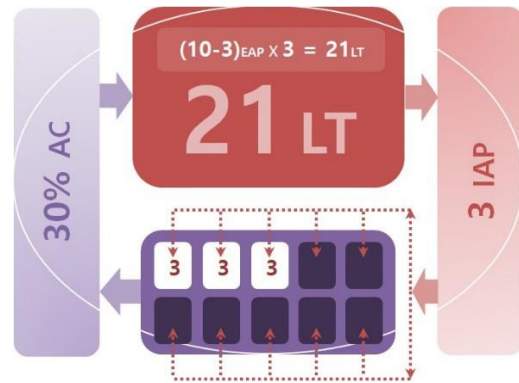
Imagine that a fire last night put 50% of the family in a coma, totaling five people. The "sum of grief" from the remaining five family members is reflected in the crying (tinnitus), which reaches a volume level of 25.



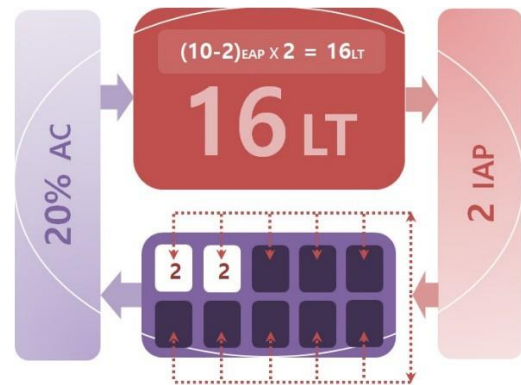
Suppose a fire last night put six family members, 60% of the family, in a coma. The "sum of grief" from the remaining four family members is reflected in their crying (tinnitus), which is at a volume level of 24.



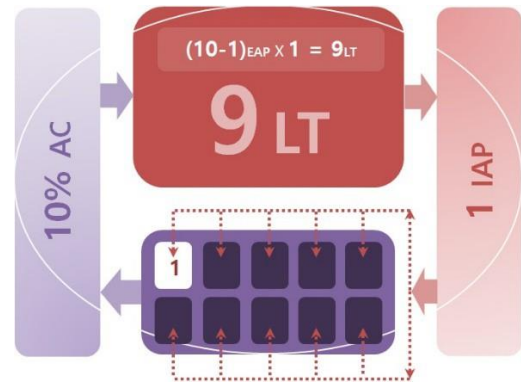
Let's say a fire last night put seven people in a coma, 70% of the family, and the "sum of their grief" from the remaining three is reflected in their crying (tinnitus), which is at a volume level of 21.



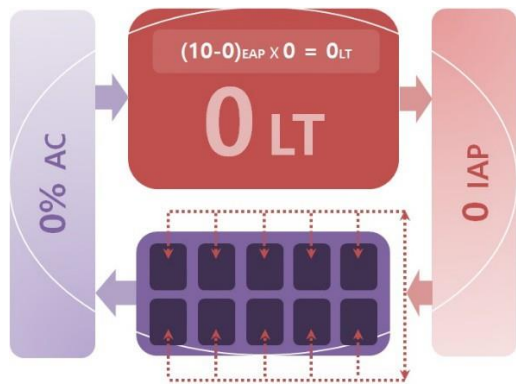
Imagine that a fire last night put eight people in a coma, 80% of the family. The remaining two people feel very sad and cry loudly, but the combined volume level of their crying (tinnitus) is only 16 or so.



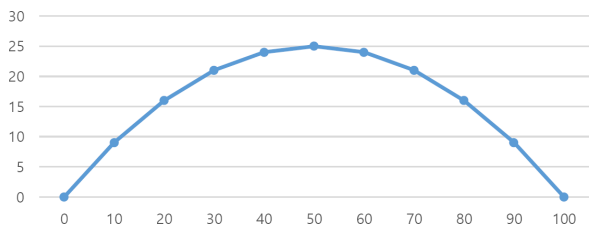
Let's assume that due to the fire last night, 90% of the family members, a total of nine, have fallen into a coma. The remaining one family member, overwhelmed with immense sorrow, cries out loudly, but the loudness level of this one cry (tinnitus) would be 9.



The final diagram depicts the situation where, due to the fire last night, all 10 family members have fallen into a coma and can no longer cry out. The loudness level of the cry (tinnitus) is 0.



The "sum of grief" of the 10 family members listed so far: 0, 9, 16, 21, 24. The 11 numbers, 25, 24, 21, 16, 9, 0, are the α values for the current loudness level (LT) of the tinnitus in the tinnitus intensity function, which, when plotted in coordinates, looks like this.



The tinnitus generation mechanism observed in the passive auditory system, which we have discussed so far, follows the Welch curve. On the other hand, the Welch model for tinnitus intensity has certain limitations when applied to the active auditory system, where auditory cognitive functions are operating normally. The damping effect of the normal auditory nerve system or the recruitment phenomenon, which occurs during the process of frequency specificity impairment, cannot be explained by the Welch model. The damping effect refers to the auditory phenomenon observed only in healthy active auditory systems, where loud sounds are appropriately reduced and processed based on the cognitive context (it should be noted that this does not refer to the damping function at the outer or middle ear stage). An example of this would be the final loud note in an orchestral performance, which some perceive as emotional while others perceive as noise. When 10 individuals with normal hearing are exposed to the same symphony at the same volume, the physical intensity of the sound they perceive may be identical, but the psychological loudness they experience can differ. The damping effect is a phenomenon that aligns with neurological mechanisms such as selective attention or efferent inhibition in the active auditory system, and various studies on this are still ongoing.

Regarding auditory recruitment, for the past few decades, thousands of papers have reported cases of recruitment phenomena in both passive and active auditory systems. However, research results in the passive auditory system often fail to find consistent conclusions based on uniform experimental methods across different researchers. Many studies, in the name of complementing previous research, create slightly modified experimental designs and claim results that contradict earlier conclusions. Moreover, compared to recruitment research in the active auditory system, research on recruitment in the passive auditory system has very limited applicability in terms of acoustic experimental design models and depth of interpretation. The difference in the damping effect and recruitment phenomenon between the passive and active auditory systems may be much larger than anticipated in existing academic circles. Therefore, the Welch curve theory for tinnitus intensity appears to be valid only for the passive auditory system. A modification of the Welch curve theory for tinnitus intensity is inevitable in the active auditory system.

In the active auditory system, if one wishes to conduct studies on harmonic plates or tonotopy in human subjects while controlling brain activity variables, it is essential to create an experimental environment free from various mental activities such as attention, memory, expectation, and prediction. The most ideal condition for such an environment would be sleep, but it is not possible to measure exact frequency-specific hearing thresholds or the psychological intensity of tinnitus in sleeping subjects, as they cannot respond behaviorally. As behavior response experiments in non-sleeping states for harmonic plates and tonotopy require highly "sophisticated" psychoacoustic experimental designs, so does the study of the subjective intensity of tinnitus based on the dBSL (dB Sensation Level) scale. An example of an advanced experimental design to observe random outbursts or neural synchronization patterns occurring in the tinnitus frequency range over time is the RCPTA algorithm. RCPTA sets an arbitrary time frame of "15 minutes," within which it controls the subject's brain activity as much as possible through a random arrangement of frequency/intensity/time, extracting the actual approximate values of the tinnitus frequency range and intensity. By using the RCPTA method, it is possible to trace not only phenomena like random outbursts or neural synchronization in an active auditory system with normal auditory cognitive function, but also the microscopic response patterns of the basal neural network, such as harmonic plates and tonotopy. Following the Welch curve theory in the passive auditory system, let's explore the principles of tinnitus generation in the active auditory system based on Sam Kwak's theory of the Gaussian curve for tinnitus intensity. As explained earlier in the Welch curve theory, the auditory cells located within a single critical band and the auditory neurons connected to these cells are

metaphorically described as a "family." The auditory cells within a single critical band are grouped into a total of 10 groups, forming "one family," or 10 family members. The auditory cells represent the physical reality of family members, while the auditory neurons represent their psychophysical reality. Before diving into the understanding of the Gaussian curve theory of tinnitus intensity, let's recall the key terms from the passive auditory system, as some of the definitions differ slightly from those presented earlier in the passive auditory system.

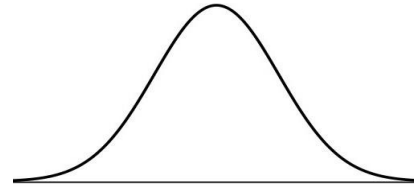
AC	Auditory Capacity in the N-th Auditory Filter
100% AC	Most Perfect Hearing State in the N-th Auditory Filter
0% AC	Complete Hearing Loss in the N-th Auditory Filter
AAS	Afferent Auditory System in the N-th Auditory Filter
AHC	Auditory Hair Cells in the N-th Auditory Filter
CAS	Central Auditory System Overseeing the N-th Auditory Filter
EAP	Excitatory Action Potential in the Afferent Auditory System of the N-th Auditory Filter
EAS	Efferent Auditory System in the N-th Auditory Filter
IAP	Inhibitory Action Potential in the Efferent Auditory System of the N-th Auditory Filter
LT	Loudness Level of Tinnitus in the N-th Auditory Filter
N	N-th Auditory Filter in the Cochlea
α	Current Loudness Level of Tinnitus in the N-th Auditory Filter
β	Inhibitory Action Potential Transmitted Through the Efferent Auditory System in the N-th Auditory Filter
γ	Activity Potential Constant in the Most Ideal Hearing Condition of the N-th Auditory Filter, or δ Value in the Most Perfect Hearing State
δ	Number of Normally Operating Auditory Hair Cell Groups in the N-th Auditory Filter

The difference between the definitions of terms in the active auditory system and the passive auditory system lies in the introduction of the "N" concept. "N" refers to the serial number of the auditory filter (critical band) within the cochlea. Although it is not impossible to apply the critical band principle accompanied by the "N" concept in the passive auditory system, there are very few quantitative research examples related to the critical band in the passive auditory system. The critical band principle is a very consistent and systematic research result derived from various psychological acoustics experimental designs by researchers in the field of the active auditory system. Therefore, when understanding the principles of tinnitus generation in the Gaussian curve theory of tinnitus intensity, it is essential to consider the "N" concept to understand the principles of tinnitus generation in the active auditory system.

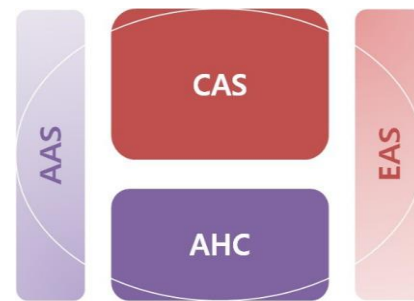
The Gaussian curve theory of tinnitus intensity was introduced in mid-2018 by the Korean cognitive acoustician Sam Kwak in the United States, South Korea, and Colombia. Along with the Welch curve theory from the

passive auditory system, the Gaussian curve theory serves as a stochastic model that clearly explains the principles of tinnitus generation in the active auditory system. The theory received a great deal of support from academics who attended the presentation at that time.

The basic form of the Gaussian curve is as follows.



The anatomical basic diagram of the active auditory system is the same as that of the passive auditory system discussed earlier.



Sam Kwak's tinnitus intensity function is the same as that of the passive auditory system discussed earlier, but differences in the β (inhibitory action potential) value arise near normal hearing and severe to profound hearing loss. The factors causing the difference in β values between the active and passive auditory systems are the damping effect and recruitment phenomenon.

$$\alpha_{LT} = \delta (\gamma - \beta)_{EAP}$$

α = The loudness level of the tinnitus currently occurring at the Nth auditory filter β = the loudness level of the tinnitus transmitted through the centrifugal auditory system at the Nth auditory filter Inhibitory action potential value

γ = the action potential constant at the Nth auditory filter or the value of δ at the most perfect hearing state

δ = The number of currently auditory hair cell groups in the Nth auditory filter.

