Tinnitus: The Neurophysiological Model and Therapeutic Sound

Background

Tinnitus can be defined as “the perception of sound that results exclusively from activity within the nervous system without any corresponding mechanical, vibratory activity within the cochlea and is not related to external stimulation of any kind” (Jastreboff, 1995) The bulk of evidence indicates that tinnitus arises as a result of discordant hair cell damage when outer hair cells (OHCs) are more damaged than their adjacent inner hair cells (IHCs). OHCs and IHCs provide input to the dorsal cochlear nucleus (DCN). Discordant damage results in imbalanced input to the DCN which generates abnormal high-frequency neural activity within the DCN. This abnormal high-frequency neural activity eventually is perceived by the auditory cortex as sound: tinnitus.

The American Tinnitus Association (REF) reports that 30-50 Americans experience tinnitus: 10-12 million of whom seek medical advice for their tinnitus and approximately 2 million of these are severely debilitated by it. The Neurophysiological Model (Jastreboff, 1990) is the most widely accepted theory of tinnitus generation and disturbance. The Neurophysiological Model provides a framework for understanding the differences in tinnitus experience by positing that once the tinnitus signal is created in the damaged cochlea, specific brain centers engage to generate the actual disturbance of tinnitus. We present a simplified interpretation of the Neurophysiological Model which can be modified for patient counseling purposes.
The “subconscious auditory filter,” or SAF, classifies auditory signals as significant or insignificant. Sounds classified as insignificant are considered unworthy of attention and are minimally noticed; sounds classified as significant are considered worthy of attention and proceed to higher processing centers. Research suggests that the inferior colliculus (IC) may perform this role. Experiments demonstrate that the IC is involved in many functional roles in the auditory system and is metabolically the most active site in the brain. It is considered interface between the lower auditory pathways, the auditory cortex and motor systems. According to Gerken (1996), there is a “convergence of auditory and non-auditory functions at the inferior colliculus. One non-auditory function [is] the initiation of aversive behavioral responses. . .” For people who experience non-bothersome tinnitus, the SAF classified the tinnitus signal as insignificant; in those who experience tinnitus as a disturbing event, the SAF classified the sound as significant. Only when tinnitus is classified as significant is it allowed to proceed to the next higher processing station.

The limbic system assigns emotional reactions to sounds. In the case of tinnitus, a negative emotional reaction is assigned, including anxiety, anger and frustration. Once tinnitus is assigned a negative emotional reaction, it proceeds to the next higher processing station.

The autonomic nervous system assigns physiological reactions to sounds. In the case of tinnitus, a negative physiological reaction is assigned: the fight or flight response. The fight or flight response is a helpful reaction when there is danger and prepares the body to either fight the danger or to run away from it. Increased muscle tension, heart rate, breathing rate and perspiration may occur; furthermore, stress hormones are released (such as cortisol,
norepinephrine, serotonin and neuropeptide Y) which create a state of physiological arousal and alertness.

Finally, the tinnitus signal proceeds to the auditory cortex which processes and further evaluates sounds. In the case of tinnitus, the sound and all of the associated emotional and physical reactions are processed: the tinnitus signal is evaluated as a negative sound and as a negative emotional and physiological event. Because of the downward influence of cortical evaluation on the activity of the limbic and autonomic nervous systems, the emotional and physiological reactions are reinforced and strengthened, resulting in tinnitus-related distress that can interfere with sufferer’s quality of life. Figure 1 provides a simple graphic for this interpretation of the Neurophysiological Model.

Jastreboff and Hazell (2004) also explain how and why the SAF makes significance decisions. The SAF allows us to ignore the vast array of incoming sounds to which we are constantly exposed and to focus on those that “suggest something bad might happen. (p. 44).” After repeated exposure to a sound that is not expected and not understood, negative cortical evaluation and negative limbic and autonomic nervous system reactions can result. Tinnitus sufferers may develop worrisome questions regarding the cause, potential danger and medical significance of this unexpected and misunderstood sound which in turn can result in negative limbic and autonomic nervous system reactions. A reflex is created in which merely perceiving the tinnitus immediately results in fear, anxiety, muscle tension and sleeplessness.
A graphic of this simplified interpretation of the Neurophysiological model is presented in Figure 1. As shown here, a vicious cycle of ever-strengthening limbic and autonomic nervous system activity is created when tinnitus is repeatedly perceived.

**Figure 1.** Simplified Neurophysiological Model demonstrating the vicious cycle of Increasing tinnitus disturbance following repeated exposure to the tinnitus signal.

**Other Processes Affecting Tinnitus Perception**

Other processes likely contribute to the generation of tinnitus and tinnitus disturbance. **Lateral inhibition** is the capacity of an excited neuron to reduce the activity of its neighbors. Firing neurons suppress the stimulation of nearby neurons. The fewer nearby neurons that are stimulated, the more strongly excited neuron responds. As a result, only neurons that are most stimulated and least inhibited will fire. Damaged hair cells reduce neuronal activity which reduces lateral inhibition that propagates through the central auditory system, resulting in an
increase in the firing of neighboring neurons. The auditory cortex may respond to this increased neural activity as it would to normal sound stimulation: tinnitus.

Auditory contrast is the magnitude of the difference between perceived tinnitus loudness and loudness of the ambient sound environment. As Jastreboff and Hazell stated (2004, p. 44), we “react not to the absolute value of a stimulus but to the difference or contrast between stimulus and background,“ In the same way that a lit candle in a dark room appears much brighter than the same lit candle in a well-lit room, tinnitus is perceived as much louder in a reduced-sound environment than in a low-level sound environments.

