

Chapter 2

Tinnitus Treatment as a Problem Area

Abstract This chapter presents the decision problem area which will be supported with a recommender system technology, that is, tinnitus diagnosis and treatment. It will introduce the problem of tinnitus and next, the successful method of treatment applied by doctor P. Jastreboff. At the end of this chapter major results from the treatment will be showed, along with possible new challenges, which can be handled with the help of information technology.

2.1 Tinnitus

2.1.1 Problem Description

Tinnitus, often described as “ringing in the ears”, is a serious problem affecting a significant portion of population nowadays. According to our medical knowledge, it is important to differentiate between people who “experience” tinnitus from those who suffer because of it. According to some estimations, about 10–20% of general population is affected—in other words—they experience tinnitus—in the USA it accounts to about 25–50 million people) and close to 90% had experienced from at least temporary tinnitus. It is most common in the group age of above 65 years old (tinnitus is reported by about 30% people in this age group). Certain occupational populations are high at risk of developing tinnitus: military personnel, police officers and firefighters, but also patients, who are undergoing ear-related surgery. Soldiers returning from Iraq or Afghanistan who were exposed to a blast noise, are reporting tinnitus in 49% of cases [MLDK10]. This also has financial implications: the American Veteran Administration spent \$ 1.1 billion in 2009 on compensation for tinnitus alone, and it was expected to reach \$2.3 billion by 2014 [MLDK10].

Only about 20% of those experiencing tinnitus, that is about 4–8% of general population suffer because of it—has prolonged tinnitus, moderately or significantly

annoying, causing them to seek help (they are labeled as having clinically significant tinnitus) [JJ00]. In the UK, for example, currently, it affects around 10% of adults, and for about 1% it is so severe so that deteriorates a quality of their life (they have tinnitus with debilitating results [Web15]).

Causes of tinnitus are often not clear. It is associated with hearing loss, ear infections, acoustic neuroma, Menere's syndrome, and aging. It can be also a side-effect of some drugs. There is no cure for it and treatment methodologies prove ineffective in many cases, accompanied by significant side-effects or fail to provide systematic relief to patients. Also methods of treatment that work well for some patients, are not necessary effective for the others (therapies must be highly personalized).

2.1.2 *Medical Background*

The common understanding of tinnitus is a noise in the ears or head, described by the affected, as ringing, buzzing, humming, hissing, the sound of escaping steam, etc. [JJ00]. Tinnitus is more formally defined as “a phantom auditory perception, namely perception of sounds that results exclusively from activity within the nervous system without any corresponding mechanical, vibratory activity within cochlea, and not related to stimulation of any kind” [JH04]. This translates to a real perception of sound, for which there is no corresponding physical correlate. It can be compared to phantom limb and phantom pain phenomena. Tinnitus is often accompanied by decreased sound tolerance, consisting of hyperacusis,¹ misophonia.² Some patients exhibit phonophobia, which is a specific version of misophonia when fear is dominant factor.

Tinnitus-related neuronal activity (labeled in this chapter as tinnitus signal) is perceived as a sound. The tinnitus signal, perceived as a sound, is that of a neural activity somewhere in the brain. It is not exactly known, where in the brain this occurs, but some recent studies have indicated the secondary auditory cortex, as playing an important role in this. In 2015, for the first time, tinnitus signals have been mapped across the brain of a patient undergoing a surgery [Web15]. Previous experiments have been conducted with fMRI technique, which is nevertheless much less precise than recording electrical activity of the brain via electrodes inserted into the cortex. This method is, on the other hand, much more invasive, but in this case the electrodes were used for epilepsy monitoring, from which the patient happened to suffer, along with tinnitus, and on which he was operated.

As Fig. 2.1 shows, the tinnitus the patient is hearing correlates not only with a small area of auditory cortex, but throughout a huge proportion of the brain areas. It

¹Commonly known as “discomfort to sounds”, defined as an abnormally high level of sound induced activity occurring within auditory pathways, due to an abnormal amplification of sound-evoked neural signals [JJ06].

²The phenomenon of an overall negative attitude toward sound. Reflects an abnormally strong reaction of the limbic and autonomous system to sound without abnormally high activation of the auditory system [JJ06].