LT= Loudness Level of Tinnitus (Loudness Level of Tinnitus)

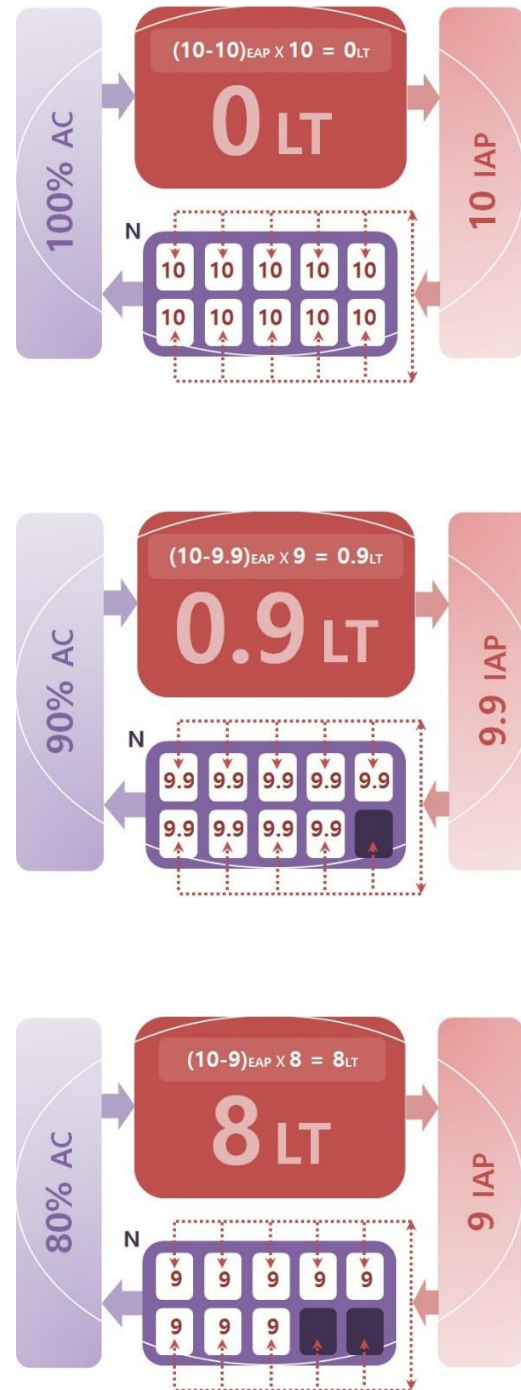
EAP= Excitatory Action Potential

In the active auditory system, the tinnitus loudness level (LT) in the central auditory system (CAS) is proportional to the excitatory action potential (EAP) size. For the Nth critical band in the active auditory system, the tinnitus loudness level follows a Gaussian curve relationship with the number of normal hair cell groups (δ) in that critical band.

The inhibitory action potential (β) in the Nth critical band is determined by the number of normal hair cell groups. However, when the hearing in that critical band is relatively healthy versus when it is very poor, the β value is no longer determined solely by the number of normal hair cells in that critical band. In healthy hearing, the brain actively dampens and disregards sounds it deems unnecessary, a process that is crucial for even very subtle tinnitus. Healthy hearing means the brain does not perceive very slight tinnitus as a sound at all. In contrast, when the hearing in the Nth critical band deteriorates significantly, the β value is no longer dependent on the number of normal hair cell groups (δ) within the same critical band. As hearing in the Nth critical band worsens, the brain begins a process of reorganization, attempting to form new auditory structures by recruiting neighboring critical bands (N-1, N+1, N-2, N+2, etc.). This reorganization is what leads to the phenomenon of recruitment. When hearing in the Nth critical band becomes very poor, the brain may no longer need to inhibit it, but unlike the passive auditory system, the brain of the active auditory system compensates by recruiting relatively healthy hair cell groups from neighboring critical bands. This recruitment process results in an increased inhibitory action potential (β). Consequently, when loud sounds are received externally, excessive computations of total sound intensity can occur, making it seem as though the system is functioning like "healthy hearing." The γ constant for the Nth critical band in the active auditory system is the intrinsic action potential value for that critical band when it is in an ideal hearing state, and this is equivalent to the " δ value in the most perfect hearing state." To explore the Gaussian curve theory of tinnitus intensity based on Sam Kwak's tinnitus intensity function, we can apply this to the tinnitus generation mechanism in the Nth critical band in the active auditory system. This will involve looking at the following 11 diagrams and analyzing the data from MTM clinical results.

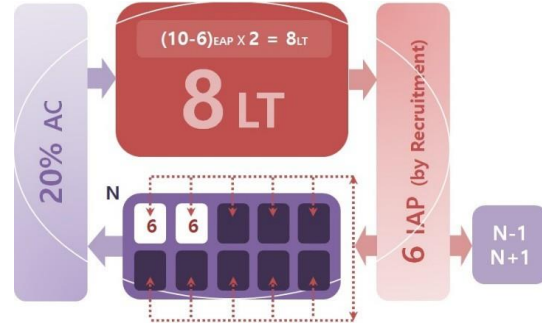
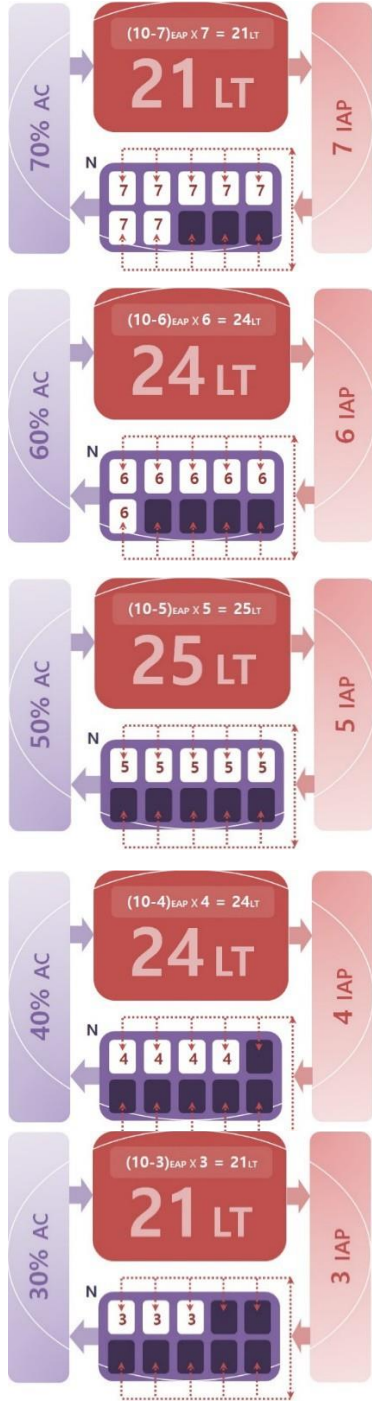
The mechanism of tinnitus generation in the active auditory

The mechanism of tinnitus generation in the active auditory system is not significantly different from that in the passive auditory system. However, when considering the damping effect observed in relatively healthy auditory pathways and the recruitment phenomenon seen in the auditory system with severe hearing loss, the interpretation of the tinnitus intensity functions in the Welch model and Gaussian model differs slightly. The first diagram below is the same as that of the passive auditory system.



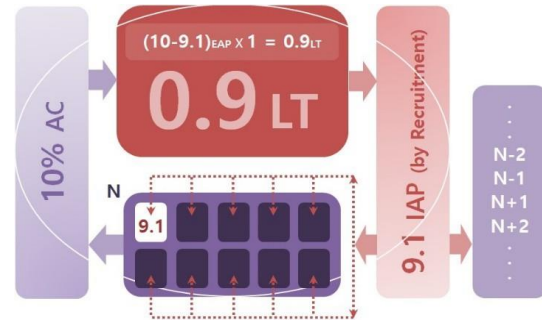
However, there is a difference between the active and passive auditory systems in the second and third diagrams. The following diagram depicts the case where the hearing of the Nth critical band in the active auditory system is approximately 90% normal and when it is approximately 80% normal.

When the auditory capacity is between 70% and 30% normal, both the active and passive auditory systems share the same tinnitus intensity function diagram. However, when the auditory capacity is reduced to only 10-20%, the compensatory phenomenon in the active auditory system must be considered.

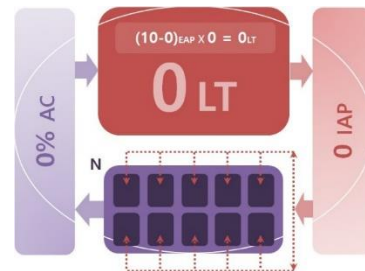


If the Nth critical band hearing is at the level of severe hearing loss, it is labeled as 20% hearing capacity. In this case, the passive auditory system shows a β value of about 2 IAP, but in the active auditory system, the β value suddenly increases to 6 IAP as shown in the diagram above. This is due to the compensatory phenomenon of the efferent auditory system (EAS), which transmits inhibitory signals beyond the frequency range of the Nth critical band to relatively healthy auditory cells in neighboring critical bands (N-1, N+1).

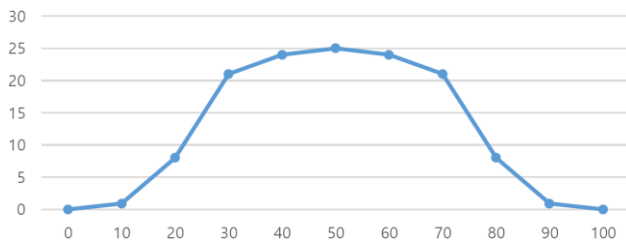
The more severe the replenishment, the higher β value and the more suppressed the tinnitus.



Auditory capacity of 10% indicates that only 10% of hearing ability remains, and the hearing in the Nth critical band is close to the profound hearing loss level. Among the 11 diagrams, this represents the most severe compensatory phenomenon, where the β value in the passive auditory system was 1 IAP, but in the diagram above, it is shown as 9.1 IAP. The β value, which represents the inhibitory action potential, should be applied differently in the tinnitus intensity function for the passive and active auditory systems as a parameter. In zero hearing (0% auditory capacity), the β value is also zero.



The 11 α values listed for the active auditory system—0, 0.9, 8, 21, 24, 25, 24, 21, 8, 0.9, and 0—can be plotted on a coordinate system as follows.



Gross Hearing Index Parameters



The bar graph showing the distribution of subjects by hearing loss index groups was introduced in Chapter 8. If we want to categorize 195 random hearing loss index values into 11 groups based on hearing loss level, what rule should we follow? The minimum hearing loss index is negative, but for convenience, let's assume the minimum is 0, and the maximum is 13,360. Should we simply divide 13,360 by 11 to create 11 groups with equal intervals, or should we divide the range from 0 to 13,360 into 11 groups with precise geometric intervals? The term "hearing loss index" frequently used in this textbook was first introduced by the authors based on MTM clinical results. The concept of gross hearing, which is the simple sum of 67-band high-resolution RCPTA hearing thresholds, and the hearing loss index, which is derived from it, are terms first introduced in this textbook. When the 195 random hearing loss index values are classified into 11 groups, the grouping criteria must be established to confirm whether the sample follows a normal distribution. In other words, to construct a gross hearing (hearing loss index) normal distribution for the subjects participating in the MTM clinical trial, appropriate parameters must first be identified. The arbitrary constant value, referred to as the "gross hearing normal distribution parameter," was determined through this MTM clinical trial. When conducting the same MTM clinical trial in other countries or medical institutions in the future, it is recommended to classify the hearing loss index into 11 groups according to the same parameters. Let's call the parameter that the textbook presents the "gross hearing

normal distribution parameter," P. When the hearing loss index of any subject participating in the MTM clinical trial is classified into 11 groups using the P value, if the hearing loss index distribution does not approach a normal distribution, it may be assumed that the participant recruitment method was different, or the MTM clinical protocol was not followed.

In this MTM clinical study, the 11 hearing loss index groups by level were classified based on the results of the primary fine hearing test according to the following criteria. The 11 hearing loss index groups were determined starting from a hearing loss index of 500, with differences between the groups defined accordingly. The first group was categorized as the hearing loss index range of 500–1,000, and this set the basis for determining the next groups. There were only three subjects with a hearing loss index below 500, so they were included in the first group. It is important to note that although the first group was classified as having a hearing loss index of 500–1,000, the second group should not follow a simple arithmetic interval, such as 1,000–1,500, and so on. If the groups were categorized by a simple 500-interval, more than 20 groups would be created instead of the intended 11. To classify into the original target of 11 groups, it is preferable to increase the hearing loss index interval from 500 by about 10% to 550 for the next group. In this case, the hearing loss index range for the second group would be 1,000–1,550. By applying a 10% increase to the 550hearing loss index interval of the second group, the third group's range would be 1,550–2,155. In this way, by adding approximately 10% of the "gross hearing normal distribution parameter" P value to the previous group's hearing loss index interval, the next group's hearing loss index interval can be determined. This process would result in the completion of the 11 hearing loss index groups. The minimum hearing loss index of the N-1th group is denoted as m, and the maximum hearing loss index as M. By multiplying the difference (M-m) by 0.1, the Nth group's parameter P (with an error rate of +/- 5%) value is determined.