Internal auditory gain is described as enhanced sensitivity to sound in reduced sound environments. At the level of the cochlea, gain is achieved by mechanical means. At the level of the central auditory system, gain is achieved by automatic enhancement of incoming signals. Internal auditory gain increases naturally when the ambient sound levels diminish and it returns to more normal levels when ambient sound level increases. Because tinnitus often is the only auditory signal present in reduced-sound environments, there is an increase in perceived tinnitus loudness.

Enhanced pattern recognition describes the ability of the auditory system to seek out signals based on specific features which allows for significant soft sounds to be detected in the presence of other louder environmental sounds. Since the SAF already classified tinnitus as significant, the auditory system becomes “tuned” to detect it even in the presence of other competing signals. The resulting constant monitoring of the tinnitus, even in sound-filled
environments, increases the significance of the tinnitus and facilitates further tinnitus-related distress.

**Therapeutic Sound and the Neurophysiologic Model**

*Progressive Tinnitus Management*, or PTM (Henry, Zaugg, Myers, Kendall & Turbin, 2009) emphasizes patient education and the use of therapeutic sound to manage tinnitus disturbance. PTM goals are to help the patient feel less stressed about tinnitus, have fewer emotional reactions to tinnitus, almost never think about tinnitus, feel like tinnitus has little effect on daily activities (concentration, work, sleep, etc.), feel like tinnitus is not much of a problem, and feel like there is no need for further tinnitus help. The specific recommended therapeutic sounds address limbic and autonomic nervous system activity as described by the Neurophysiological Model. The specific use of sound that is most suitable depends on the situation in which the tinnitus is disturbing the patient.

**Background Sound** reduces auditory contrast and is the very definition of environmental sound enrichment. Background Sound decreases the strength of the tinnitus signal as it travels from the ear to the brain. Because the tinnitus signal is not as strong when embedded in Background Sound, activation of the limbic and autonomic nervous systems also is not as strong. Background Sound also restores lateral inhibition and reduces abnormal internal auditory gain. Reduced limbic and autonomic system activity reduces tinnitus-related distress which, in turn, improves quality of life. Examples of Background Sounds are shown in *Figure 2*. 
**Interesting Sound** redirects attention away from tinnitus by addressing selective perception, the process whereby the most attention is paid to sounds that are most important. Because the tinnitus signal has been classified as significant, tinnitus is frequently monitored. Monitoring increases negative emotional and physiological reactions, resulting in frustration, inability to concentrate, greater sleeplessness and reduced quality of life. Interesting Sound impacts tinnitus by reducing the subconscious importance of tinnitus, thereby reducing the negative consequences of constant tinnitus monitoring. Reduced monitoring behavior improves concentration which, in turn, reduces frustration and improves quality of life. Examples of Interesting Sounds are shown in Figure 2.

**Soothing Sound** provides relief from the anxiety, tension and stress that is caused by, or that exacerbates, tinnitus by creating the relaxation response. The fight or flight response is a state of extreme physiological alertness and arousal. The relaxation response is the counterpart of "fight or flight" and returns the body's status to normal. Inducing the relaxation response through Soothing Sound actively fights negative limbic and autonomic nervous system activity created by the tinnitus signal. The body transitions from a state of physiological arousal and alertness to a state of physiological relaxation. Improving the patient’s emotional and physiological status reduces the significance of tinnitus. Reducing the significance of tinnitus improves concentration, which in turn reduces frustration and improves quality of life. Perhaps most importantly, Soothing Sound allows relaxation which improves sleep, resulting in improved concentration while reducing mood swings and irritability.
Two specific types of Soothing Sound which counteract stress and tension are Guided Relaxation and Guided Imagery. In Guided Relaxation, a soothing recorded voice directs the patient through deep breathing exercises. In Guided Imagery, the recorded voice assists the patient in creating a vivid mental image of a safe, relaxing place. Benefits of relaxation include reduced negative limbic and autonomic nervous system activity. By helping decrease anger, anxiety, frustration, and muscle tension and stress, sleep is improved and patients experience greater calmness, happiness and energy. Examples of Soothing Sounds are shown in Figure 2.

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<thead>
<tr>
<th>Interesting Sounds</th>
<th>Background Sounds</th>
<th>Soothing Sounds</th>
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<tr>
<td>Music with Words</td>
<td>White Noise</td>
<td>Instrumental Music</td>
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<tr>
<td>Live Speech</td>
<td>Fan Noise</td>
<td>Nature Sounds</td>
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<td>Face-to-Face Conversation</td>
<td>Ceiling Fan</td>
<td>Wind Chimes</td>
</tr>
<tr>
<td>Telephone Conversation</td>
<td>Box Fan</td>
<td>Storm Sounds</td>
</tr>
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<td>Recorded Speech</td>
<td>Many Soothing Sounds</td>
<td>Ocean waves</td>
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<td>Audio Books</td>
<td>Television</td>
<td>Bird Sounds</td>
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<td>Babbling Brook Sounds</td>
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<td>Internet Resources</td>
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<tr>
<td>Television</td>
<td>Guided Relaxation</td>
<td>Guided Imagery</td>
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**Figure 2.** Examples of Interesting, Background and Soothing Sounds

**Discussion and Conclusions**

Recommending therapeutic sound for tinnitus management is supported by the Neurophysiological Model.
References