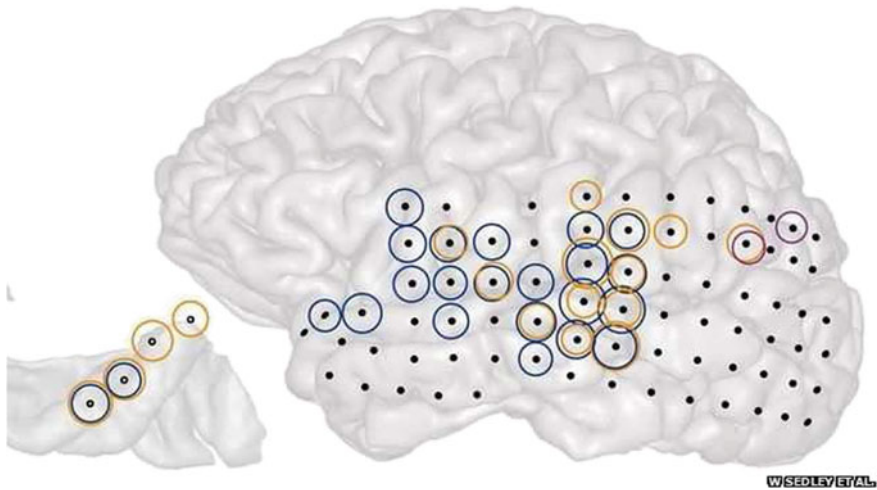


Fig. 2.1 The areas in the brain activity correlating with the heard tinnitus [[Web15](#)]

should, however, be taken into account that the data comes from one tinnitus patient only and the condition can vary.

2.2 Tinnitus Retraining Therapy

Tinnitus Retraining Therapy is a method proposed by Dr. Pawel Jastreboff, which is based on neurophysiological model of tinnitus [[JJ00](#)]. The method proved to have a very high success rate, although TRT does not cure tinnitus (tinnitus perception is still present). Method is based at retraining functional connections between the auditory system and other system in the brain, including limbic and autonomic nervous systems (but not only these two systems).

According to our medical experience [[JJ00](#)] this methodology is not only high-effective, but also does not have side-effects, requires limited amount of time and can be used on all of the patients disregarding etiology of tinnitus.

2.2.1 Neurophysiological Model

The definition of tinnitus proposed by Jastreboff stresses the involvement of a nervous system as a key component responsible for the emergence of tinnitus [[JJ00](#)]. Tinnitus is a result from not only neural activity in the auditory pathways, but as symptoms include anxiety, annoyance, strong emotional reactions, also involves activation of limbic and autonomic nervous systems as well as other systems in the brain. Thus the focus of the problem should be moved from the cochlea to the central nervous system. The first mentioned system—limbic—controls emotions and mood, for example,

fear, thirst, hunger, joy and happiness, as well as motivation behaviors. Furthermore, it activates the second mentioned system-autonomic, which is responsible for basic organism functions, such as breathing, heart rate and hormones (action of glands). The Tinnitus Retraining Therapy is focused on the neurophysiology of these systems. Its main objective is habituation of activation of sympathetic part of the autonomic nervous system and therefore, habituation of negative reactions evoked by tinnitus and subsequently habituation of tinnitus perception occurs, without need for any specific treatment. It removes factors worsening the problem—negative feelings and emotions associated with it. On the other hand, most previous approaches and treatments were focused on removing, or at least decreasing tinnitus perception (tinnitus source), but were not very successful [MLDK10]. For example, one of such methods was based on introducing a medication directly to the cochlea. Other treatments, aiming at suppressing tinnitus perception, included using external sound that could “mask” tinnitus signal or making use of electrical stimulation of the cochlea, auditory nerve or recently even the auditory cortex [MLDK10]. All these methods proved either unsuccessful or only partially successful, low rate of success between 10 and 50%. Tinnitus treatments have high placebo effect which has been shown to be 40%.