~1,000
1,000~1,550 (550=500+50)
1,550~2,155 (605=550+55)
2,155~2,820 (665=605+60)
2,820~3,550 (730=665+65)
3,550~4,350 (800=730+70)
4,350~5,230 (880=800+80)
5,230~6,200 (970=880+90)
6,200~7,270 (1,070=970+100)
7,270~8,450 (1,180=1,070+110)
8,450~

The RCPTA 67-band algorithm test, which served as the basis for calculating the gross hearing index (hearing loss index), was conducted a total of 585 times (1st, 2nd, and 3rd rounds) on 195 subjects. The tinnitus resistance scores were collected during the 1st and 3rd tests through the tinnitus survey evaluation. To compare the hearing loss index with the tinnitus resistance scores, the 1st and 3rd test hearing loss indices were selected as samples, and the correlation between the 390 gross hearing results and 390 tinnitus resistance scores was analyzed. The image on the right shows the results of the 390 gross hearing scores and 390 tinnitus resistance scores.

For the correlation analysis between hearing loss and tinnitus, the 11 gross hearing groups were further subdivided into upper and lower hearing loss index groups within each group. The average gross hearing index (hearing loss index) and the average tinnitus resistance scores for a total of 22 detailed subgroups are shown in the table below.

When comparing the distribution of average gross hearing values and the distribution of average tinnitus resistance scores in the table, it is observed that tinnitus resistance decreases from Group 1 to Group 6. A lower tinnitus resistance score indicates that the intensity of tinnitus is relatively higher and that the frequency of tinnitus occurrence is greater. However, this decrease in tinnitus resistance is no longer apparent after

[illegible]

Group 6, and instead, the tinnitus resistance in Group 11, which has the worst hearing, is the highest among the groups 6 to 11.

1 Var1	2 Var2
371	8.8
867	8
1120	9.2
1385	8.1
1760	8.3
2065	6.7
2284	6.8
2633	6.6
3037	4.9
3389	4.9
3706	4.8
4107	4.6

This means that the subjective intensity of tinnitus and the frequency of tinnitus episodes are lower than in the case of moderate hearing loss. regression analysis of the mean of total hearing and the mean of tinnitus resistance score of the 22 subgroups showed a strong inverse relationship between the degree of hearing loss and tinnitus resistance in groups 1-6 ($R=0.94$).

This means that there is a strong proportional relationship between the severity of hearing loss and the severity of tinnitus in groups 1-6.

Regression Summary for Dependent Variable: Var2 (Spreadsheet1)						
R= .94462408 R²= .89231465 Adjusted R²= .88154612 F(1,10)=82.663 p<.00000 Std.Error of estimate: .58009						
N=12	b*	Std.Err. of b*	b	Std.Err. of b	t(10)	p-value
Intercept			9.807984	0.369635	26.53426	0.000000
Var1	-0.944624	0.103772	-0.001347	0.000148	-9.10292	0.000004

We attempted a regression analysis to determine the relationship between the mean total hearing and the mean tinnitus resistance score for groups 6-11.

1 Var1	2 Var2
3706	4.8
4107	4.6
4579	4.6
4922	5
5460	4.3
5890	5.8
6400	5.1
6962	4.6
7463	4.5
7968	5.6
8716	5.4
9418	7.8

There was a weak proportional relationship between tinnitus resistance ($R=0.63$). This means that for groups 6 to 11, there is a weak inverse relationship between the severity of hearing loss and the severity of tinnitus. This means that the subjective intensity of tinnitus may be weaker at the 90 dBHL hearing threshold than at the 50 dBHL hearing threshold.

Regression Summary for Dependent Variable: Var2 (Spreadsheet1)						
R= .63419996 R²= .40220959 Adjusted R²= .34243055 F(1,10)=6.7283 p<.02677 Std.Error of estimate: .76939						
N=12	b*	Std.Err. of b*	b	Std.Err. of b	t(10)	p-value
Intercept			3.119737	0.622888	3.791205	0.003536
Var1	0.634200	0.244498	0.000326	0.000126	2.593891	0.026771

The MTM protocol is a practice and procedure for diagnosing and treating tinnitus based on the RCPTA 67-band algorithm and TSC acoustic technology.

The ultimate goal of tinnitus treatment at MTM is to fundamentally improve hearing.

Tinnitus treatment

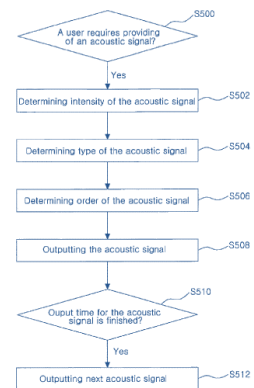
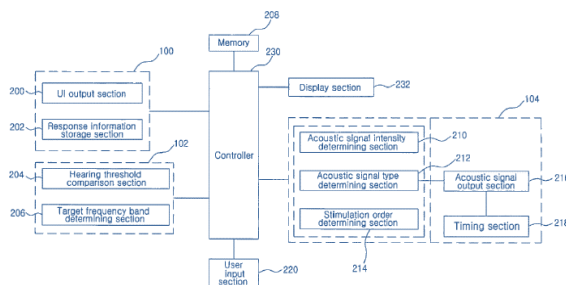
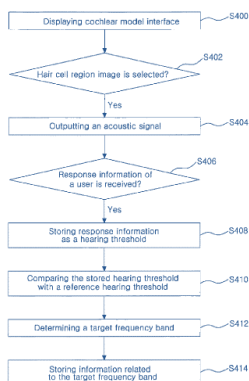
Ideally, you'd also want to improve your hearing.

- Sam S. Kwak -

14. RCPTA AND REVE134

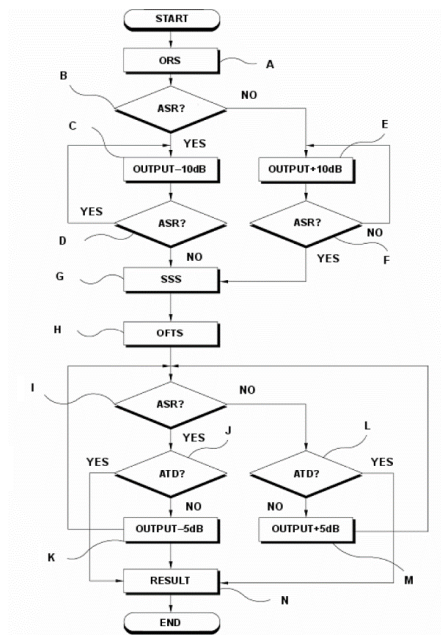
RCPTA stands for "Randomized Controlled Pure Tone Audiometry," which means "Randomized Controlled Pure Tone Audiometry" or "Randomized Controlled Pure Tone Hearing Test." RCPTA is a fine hearing test algorithm based on the random presentation of 67 frequency test tones, and it is an optimized version of the AMA-PTA, a medical device registered with the FDA in the United States and Korea, specifically for tinnitus diagnosis and treatment. The RCPTA algorithm consists of two stages: one is tracking the approximate primary thresholds for about 17 representative frequencies in key audible frequency bands from 250 to 12,000 Hz, and the other is tracking the secondary thresholds for all 67 frequency bands based on the primary thresholds determined in the first stage to finalize the hearing threshold. The 67 frequency test tones are randomly presented to both ears according to the RCPTA algorithm.

In REVE134, "REVE" stands for "Restoration and Elevation in Viscoelasticity and Electromotility," referring to the "restoration and enhancement of the viscoelasticity and electromotility of outer hair cells." The 134 TSC acoustic signals embedded in the REVE134 acoustic stimulator aim to improve both peripheral and central auditory functions. For normal operation of central auditory processing, it is crucial to understand and manage the peripheral auditory information processing process. To this end, the REVE134 acoustic stimulator provides various functions that allow healthcare professionals to subdivide the cochlea into 134 frequency bands, enabling the precise improvement and maintenance of auditory processing performance starting from the peripheral auditory cell level. The point where the auditory nervous system first receives and processes sound intensity information is the outer hair cells within the cochlea, numbering around 12,000. The firing ability of these outer hair cells originates from the normal viscosity and elasticity of the internal and external environments of the outer hair cells, as well as their electromotility. In this sense, the cochlea is essentially the "gateway to hearing." The number "134" in REVE134 means that the cochlear auditory cell groups at the hearing gateway have been microscopically subdivided into 134 central frequencies, and the origin of the number "134" is based on the frequency series of ISO16's "12-tone equal temperament." ISO16 subdivides one octave into 12 frequencies according to an equal frequency ratio, presenting a total of 12 standard musical pitches. These 12 standard musical pitches have been universally used across diverse music cultures around the world for centuries. One octave equals 1,200 cents. Within the frequency range of 250-12,000 Hz, there are a total of 67 equal temperament frequencies, and the interval between these 67 frequencies is uniformly 100 cents or one semitone. The number "134" represents the subdivision of the cochlea auditory cells within the 250-12,000 Hz range into 134 central frequencies.



RCPTA

RCPTA stands for "Randomized Controlled Pure Tone Audiometry." It is a method used for "Randomized Controlled Pure Tone Audiometry" or "randomized controlled pure tone hearing test." The RCPTA algorithm was developed by Sam Kwak with funding from the Cora Black Fund at the University of California between 2002 and 2004. RCPTA is a fine hearing test algorithm that presents 67 frequency test tones randomly and is an optimized version of the AMA-PTA fine hearing test device, which is registered as a medical device by the FDA in the U.S. and Korea, tailored for tinnitus diagnosis and treatment. The RCPTA algorithm consists of two main stages: first, tracking the approximate primary threshold for about 17 representative frequencies in critical frequency bands within the audible frequency range of 250-12,000 Hz, and then, based on the determined primary hearing threshold values, tracking the secondary hearing thresholds across the entire 67 frequency bands to confirm the final thresholds. The 67 frequency test tones are presented randomly to both ears according to the RCPTA algorithm.



The above flowchart illustrates the basic logical flow of the RCPTA algorithm, which controls the presentation of pure tone test sounds randomly to determine the hearing thresholds. During the pure tone hearing test using the RCPTA algorithm, the examinee must press the response button every time the algorithm randomly presents a test sound that is perceived audibly. The algorithm recognizes the moment when the examinee's finger is no longer on the response button, triggering the presentation of the next test sound. If the examinee does not press the response button within 2.5 seconds of the test sound being presented, the algorithm is designed to automatically present the next test sound. The 2.5 seconds is a sufficient length of time for

humans to make a decision on whether a sound is present or not. If the examinee fails to press the response button within 2.5 seconds, it essentially means that the sound was not perceived.

The reason for presenting the test sounds in a random sequence is to control auditory cues that could unnecessarily stimulate the auditory nervous system of the examinee. Control of cues in behavioral response tests is very important. In pure tone audiometry, which tests auditory behavioral responses, it is difficult to perform an accurate hearing test without controlling auditory cues. One of the most representative auditory cues that the ISO 8253 series of international standards for pure tone audiometry overlooks is the harmonic cue. As discussed earlier, the harmonic cue is also referred to as the spectral cue. For example, testing the hearing ability for a frequency of 2,000 Hz after first playing and having the examinee memorize a 1,000 Hz pure tone is essentially a test involving a spectral cue, as the harmonic cue (the frequency of 2,000 Hz being double that of 1,000 Hz) has already been provided. The manually-operated pure tone audiometry (PTA) in the ISO 8253 series, which is standardized and commonly used worldwide in medical institutions, does not consider the response patterns of auditory neurons sensitive to spectral cues. Testing hearing only at octave or frequency doubling intervals, such as 250, 500, 1,000, 2,000, 4,000, and 8,000 Hz, is equivalent to testing only a specific frequency neuron network or a particular unit of auditory neurons that is fully exposed to the spectral cue. Human hearing in daily life is exposed to an environment where sounds are received randomly without any predetermined auditory cues, not in a controlled acoustic environment where artificial cues are provided in advance. To accurately assess the auditory capabilities of different lattice-like auditory neuron networks in the active auditory system, the test must be free from harmonic or spectral cues. For instance, when performing a hearing test with 1,000 Hz and 2,000 Hz frequency test sounds, the presentation times and order of these two frequencies should be randomly mixed without any cues, and the intensity levels of the presented sounds should also follow an unpredictable random intensity order. Additionally, between the presentations of the 1,000 Hz and 2,000 Hz stimuli, an oddball experimental design should be followed, introducing a stimulus that disrupts the frequency relationship between these two frequencies. This is necessary to prevent unnecessary focus or prediction/expectation activities from unit auditory neuron networks that are sensitive to spectral cues.

For consistent hearing testing, the internationally standardized pure tone audiometry, which uses a sine wave with a single physical frequency component, is limited by its reliance on a single spectral-based harmonic plate and its wide frequency interval configuration. The frequency composition of the test tones in pure tone audiometry is well-known, consisting of 6 stimulus frequencies arranged in harmonic

multiples (octave intervals) of 250, 500, 1,000, 2,000, 4,000, and 8,000 Hz, with 1,000 Hz as the reference. In other words, the international standard pure tone audiometry only stimulates a single harmonic plate of the auditory nervous system. Sometimes, 3,000 Hz or 6,000 Hz are added, but these frequencies also belong to the same spectral-based harmonic plate. The frequency composition of the international standard pure tone audiometry, with a 1-octave (1:2) relationship, has an interval that is too wide to accurately determine hearing thresholds. Stimulating the cochlea at approximately 3 mm intervals and testing only about 6 auditory cell groups within the 250–12,000 Hz frequency range does not provide a precise measurement of hearing. The basic interval of the auditory filter is about 1 mm. In order to accurately assess the performance of the auditory nervous system in key audible frequency ranges, the test must be conducted with frequencies configured more densely than the basic auditory filter unit of 1 mm intervals. If the 250–12,000 Hz frequency range is to be tested using the basic auditory filter unit, the minimum number of frequencies required for the test is approximately 17.

To overcome the various limitations of the ISO8253 series international standard pure tone audiometry, one of the major issues of traditional pure tone audiometry, which is "audiologist-operated pure tone audiometry," must be replaced by the "algorithm-controlled pure tone audiometry" approach. As long as the existing international standard pure tone audiometry relies on the audiologist's subjective judgment in a manual testing system, it will be difficult to implement even a 17-band basic auditory filter unit test, let alone a 67-band fine hearing test. Considering that the existing 6-band pure tone audiometry, which is operated manually by the audiologist, takes an average of over 15 minutes, conducting a 17-band manual test would require at least 40–45 minutes. Behavior response tests conducted with conscious patients should not last more than 30 minutes. Therefore, the current international standard pure tone audiometry, which depends on the audiologist's manual manipulation, cannot even carry out a 17-band pure tone audiometry test with the basic auditory filter unit.

A 3 mm interval 1-octave (6-band) based pure tone audiometry is not free from the harmonic cue, a representative auditory cue, as it relies on a single harmonic spectrum. In contrast, a 1 mm interval 1/3-octave (17-band) based pure tone audiometry overcomes this limitation. By randomly mixing the 17-band frequency configuration provided by RCPTA, it becomes difficult to determine which harmonic spectrum was stimulated at any given moment. On the other hand, with the existing 6-band test, regardless of how the frequencies are mixed, it is clear that it stimulates the harmonic spectrum of the 1,000 Hz range.

<1/3 octave frequency resolution>

17 bands A (Hz)					
262	523	1047	2093	4186	8372
330	659	1319	2637	5274	10548
415	831	1661	3322	6645	

<1 octave frequency resolution>

6 bands (Hz)					
250	500	1000	2000	4000	8000

The primary reason that the RCPTA algorithm test is necessary when conducting pure-tone audiometry to examine the performance of the human auditory nervous system is that it allows the multidimensional neural responses within different harmonic plate relationships of the auditory nervous system to be examined three-dimensionally along the time axis. In the context of hearing tests, "three-dimensional" refers to observing hearing not only across frequency and intensity variables, but also in terms of time. Here, the time frame is no more than 30 minutes. Within 30 minutes, any hearing changes occurring within a single harmonic plate or auditory filter can be identified using the 67-band or 134-band RCPTA algorithm. To carry out such a three-dimensional hearing test, a 17-band frequency resolution is not sufficient. Each auditory filter unit must be tested at least three times, and the test frequencies must vary with each repetition. Therefore, approximately 51 to 68 distinct test frequencies are required—three to four times more than 17 bands. For this purpose, the internationally standardized 12-tone equal temperament frequency configuration, as specified by ISO 16, is ideal. According to ISO 16, a total of 67 standardized geometric mean frequencies can be derived within the primary audible range of 250 to 12,000 Hz. The 67 frequency components adopted by RCPTA are composed of two configurations: 67-band A and 67-band B. 67-band B is derived by shifting the frequencies of 67-band A by 50 cents (i.e., half a semitone).

67 bands A (Hz)					
262	523	1047	2093	4186	8372
277	554	1109	2217	4435	8870
294	587	1175	2349	4699	9397
311	622	1245	2489	4978	9956
330	659	1319	2637	5274	10548
349	698	1397	2794	5588	11175
370	740	1480	2960	5920	11840
392	784	1568	3136	6272	
415	831	1661	3322	6645	
440	880	1760	3520	7040	
466	932	1865	3729	7459	
494	988	1976	3951	7902	

67 bands B (Hz)					
254	508	1017	2034	4067	8134
269	538	1076	2154	4309	8617
285	570	1142	2282	4565	9130
302	604	1209	2418	4836	9672
320	640	1281	2562	5124	10248
339	678	1357	2714	5429	10857
359	719	1438	2876	5752	11503
381	762	1523	3047	6093	
403	807	1614	3228	6456	
427	855	1710	3420	6840	
453	906	1812	3623	7246	
480	960	1920	3838	7677	

67 Combining the frequency histories specified in Bands A and B results in 134 frequency histories with a resolution of 1/24th of an octave, as shown below. This corresponds to the maximum frequency resolution specification provided by the RCPTA algorithm. A pure tone audiogram at 67 frequencies yields a total of 134 hearing thresholds from both ears,

and a pure tone audiogram at 134 frequencies a total of 268 hearing thresholds from both ears.

<1/24 octave frequency resolution>

134 bands (Hz)					
254	508	1017	2034	4067	8134
262	523	1047	2093	4186	8372
269	538	1078	2154	4309	8617
277	554	1109	2217	4435	8870
285	570	1142	2282	4565	9130
294	587	1175	2349	4699	9397
302	604	1209	2418	4836	9672
311	622	1245	2489	4978	9956
320	640	1281	2562	5124	10248
330	659	1319	2637	5274	10548
339	678	1357	2714	5429	10857
349	698	1397	2794	5588	11175
359	719	1438	2876	5752	11503
370	740	1480	2960	5920	11840
381	762	1523	3047	6093	
392	784	1568	3136	6272	
403	807	1614	3228	6456	
415	831	1661	3322	6645	
427	855	1710	3420	6840	
440	880	1760	3520	7040	
453	906	1812	3623	7246	
466	932	1865	3729	7459	
480	960	1920	3838	7677	
494	988	1976	3951	7902	



In REVE134, "REVE" stands for "Restoration and Elevation in Viscoelasticity and Electromotility," referring to the restoration and enhancement of the viscoelasticity and electromotility of outer hair cells. The REVE134 technology is an algorithm that integrates 134 TSC acoustic signals into a single cloud platform. Various domestic and international funding sources and the participation of three ministries of the Korean government contributed to the development of the REVE134 technology. The full-scale development of REVE134 began with investment from the STIC fund in 2007, followed by additional investment from the KTIC fund and the Seoul Global Biomedical Fund (KSLSF), and was selected as a policy-driven development project by the Ministry of Health and Welfare, the Ministry of Knowledge Economy, and the Ministry of Trade and Industry. In 2012, through a clinical affiliation agreement with Stanford University School of Medicine in the United

States, a foothold was established for REVE134's entry into the global medical market. Upon the successful completion of clinical trials at Stanford Medical School, Stanford faculty presented the clinical results at the American Academy of Neurology in April 2015. In 2016, the REVE134 technology began to be actively supplied, centered on the domestic medical market. As of 2019, training for professional personnel to spread the REVE134 technology is being conducted in a total of 15 countries, including South Korea, the United States, China, Japan, Germany, the United Kingdom, Brazil, Mexico, Taiwan, Argentina, Colombia, Malaysia, Chile, Vietnam, and Peru. The REVE134 technology, which integrates 134 TSC acoustic signals into a single cloud platform, has been commercialized in the form of a medical device called the REVE134 Acoustic Stimulator, having obtained sales approval from both the Korean and U.S. FDA. As of 2019, approximately 100 medical institutions across 15 countries have introduced and are operating the REVE134 Acoustic Stimulator on a trial basis. The 134 TSC acoustic signals embedded in the REVE134 Acoustic Stimulator aim to improve both peripheral and central auditory functions. For the proper functioning of the central auditory system, it is crucial to precisely understand and manage the information processing of peripheral hearing. To this end, the REVE134 Acoustic Stimulator supports various features that allow medical professionals to subdivide the patient's cochlea into 134 frequency bands, enabling precise improvement and maintenance of auditory processing performance from the stage of peripheral auditory cells. The starting point of the auditory nervous system's firing cue, which receives and processes sound intensity information, is the approximately 12,000 outer hair cells within the cochlea. The firing ability of outer hair cells originates from the normal viscosity and elasticity of their internal and external environments, as well as their electromotility. In this respect, the cochlea is nothing less than the "gateway to hearing." The number "134" in REVE134 signifies the microscopic subdivision of cochlear auditory cell groups—the gateway to hearing—according to 134 center frequencies. The origin of the number "134" lies in the frequency series of ISO 16's 12-tone equal temperament. ISO 16 divides one octave into 12 frequencies at equal frequency ratios and presents 12 standard musical pitches. These 12 standard pitches represent a universal frequency array system used in diverse global music cultures for hundreds of years. One octave equals 1,200 cents. Within the frequency range of 250 to 12,000 Hz, there are a total of 67 equal-tempered frequencies, and the pitch interval between these 67 frequencies is uniformly 100 cents or one semitone. The number "134" is the total number of frequencies produced when the 250–12,000 Hz range is divided at 50-cent intervals.

The multi-channel TSC (Temporally Structured Cues) technology using REVE134 is a registered patent technology in 50 major countries, including the United States, and is protected under the priority rights of each country's respective patent laws.



(12) **United States Patent**
Kwak

(10) **Patent No.:** **US 8,398,563 B2**
(45) **Date of Patent:** **Mar. 19, 2013**

(54) **METHOD AND APPARATUS FOR HAIR CELL STIMULATION USING ACOUSTIC SIGNALS**

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(73) Assignee: **Earlogic Korea, Inc.**, Seoul (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1355 days.

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A61B 5/00
A61N 1/00 (2006.01)

(52) **U.S. Cl.** (2006.01)
600/559; 607/55

(58) **Field of Classification Search** 607/55, 56, 57
See application file for complete search history.

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(57) **ABSTRACT**
A method for hair cell stimulation includes determining a frequency band corresponding to damaged hair cell region in accordance with a preset algorithm, determining the frequency band corresponding to the damaged hair cell region as a target frequency band, and outputting an acoustic signal with given intensity to the target frequency band so as to stimulate the damaged hair cell region. The method treats hearing loss by acoustic signal.

15 Claims, 15 Drawing Sheets

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graph LR
    User[Response of a User] --> 100[Hearing diagnosis section]
    100 --> 102[Stimulation region detecting section]
    102 --> 104[Stimulating treatment section]
    104 --> AS[Acoustic signal]
```

```
graph TD
    S400[Displaying cochlear model interface S400] --> S402{Hair cell region image is selected? S402}
    S402 -- Yes --> S404[Outputting an acoustic signal S404]
    S404 --> S406{Response information of a user is received? S406}
    S406 -- Yes --> S408[Storing response information as a hearing threshold S408]
    S408 --> S410[Comparing the stored hearing threshold with a reference hearing threshold S410]
    S410 --> S412[Determining a target frequency band S412]
    S412 --> S414[Storing information related to the target frequency band S414]
    S414 --> S500{A user requires providing of an acoustic signal? S500}
    S500 -- Yes --> S502[Determining intensity of the acoustic signal S502]
    S502 --> S504[Determining type of the acoustic signal S504]
    S504 --> S506[Determining order of the acoustic signal S506]
    S506 --> S508[Outputting the acoustic signal S508]
    S508 --> S510{Output time for the acoustic signal is finished? S510}
    S510 -- Yes --> S512[Outputting next acoustic signal S512]
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<Diagram of REVE134 Technology's U.S. Registered Patent and Patent Claims>

Tinnitus Subjects

[illegible]

Changes in Gross Hearing Index Among 77 Subjects (39.5%) Who Reported Decreased Tinnitus Loudness or Frequency After 2 Weeks of Treatment

TSC		T-Test for Dependent Samples (Spreadsheet)									
		Marked differences are significant at $p < .05000$									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv.	t	df	p	Confidence -95.000%	Confidence +95.000%	
Var1	3623.104	214.1749	76								
Var1	3663.104	214.1749	76	0.0000	0.00000	0.00000	76	1.00000	0.0000	0.00000	
Var1	3663.104	214.1749	76	0.0000	0.00000	0.00000	76	1.00000	0.0000	0.00000	
Var2	3663.584	203.1159	77	153.519	771.5591	1.74590	76	0.04870	-328.651	21.61155	
Var1	3623.104	214.1749	76								
Var3	3664.831	212.0665	77	218.273	935.2114	-2.04902	76	0.04402	-430.540	-6.00578	
Var2	3663.584	203.1159	77								
Var2	3623.104	214.1749	77	-153.519	771.5591	-1.74590	76	0.04870	-328.651	21.61155	
Var2	3663.584	203.1159	77	0.0000	0.00000	0.00000	76	1.00000	0.0000	0.00000	
Var2	3663.584	203.1159	77	0.0000	0.00000	0.00000	76	1.00000	0.0000	0.00000	
Var3	3664.831	212.0665	77	64.763	492.7131	1.15322	76	0.25243	-176.555	47.07891	
Var3	3664.831	212.0665	77								
Var1	3623.104	214.1749	77	-218.273	935.2114	-2.04902	76	0.04402	-430.540	-6.00578	
Var1	3664.831	212.0665	77								
Var3	3663.584	203.1159	77	-64.763	492.7131	-1.15322	76	0.25243	-176.555	47.07891	
Var3	3664.831	212.0665	77	0.0000	0.00000	0.00000	76	1.00000	0.0000	0.00000	

Changes in Gross Hearing Index Among 76 Subjects (39.0%) With No Change in Tinnitus Loudness or Frequency After 2 Weeks of TSC

Marked differences are significant at $p < 0.05000$										
Variable	Mean	Std. Dev.	N	Diff.	Std. Dev.	t	df	p	Confidence -95.00%	Confidence +95.00%
Var1	4536.895	1810.387	75							
Var2	4536.895	1810.387	75	0.0000	0.00000	0.000000	75	0.000000	0.0000	0.0000
Var3	4536.895	1810.387	75	0.0000	0.00000	0.000000	75	0.000000	0.0000	0.0000
Var4	4677.934	1908.578	76	-41.039	642.3792	-0.55595	75	0.579219	-105.750	187.8225
Var5	4536.895	1810.387	75							
Var6	4536.895	1810.387	75	265.556	855.6031	2.70587	75	0.008429	-451.079	-70.0525
Var7	4536.895	1810.387	75							
Var8	4677.934	1908.578	76	41.039	642.3792	0.55595	75	0.579219	-105.750	187.8225
Var9	4536.895	1810.387	75							
Var10	4677.934	1908.578	76	0.0000	0.00000	0.000000	75	1.000000	0.0000	0.0000
Var11	4536.895	1810.387	75							
Var12	4536.895	1810.387	75							
Var13	4371.329	1989.204	76	306.565	793.9234	3.35579	75	0.001202	-488.025	-125.1816
Var14	4371.329	1989.204	76							
Var15	4371.329	1989.204	76	-265.556	855.6031	-2.70587	75	0.008429	-451.079	-70.0525
Var16	4536.895	1810.387	75							
Var17	4677.934	1908.578	76	-306.565	793.9234	-3.35579	75	0.001202	-488.025	-125.1816
Var18	4536.895	1810.387	75							
Var19	4371.329	1989.204	76	0.0000	0.00000	0.000000	75	1.000000	0.0000	0.0000

Changes in Cross Hearing Index Among 42 Subjects (21.5%) Who

Reported	Mean		SD	t	df	p	Confidence Interval
	Before	After					
Increased Tinnitus Loudness or Frequency After 7 Weeks of	1.0	1.0	0.0	41	0.9990	0.9990	0.9990

[illegible]

Differences in Hearing Index Change Rates Between 1st/2nd and 1st/3rd

Timepoints										
T-test for Dependent Samples (Spreadsheet)										
Sorted differences are significant at $p < .00000$										
Variable	Mean	Std. Dev.	N	Diff.	Std. Dev. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	0.921897	17.520398	192	0.000000	0.000000	0.000000	191	1.000000	0.000000	0.000000
Var2	0.921897	17.520398	192	0.000000	0.000000	0.000000	191	1.000000	0.000000	0.000000
Var1	0.921897	17.520398	192	-4.837590	15.932939	-4.030306	191	0.000000	2.369436	6.905566
Var2	0.921897	17.520398	192	-4.837590	15.932939	-4.030306	191	0.000000	2.369436	6.905566
Var1	0.921897	17.520398	192	4.837590	15.932939	4.030306	191	0.000000	-2.369436	-6.905566
Var2	0.921897	17.520398	192	4.837590	15.932939	4.030306	191	0.000000	-2.369436	-6.905566

Differences in RCPTA 67-Band Test Duration (in Seconds) Across the 1st, 2nd, and 3rd Sessions

Variable	mean	Std. Dev.	N	Dim.	Std. Dev.	Dim.	Corr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000
Var1	344.1359	137.3913	195	0	0.0000	0.0000	0.0000	194	1.00000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												

Changes in Gross Hearing Index Among 85 Subjects Who Showed

Improvement Across All Three Hearing Evaluation Indicators

Improvement Across Air-pollution Hearing Evaluation Indicators										
Marked differences are significant at p < .0500										
Variable	Mean	Std. Dev.	N	Df.	t	df	p	Confidence -95.000%	Confidence +95.000%	
Var1	4198.812	1897.178								
Var2	4198.812	1897.178	95	0.000	0.00000	84	1.000000	0.000	0.000	
Var3	4198.812	1897.178	95	228.647	739.2195	2.86159	84	0.005472	-388.093	-68.201
Var1	4198.812	1897.178								
Var2	4198.812	1897.178	95	658.106	983.1342	6.17152	84	0.000000	-870.163	-446.049
Var3	4198.812	1897.178	95	-228.647	739.2195	-2.86159	84	0.005472	-388.093	-68.201
Var1	4198.812	1897.178								
Var2	4198.812	1897.178	95	0.000	0.00000	0.00000	84	1.000000	0.000	0.000
Var3	4198.812	1897.178	95	658.106	983.1342	-6.17152	84	0.000000	-870.163	-446.049
Var1	4198.812	1897.178								
Var2	4198.812	1897.178	95	-228.647	739.2195	-2.86159	84	0.005472	-388.093	-68.201
Var3	4198.812	1897.178	95	658.106	983.1342	-6.17152	84	0.000000	-870.163	-446.049
Var1	4198.812	1897.178								
Var2	4198.812	1897.178	95	-228.647	739.2195	-2.86159	84	0.005472	-388.093	-68.201
Var3	4198.812	1897.178	95	658.106	983.1342	-6.17152	84	0.000000	-870.163	-446.049
Var1	4198.812	1897.178								
Var2	4198.812	1897.178	95	0.000	0.00000	0.00000	84	1.000000	0.000	0.000
Var3	4198.812	1897.178	95	658.106	983.1342	-6.17152	84	0.000000	-870.163	-446.049
Var1	4198.812	1897.178								
Var2	4198.812	1897.178	95	-228.647	739.2195	-2.86159	84	0.005472	-388.093	-68.201
Var3	4198.812	1897.178	95	658.106	983.1342	-6.17152	84	0.000000	-870.163	-446.049

Gross Hearing Index Changes in 105 Male Subjects

T-test for Dependent Samples (Spreadsheet)										
Marked differences are significant at $p < .05000$										
Variable	Mean	Std. Dev.	N	Diff.	Std. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	1904.234	105	0.000	0.0000	0.00000	104	1.00000	0.000	0.0000
Var2	4623.962	1904.234	105	-28.752	569.1152	0.51769	104	0.60575	-81.385	138.892
Var3	4502.714	1904.158	105	152.829	511.5308	-0.30586	104	0.002843	-251.642	-53.6154
Var1	4503.362	19								

Gross Hearing Index Changes in 90 Female Subjects

Marked differences are significant at $p < .05000$										
Variable	Mean	Std.Dev.	N	Diff.	Std.Dev. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var2	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var3	3997.299	2225.558	90	-314.676	1119.512	-2.66830	89	0.009059	-543.365	-80.4005
Var2	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var3	3997.299	2225.558	90	-314.676	1119.512	-2.66830	89	0.009059	-543.365	-80.4005
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var3	3997.299	2225.558	90	-314.676	1119.512	-2.66830	89	0.009059	-543.365	-80.4005
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000	89	1.000000	0.0000	0.0000
Var3	3997.299	2225.558	90	-148.6333	778.446	-1.81188	89	0.073456	-311.676	14.4090
Var2	3997.299	2225.558	90	0.0000	0.0000	0.000000</				

Gross Hearing Index Changes in 109 Subjects Aged 55 and Older

T-test for Dependent Samples (Spreadsheet)										
Marked differences are significant at p < .0000										
Variable	Mean	Std. Dev.	N	Diff.	Std. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	5202.835	1728.451								
Var2	5202.835	1728.451	109	0.000	0.0000	0.00000	108	1.00000	0.000	0.0000
Var1	5202.835	1728.451								
Var2	5245.018	1780.538	109	-43.183	532.9033	-0.84502	108	0.399410	-57.992	144.3593
Var1	5245.018	1780.538								
Var2	5118.211	1800.378	109	84.624	781.9216	1.12991	108	0.261018	-233.076	63.8930
Var1	5245.018	1780.538								
Var2	5245.018	1780.538	109	0.000	0.0000	0.00000	108	1.00000	0.000	0.0000
Var1	5245.018	1780.538								
Var2	5245.018	1780.538	109	0.000	0.0000	0.00000	108	1.00000	0.000	0.0000
Var1	5118.211	1800.378								
Var2	5118.211	1800.378	109	-84.624	781.9216	-1.12991	108	0.261018	-233.076	63.8930
Var1	5118.211	1800.378								
Var2	5245.018	1780.538	109	-127.807	794.5499	-1.67398	108	0.095970	-278.659	23.0441
Var1	5245.018	1780.538								
Var2	5118.211	1800.378	109	0.000	0.0000	0.00000	108	1.00000	0.000	0.0000
Var1	5118.211	1800.378								
Var2	5118.211	1800.378	109	0.000	0.0000	0.00000	108	1.00000	0.000	0.0000

Gross Hearing Index Changes in 86 Subjects Younger Than 55

Marked differences are significant at p < .05000										
Variable	Mean	Std. Dev.	N	Df.	Std. Dev. Df.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	3234.483	1.954 615	86							
Var2	3232.483	1.954 615	86	0.000	0.00000	0.000000	85	1.000000	0.000	0.000
Var3	3234.483	1.954 615	86	175.174	812.9769	1.99921	85	0.048990	-345.477	-0.872
Var2	3059.276	1.956 057	86	373.512	896.9617	3.86171	85	0.000219	-565.821	-1.81 205
Var3	3234.483	1.954 615	86							
Var2	3059.276	1.956 057	86	-1.75 174	812.9769	-1.99921	85	0.048990	-345.477	-0.872
Var3	3059.276	1.956 057	86							
Var2	3059.276	1.956 057	86	0.000	0.00000	0.000000	85	1.000000	0.000	0.000
Var3	3059.276	1.956 057	86							
Var2	3059.276	1.956 057	86	198.337	475.8292	3.86547	85	0.000216	-300.355	-95.319
Var3	2890.942	1.897 713	86							
Var2	2890.942	1.897 713	86	-973.512	696.9617	-3.86171	85	0.000219	-565.821	-1.81 205
Var3	2890.942	1.897 713	86							
Var2	3059.276	1.956 057	86	-198.337	475.8292	-3.86547	85	0.000216	-300.355	-95.319
Var3	2890.942	1.897 713	86	0.000	0.00000	0.000000	85	1.000000	0.000	0.000
Var2	2890.942	1.897 713	86							

Gross Hearing Index Changes in 97 Subjects With Baseline Index Below

4,000

T-test for Dependent Samples (Spreadsheet)

Marked differences are significant at $\alpha = .05000$

Variable	Mean	Std.Dev.	N	Diff.	Std.Dev. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Var1	2593.536	967.189	97							
Var2	2593.536	967.189	97	0.0000	0.0000	.96	1.000000	.0000	0.0000	0.0000
Var1	2593.536	967.189	97							
Var2	2547.010	1060.919	97	-46.526	510.9428	-0.99682	96	0.372056	-149.504	56.4520
Var1	2593.536	967.189	97							
Var2	2593.536	967.189	97	190.258	600.8511	3.24974	96	0.001593	-319.356	-77.1594
Var1	2593.536	967.189	97							
Var2	2547.010	1060.919	97	-46.526	510.9428	-0.99682	96	0.372056	-149.504	56.4520
Var1	2593.536	967.189	97							
Var2	2547.010	1060.919	97	0.0000	0.0000	.96	1.000000	.0000	0.0000	0.0000
Var1	2547.010	1060.919	97							
Var2	2593.536	967.189	97	151.732	445.6001	3.95395	96	0.001143	-241.540	-61.9237
Var1	2593.536	967.189	97							
Var2	2593.536	967.189	97	-198.258	600.8511	-3.24974	96	0.001593	-319.356	-77.1594
Var1	2593.536	967.189	97							
Var2	2547.010	1060.919	97	-151.732	445.6001	-3.95395	96	0.001143	-241.540	-61.9237
Var1	2593.536	967.189	97							
Var2	2593.536	967.189	97	0.0000	0.0000	.96	1.000000	.0000	0.0000	0.0000

T-test for Dependent Samples (Spreadsheet)
Marked differences are significant at $p < .05000$

Gross Hearing Index Changes in 166 Subjects With Moderate to Severe

Tinnitus

Var3	4265.976	1995.875	166	0.000	0.0000	0.00000	165	1.000000	0.000	0.0000
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Stimulation)

Gross Hearing Index Changes in the NES Group (Non-identical Filter

Stimulation)

Var2	4152.441	2152.441	50	1.171551	0.1116004	1.160359	52	0.0000000	2.441102	2.011207
Var3	4414.649	2118.154								
Gross Heating Index	4414.649	2118.154	95	0.600	0.0011	0.0000000	0.0000	0.0000	0.0000	0.0000

Filter Stimulation)

Var3	4376.
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Var1	-0.931710	0.181601	-164.514	32.0657	-5.13054	0.005836	6	1732
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Var	-0.938135	0.173142	-0.399143	0.073666	-5.41826	0.005624	6	1.82
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Var	0.971561	0.118394	383.457	46.7278	8.206182	0.001202	6	3675
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Var1	0.077585	0.498493	16.571	106.4728	0.15564	0.883855	6	6687
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Var3	4773.087	2063.523	69	0.000	0.0000	0.00000	68	1.000000	0.000	0.0000
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Var3	4134.287	2153.554	108	0.000	0.0000	0.00000	107	1.00000	0.000	0.000
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Var3	4214.048	2124.847	84	0.000	0.0000	0.00000	83	1.000000	0.000	0.0000
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Var3	4030.307	2210.368	75	0.000	0.0000	0.00000	74	1.000000	0.000	0.0000
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Var3	4032.895	2084.800	76	0.000	0.0000	0.00000	75	1.000000	0.000	0.0000
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Var1	-0.944624	0.103772	-0.001347	0.000148	-9.10232	0.000004
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Var1	0.634200	0.244496	0.000326	0.000126	2.553691	0.026771
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System On

Left Level Tracking

Right Level Tracking

Signal Generation

Pause

Resume

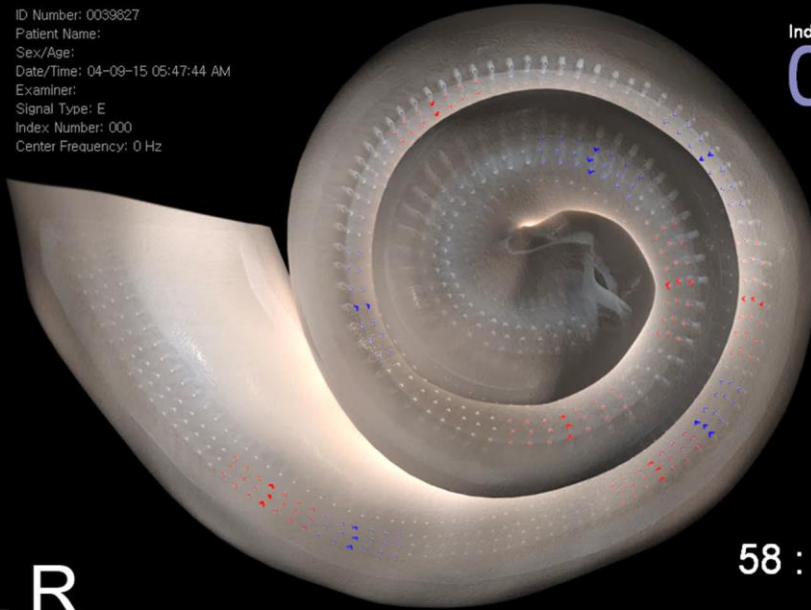
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Patient Name:
Sex/Age:
Date/Time: 04-09-15 05:47:44 AM
Examiner:
Signal Type: E
Index Number: 000
Center Frequency: 0 Hz

Index No.

000

0 Hz

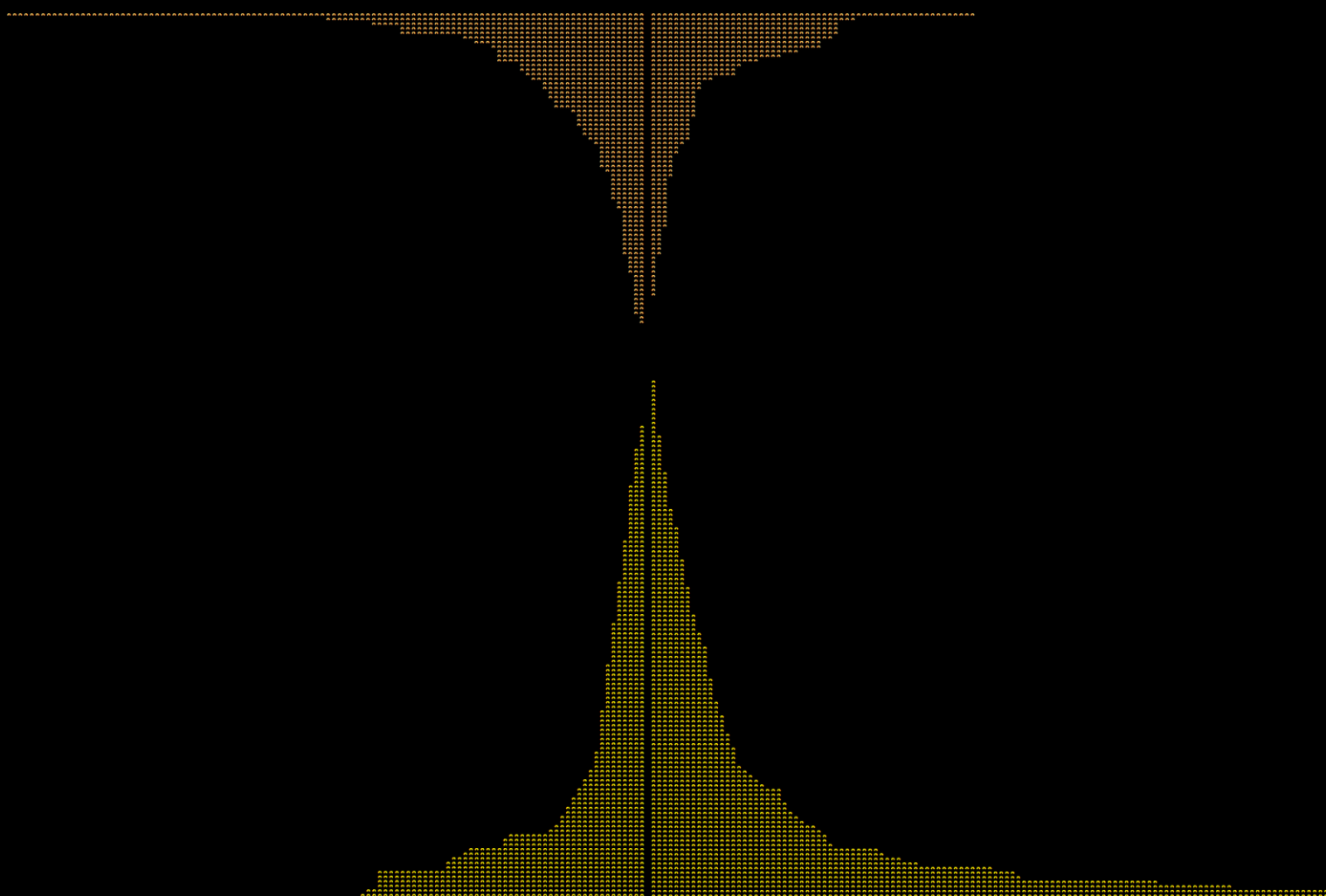
0 dBr



LR

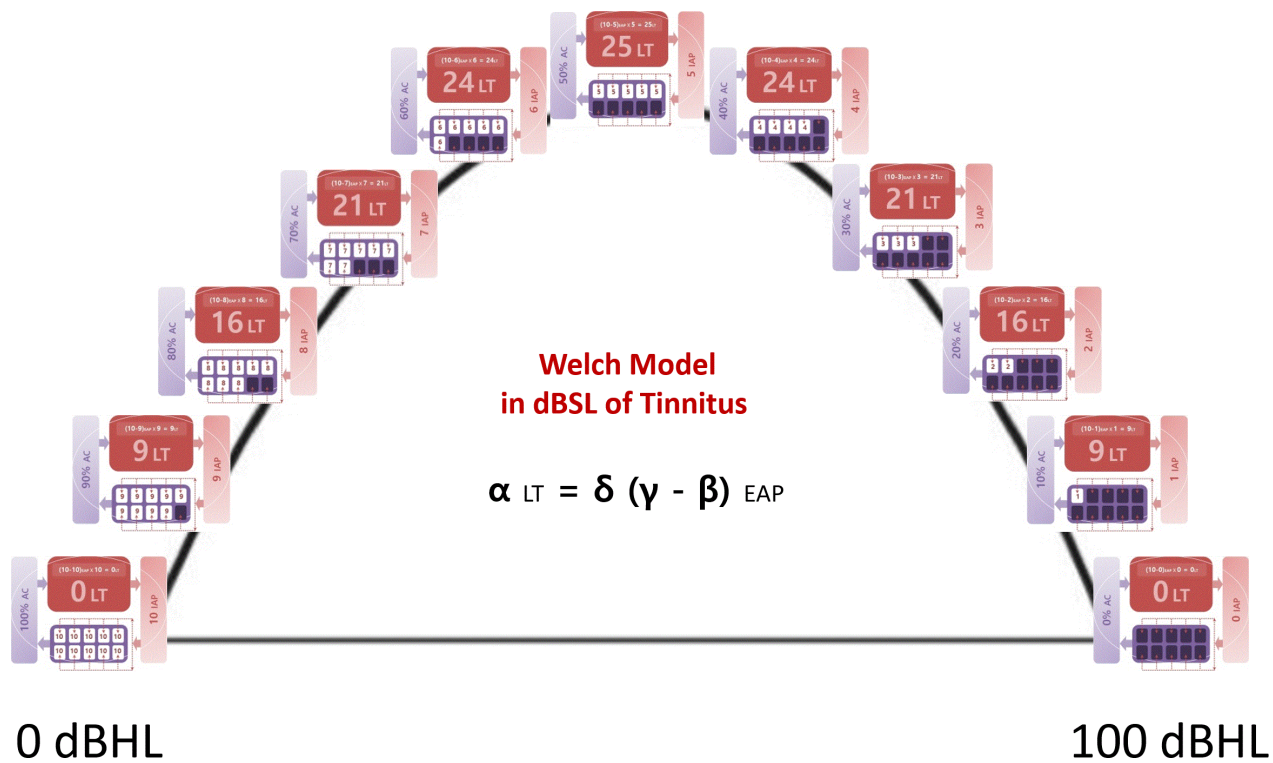
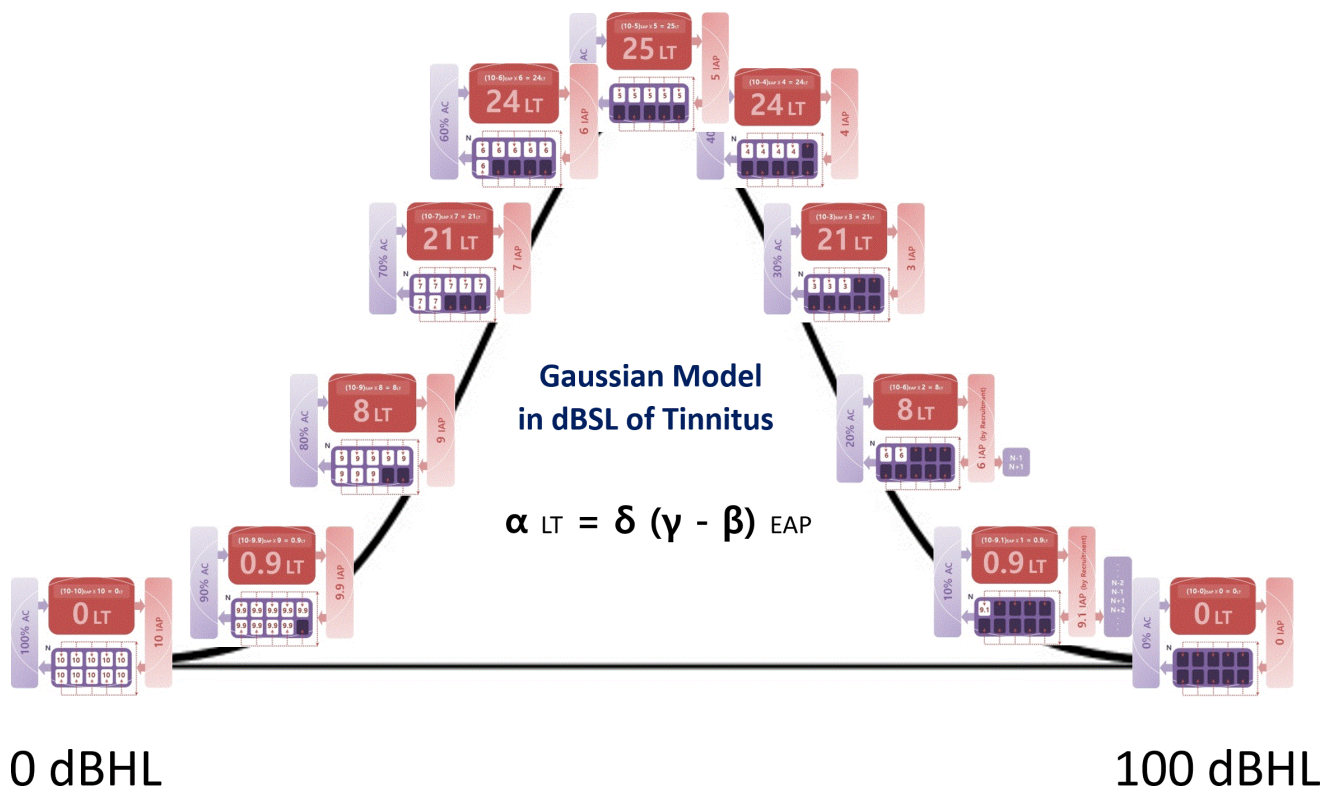
58 : 10





Subject			L			R			Sum			Diff of Threshold			Diff Ratio(%)			Time		TSC Level			TQ			N of Targ			Subject		
ID	G	A	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1vs2	2vs3	1vs3	1vs2	2vs3	1vs3	/28	Start	End	D	1st	2nd	D	L	R	G	A	ID		
1801001	M	45	1227	1010	882	937	940	745	2164	1950	1627	-214	-323	-537	9.8	16.5	24.8	27	25	17	8	5	3	-2	3	0	M	45	1801001		
1801002	M	52	2732	2902	3085	3377	3530	3585	6109	6432	6670	323	238	561	-5.2	-3.7	-9.1	20	23	23	0	3	3	0	2	2	M	52	1801002		
1801004	F	38	1465	1447	1400	915	830	895	2380	2277	2295	-103	18	-85	4.3	-0.7	3.5	44	18	16	2	8	9	1	4	0	F	38	1801004		
1801005	M	54	1870	1857	1877	1155	1157	1152	3025	3014	3029	-11	15	4	0.3	-0.4	-0.1	28	32	32	0	3	3	0	2	2	M	54	1801005		
1801006	F	57	1080	1087	955	1605	1730	1430	2685	2817	2385	132	-432	-300	-4.9	15.3	11.1	28	17	13	4	4	4	0	1	2	F	57	1801006		
1801007	F	78	4062	3957	3995	5230	5017	5357	9292	8974	9352	-318	378	60	3.4	-4.2	-0.6	26	24	16	8	3	3	0	2	1	F	78	1801007		
1801009	F	38	532	355	427	775	485	455	1307	840	882	-467	42	-425	35.7	-5.0	32.5	27	20	19	1	6	7	1	0	3	F	38	1801009		
1801010	M	69	3527	3220	3192	3915	3772	3700	7442	6992	6892	-450	-100	-550	6.0	1.4	7.3	28	21	19	2	9	11	2	4	3	M	69	1801010		
1801011	M	59	2960	2712	2412	3067	2927	2572	6027	5639	4984	-388	-655	-1043	6.4	11.6	17.3	15	23	19	4	3	4	1	4	2	M	59	1801011		
1802001	M	63	3125	2997	2985	2395	2377	2340	5520	5374	5325	-146	-49	-195	2.6	0.9	3.5	30	25	20	5	3	3	0	3	2	M	63	1802001		
1802002	M	34	920	782	715	680	562	382	1600	1344	1097	-256	-247	-503	16.0	18.3	31.4	16	24	20	4	3	4	1	2	3	M	34	1802002		
1802003	M	82	3532	3165	3360	3367	3365	3402	6899	6530	6762	-369	232	-137	5.3	-3.5	1.9	27	25	22	3	5	3	-2	3	3	M	82	1802003		
1802004	M	59	2037	1562	1337	2637	1905	1907	4674	3467	3244	-1207	-223	-1430	25.8	6.4	30.5	13	9	16	-7	5	4	-1	3	4	M	59	1802004		
1802007	M	75	3337	3050	3132	3702	3447	3420	7039	6497	6552	-542	55	-487	7.6	-0.8	6.9	28	24	23	1	3	3	0	3	2	M	75	1802007		
1802008	F	37	710	1075	1022	1207	800	1005	1917	1875	2027	-42	152	110	2.1	-8.1	-5.7	28	22	14	8	12	8	-4	3	3	F	37	1802008		
1802009	F	27	1157	332	250	660	620	372	1817	952	622	-865	-330	-1195	47.6	34.6	65.7	11	10	10	0	13	13	0	2	2	F	27	1802009		
1802011	F	59	2520	2545	2590	2230	2215	2232	4750	4760	4822	10	62	72	-0.2	-1.3	-1.5	25	23	21	2	8	6	-2	3	3	F	59	1802011		
1803001	M	54	1515	1365	1275	1235	1155	790	2750	2520	2065	-230	-455	-685	8.3	18.0	24.9	39	2	2	0	4	9	5	3	3	M	54	1803001		
1803002	M	57	2467	2677	2570	2450	2352	2362	4917	5029	4932	112	-97	15	-2.2	1.9	-0.3	25	5	5	0	3	3	0	3	3	M	57	1803002		
1803003	M	75	2622	2750	2785	3152	3262	3412	5774	6012	6197	238	185	423	-4.1	-3.0	-7.3	40	14	12	2	10	13	3	1	2	M	75	1803003		
1803004	M	67	2812	2867	2817	2995	2957	2935	5807	5824	5752	17	-72	-55	-0.2	1.2	0.9	22	9	6	3	4	6	2	3	3	M	67	1803004		
1803005	F	84	4022	4022	4470	2742	2742	3315	6764	6764	7785	0	1021	1021	0.0	-15.0	-15.0	21	19	17	2	9	10	1	1	1	F	84	1803005		
1803007	F	37	215	487	475	310	562	747	525	1049	1222	524	173	697	-99.8	-16.4	-132.7	29	13	12	1	8	13	5	1	0	F	37	1803007		
1803008	M	78	3120	3025	2820	3172	3040	2812	6292	6065	5632	-227	-433	-660	3.6	7.1	10.4	22	18	16	2	3	3	0	3	3	M	78	1803008		
1803010	F	49	942	950	1030	782	680	732	1724	1630	1762	-94	132	38	5.4	-8.0	-2.2	29	17	15	2	9	10	1	3	3	F	49	1803010		
1803011	M	45	477	745	410	1710	1902	1735	2187	2647	2145	460	-502	-42	-21.0	18.9	1.9	24	29	26	3	5	5	0	0	3	M	45	1803011		
1803014	M	48	2350	1790	1915	2310	2205	2115	4660	3995	4030	-665	35	-630	14.2	-0.8	13.5	26	13	13	0	3	3	0	4	4	M	48	1803014		
1803015	M	50	2687	2650	2370	2685	2272	2305	5372	4922	4675	-450	-247	-697	8.3	5.0	12.9	28	22	11	11	4	4	0	4	4	M	50	1803015		
1803016	F	46	3762	3522	3245	3732	3752	3615	7494	7274	6860	-220	-414	-634	2.9	5.6	8.4	30	20	18	2	3	3	0	3	3	F	46	1803016		
1803017	F	60	1215	965	1085	757	957	1357	1972	1922	2442	-50	520	470	2.5	-27.0	-23.8	29	22	22	0	8	10	2	4	2	F	60	1803017		
1803018	M	33	1370	1335	1325	1332	1342	1322	2702	2677	2647	-25	-30	-55	0.9	1.1	2.0	38	22	21	1	4	3	-1	3	3	M	33	1803018		
1803019	F	37	517	542	642	550	550	472	1067	1092	1114	25	22	47	-2.3	-2.0	-4.4	28	3	2	1	8	13	5	3	3	F	37	1803019		
1803020	M	58	1435	1577	1382	1135	1527	1382	2570	3104	2764	534	-340	194	-20.7	10.9	-7.5	28	20	18	2	11	13	2	3	1	M	58	1803020		
1803021	M	46	1952	1830	1805	1470	1405	1377	3422	3235	3182	-187	-53	-240	5.4	1.6	7.0	19	24	20	4	4	4	0	3	2	M	46	1803021		
1803022	M	72	2845	3007	3012	2545	2547	3005	5390	5554	6017	164	463	627	-3.0	-8.3	-11.6	26	20	14	6	5	5	0	3	4	M	72	1803022		
1803023	F	70	1535	1570	1595	1552	1342	1437	3087	2912	3032	-175	120	-55	5.6	-4.1	1.7	25	11	8	3	5	5	0	4	3	F	70	1803023		
1803024	F	31	1222	1262	1040	1155	1100	1040	2377	2362	2080	-15	-282	-297	0.6	11.9	12.4	27	14	14	0	11	11	0	2	1	F	31	1803024		
1803025	M	36	1552	1450	1397	2997	2937	2922	4549	4387	4319	-162	-68	-230	3.5	1.5	5.0	31	23	27	-4	4	4	0	0	4	M	36	1803025		
1803026	M	34	1255	2487	1825	927	2142	1090	2182	4629	2915	2447	-1714	733	-112.1	37.0	-33.5	27	3	2	1	4	4	0	3	0	M	34	1803026		
1803028	M	54	2635	2857	2842	2165	2327	2190	4800	5184	5032	384	-152	232	-8.0	2.9	-4.8	26	17	17	0	3	3	0	2	2	M	54	1803028		
1803029	M	76	4132	4700	4835	4792	4087	4147	8924	8787	8982	-137	195	58	1.5	-2.2	-0.6	29	26	24	2	4	3	-1	2	3	M	76	1803029		
1803030	M	40	2262	1972	1950	2255	2275	2177	4517	4247	4127	-270	-120	-390	5.9	2.8	8.6	21	25	23	2	3	10	7	4	3	M	40	1803030		
1803032	F	65	3307	2995	3287	4692	4415	4705	7999	7410	7992	-589	582	-7	7.3	-7.8	0.0	18	26	25	1	3	3	0	3	4	F	65	1803032		
1803033	M	44	1390	1242	1167	675	655	417	2065	1897	1584	-168	-313	-481	8.1	16.4	23.2	27	22	23	-1	8	9	1	4	0	M	44	1803033		
1803034	F	56	2617	2505	12	3542	3520	610	6159	6025	622	-134	-5403	-5537	2.1	89.6	89.9	21	21	20	1	4	4	0	0	4	F	56	1803034		
1803035	M	63	1075	1192	1150	1197	1232	1212	2272	2424	2362	152	-62	90	-6.6	2.5	-3.9	28	25	27	-2	11	13	2	0	1	M	63	1803035		
1803037	M	43	1982	1950	1780	1942	2157	1902	3924	4107	3682	183	-425	-242	-4.6	10.3	6.1	19	24	20	4	3	3	0	3	0	M	43	1803037		
1804001	F	63	2705	2712	2762	2870	2845	3017	5575	5557	5779	-18	222	204	0.3	-3.9	-3.6	36	28	20	8	7	9	2	1	2	F	63	1804001		
1804002	F	62	1920	2085	1997	1412	1497	1620	3332	3582	3617	250	35	285	-7.5	-0.9	-8.5	27	32	19	13	5	5	0	3	3	F	62	1804002		
1804005	M	66	1707	1865	1732	1527	1642	1432	3234	3507	3164	273	-343	-70	-8.4	9.7	2.1	34	23	21	2										

Subject		L			R			Sum		Diff of Threshold			Diff Ratio(%)			Time		TSC Level				TQ				N of Targ				Subject	
ID	G	A	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1vs2	2vs3	1vs3	1vs2	2vs3	1vs3	/28	Start	End	D	1st	2nd	D	L	R	G	A	ID		
1807012	M	58	2850	2852	2950	2757	2890	2902	5607	5742	5852	135	110	245	-2.4	-1.9	-4.3	28	22	22	0	5	8	3	2	2	M	58	1807012		
1807016	M	71	2990	2615	2855	2660	2550	2727	5650	5165	5582	-485	417	-68	8.5	-8.0	1.2	32	21	16	5	6	5	-1	2	2	M	71	1807016		
1807017	F	58	1975	2450	2045	1455	1910	1545	3430	4360	3590	930	-770	160	-27.1	17.6	-4.6	28	17	10	7	5	5	0	2	2	F	58	1807017		
1807019	M	63	3800	3605	3377	2415	2237	2097	6215	5842	5474	-373	-368	-741	6.0	6.2	11.9	30	17	14	3	3	4	1	2	2	M	63	1807019		
1808003	M	56	2695	2515	2540	3237	3212	3262	5932	5727	5802	-205	75	-130	3.4	-1.3	2.1	28	15	15	0	3	4	1	1	1	M	56	1808003		
1808004	F	83	4252	4380	4170	4902	5220	4372	9154	9600	8542	446	-1058	-612	-4.8	11.0	6.6	26	24	25	-1	15	12	-3	2	2	F	83	1808004		
1808005	F	81	3797	4200	4222	3285	3200	3052	7082	7400	7274	318	-126	192	-4.4	1.7	-2.7	24	23	24	-1	7	5	-2	2	2	F	81	1808005		
1808006	F	46	795	485	590	775	580	750	1570	1065	1340	-505	275	-230	32.1	-25.8	14.6	27	20	17	3	10	6	-4	1	2	F	46	1808006		
1808012	M	69	3342	3442	3277	3022	2832	2752	6364	6274	6029	-90	-245	-335	1.4	3.9	5.2	31	21	8	13	3	4	1	1	1	M	69	1808012		
1808014	F	21	452	332	322	330	547	340	782	879	662	97	-217	-120	-12.4	24.6	15.3	28	7	12	5	4	8	4	1	1	F	21	1808014		
1809002	F	49	1437	1297	1342	1480	1410	1662	2917	2707	3004	-210	297	87	7.1	-10.9	-2.9	30	23	19	4	3	3	0	2	2	F	49	1809002		
1809003	M	51	1075	997	962	972	1022	695	2047	2019	1657	-28	-362	-390	1.3	17.9	19.0	28	16	8	8	4	6	2	2	2	M	51	1809003		
1809004	F	63	2500	2197	2027	2425	2712	2180	4925	4909	4207	-16	-702	-718	0.3	14.3	14.5	30	20	20	0	3	4	1	2	2	F	63	1809004		
1809005	F	68	3867	3492	3240	2645	2090	1612	6512	5582	4852	-930	-730	-1660	14.2	13.0	25.4	30	16	16	0	3	3	0	2	0	F	68	1809005		
1809007	F	74	1762	1877	2187	2032	1732	1737	3794	3609	3924	-185	315	130	4.8	-8.7	-3.4	28	22	19	3	3	4	1	1	2	F	74	1809007		
1809009	F	39	410	300	277	542	527	290	952	827	567	-125	-260	-385	31.1	31.4	40.4	28	29	27	2	6	7	1	1	0	F	39	1809009		
1809010	F	58	1587	1365	1162	2312	2130	1817	3899	3495	2979	-404	-516	-920	10.3	14.7	23.5	30	20	17	3	3	3	0	2	2	F	58	1809010		
1809011	F	71	3670	3572	3222	3487	3520	3265	7157	7092	6787	-65	-305	-370	0.9	4.3	5.1	28	17	12	5	4	4	0	0	2	F	71	1809011		
1809012	F	63	805	1055	1255	1125	1225	1012	1930	2280	2237	350	-43	307	-18.1	1.8	-15.9	28	15	15	0	9	9	0	0	1	F	63	1809012		
1809013	F	71	3315	2900	3655	2937	2910	2640	6252	5810	6295	-442	485	43	7.0	-8.3	-0.6	28	17	13	4	3	4	1	2	2	F	71	1809013		
1809016	M	63	2422	3720	2720	1887	3020	1740	4309	6740	4460	2431	-2280	151	-564	33.8	-3.5	29	6	5	1	5	9	1	2	2	M	63	1809016		
1809018	F	59	2057	2902	2155	1710	1855	1562	3767	4757	3777	990	-980	10	-26.2	20.6	-0.2	27	18	25	-7	3	3	0	2	2	F	59	1809018		
1809020	M	23	217	397	257	972	892	812	1189	1289	1069	100	-220	-120	-8.4	17.0	10.0	30	17	13	4	7	8	1	1	2	M	23	1809020		
1809021	F	48	3272	3205	3245	3250	3077	2992	6522	6282	6037	-240	-45	-285	3.6	0.7	4.3	28	20	23	-3	7	10	3	1	2	F	48	1809021		
1810001	F	37	770	647	757	745	745	877	1515	1392	1634	-123	242	119	8.1	-17.3	-7.8	26	24	15	9	8	10	2	1	1	F	37	1810001		
1810002	M	52	2185	4707	2592	4972	4695	5025	7157	9465	7617	2308	-1848	460	-32.2	19.5	-6.4	26	17	15	2	3	3	0	3	4	M	52	1810002		
1810004	F	73	3010	3447	4120	3247	3590	4055	6257	7037	8175	780	1138	1918	-12.4	-16.1	-30.6	26	22	22	0	6	8	2	3	3	F	73	1810004		
1810005	F	33	402	535	362	355	465	657	757	1000	1299	243	299	542	-32.1	-29.9	-71.5	25	1	0	1	7	9	2	2	2	F	33	1810005		
1810006	F	38	325	435	362	465	697	692	790	1132	1054	342	-78	264	-43.2	6.8	-33.4	22	26	10	16	11	13	2	1	2	F	38	1810006		
1810008	F	58	3417	3085	3000	1950	1817	1510	5367	4902	4510	-465	-392	-857	8.6	7.9	15.9	19	20	19	1	4	3	-1	4	2	F	58	1810008		
1810009	M	29	3402	3282	3280	3365	3072	3160	6767	6354	6440	-413	86	-327	6.1	-1.3	4.8	29	22	25	-3	5	4	-1	4	3	M	29	1810009		
1810010	F	48	1010	852	740	1840	1635	1350	2850	2487	2090	-363	-397	-760	12.7	15.9	26.6	14	32	32	0	5	5	0	3	4	F	48	1810010		
1810011	F	54	4305	2580	2515	4285	1925	1957	8590	4505	4472	-4085	-33	-4118	47.5	0.7	47.9	26	24	24	0	3	4	1	4	4	F	54	1810011		
1810012	F	57	2100	1252	1875	572	502	387	2672	1754	2262	-918	508	-410	34.3	-28.9	15.3	23	19	8	9	3	5	2	4	3	F	57	1810012		
1810016	F	42	1420	790	522	1325	642	565	2745	1432	1087	-1313	-345	-1658	47.8	24.0	60.4	26	13	3	10	9	14	5	4	3	F	42	1810016		
1810017	F	41	792	772	677	687	332	362	1479	1104	1039	-375	-65	-440	25.3	5.8	29.7	14	20	19	1	6	5	-1	4	3	F	41	1810017		
1810018	M	50	2032	1920	1862	1682	1532	1360	3714	3452	3222	-262	-230	-492	7.0	6.6	13.2	24	22	21	1	5	6	1	4	3	M	50	1810018		
1810021	M	55	3430	3287	3160	3370	3447	3282	7180	6734	6442	-446	-292	-738	6.2	4.3	10.2	20	23	23	0	3	3	0	4	4	M	55	1810021		
1810022	F	53	3347	2920	2960	2072	1570	1600	5419	4490	4560	-929	70	-859	17.1	-1.5	15.8	23	9	9	0	4	7	3	4	3	F	53	1810022		
1810024	F	66	2060	1830	1882	3507	3302	3180	5567	5132	5062	-435	-70	-505	7.8	1.3	9.0	25	21	14	7	4	3	-1	3	2	M	66	1810024		
1811002	F	70	2695	3367	4312	2977	3265	3420	5672	6632	7732	960	1100	2060	-16.9	-16.5	-36.3	8	25	25	0	6	10	4	1	1	F	70	1811002		
1811003	F	53	1650	1267	1035	1752	1302	970	3402	2569	2005	-833	-564	-1397	24.4	21.9	41.0	25	18	11	7	12	12	0	1	2	F	53	1811003		
1811004	F	40	872	1060	722	445	437	447	1317	1497	1169	180	-328	-148	-13.6	21.9	11.2	21	17	15	2	10	14	4	1	1	F	40	1811004		
1811005	M	49	2450	2367	2267	1865	1682	1622	4315	4049	3889	-266	-160	-426	6.1	3.9	9.8	28	26	25	1	4	6	2	2	2	M	49	1811005		
1811006	M	58	1520	1522	1485	2102	2030	2040	3622	3552	3525	-170	-27	-97	1.9	0.7	2.6	27	28	16	12	4	3	-1	2	2	M	58	1811006		
1811007	M	71	3802	3770	3775	4427	4470	4535	8229	8240	8310	11	70	81	-0.1	-0.8	-0.9	28	25	20	5	3	4	1	2	2	M	71	1811007		
1811009	M	65	2367	2205	2062	1940	1915	1762	4307	4120	3824	-187	-296	-483	4.3	7.1	11.2	26	20	20	0	3	3	0	3	2	M	65	1811009		
1811010	F	13	3880	1980	1095	3797	2050	1647	7677	4030	2742	-3647	-1288	-4935	47.5	31.9	64.2	0	0	0	0	7	10	3	3	4	F	13	1811010		
1812001	F	41	1735	1727	1077	602	437	317	2337	2164	2094	-173	-70	-243	7.4	3.2	10.3	23	26	24	2	5	4	-1	1	0	F	41	1812001		
1812002	M	47	4805	5072	5055	4772	5030	4890	9577	10102	9945	525	-157	-368	-5.4	1.5															



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Kim Suji, hearing care specialist, graduated from the Department of Psychology at the University of California, Berkeley.

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