Neurophysiology model, as depicted in the Fig.2.2, was developed by Dr. Jastreboff in the 1980s. It stresses the auditory system as secondary only, and other systems in the brain, as dominant in clinically significant tinnitus [JJ00]. According to the model, the generation of tinnitus-related neuronal activity starts in the periphery of the auditory system (the cochlea, auditory nerve). The detection occurs in the subcortical auditory centers, and the perception (or interpretation)—at cortical areas. The confirmation for that is a study presented in [Web15] (see Fig. 2.1). It shows that different areas of brain are activated before the tinnitus signal reaches the level of conscious perception. The process of detection is accompanied by the sustained activation of the limbic (emotional) and autonomous nervous system. The last occurs only when a person concurrently experiences negative emotions (anxiety, psychoso-

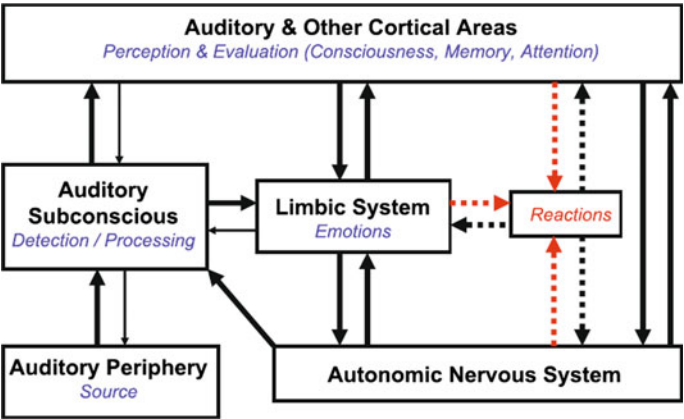


Fig. 2.2 The neurophysiological model of tinnitus [MLDK10]

matic reactions, annoyance) with their tinnitus. It is the factor causing distress and consequently, clinically relevant tinnitus. The patients with abnormally activation of limbic and autonomous systems experience stress, anxiety, loss of well-being leading them to greater annoyance with their tinnitus. Feedback loops connecting the auditory, limbic and autonomic nervous systems (see Fig. 2.2) are getting stronger, and patients continue to get worse [JJ00]. The creation and sustaining of connections between those systems are governed by the rules of conditioned reflexes (they link sensory stimulus with reaction) [JJ06]. The tinnitus signal in the auditory pathways acts as a conditioning stimulus, which via one or more reflex arc, activates the limbic and autonomous nervous systems and thus evokes negative reactions [MLDK10]. The increase in annoyance and anxiety also depends on patient's psychological profile, their association of tinnitus with something negative and not the psychoacoustic characteristic of the perceived sound of the tinnitus. In contrary, in case of hyperacusis, the reaction depends solely on the physical characteristics of a bothersome sound (such as its energy and frequency spectrum) [MLDK10]. In misophonia, on the other hand, adverse reactions occur due to specific patterns of sound. Most individuals with tinnitus experience just a sound sensation, but a part of them have negative reactions evoked by tinnitus. In the severe cases, patients may no longer enjoy any activities previously pleasant to them, which in turn may lead to depression. Patients who experienced "negative counseling" (that is statements such as "nothing can be done"; "you will have to learn to live with it"; "you have a bad brain") can further develop negative associations of their tinnitus, which triggers the development of a vicious cycle. "Negative counseling" is an example of reinforcement that creates conditioned reflex, which, in turns, creates physiological and behavioral reactions. Another common scenario of creating conditioned reflex is that, when a person experiences a strong emotionally negative stress situation, such as during retirement or divorce.

2.2.2 *Habituation*

According to Dr. Jastreboff, the presented neurophysiology model offers an approach to treat tinnitus [JJ00]. Though there is no cure for the source of tinnitus, the brain exhibits a high level of plasticity. Doctor claims that it is possible to induce habituation of tinnitus by interfering with tinnitus-related neuronal activity above its source. He proposes blocking the spread of the tinnitus signal to other than auditory regions of the brain, particularly to the limbic and autonomous nervous systems. It means that such successfully treated person will still perceive their tinnitus, but it will not bother them [MLDK10]. This is what is called 'habituation' of reactions, and is based on the principle that every conditioned reflex can be extinguished (retrained), when the reinforcement is not given (i.e., passive extinction of conditioned reflexes) or when positive reinforcement is associated with stimulus (i.e., active extinction of conditioned reflexes) and the reaction previously evoked by sensory stimulus can be abolished or modified [JJ06]. Habituation is a fundamental property of the brain function resulting from the fact, that the brain cannot handle more than one conscious task at a time (for example listening to two people talking at the same time). It

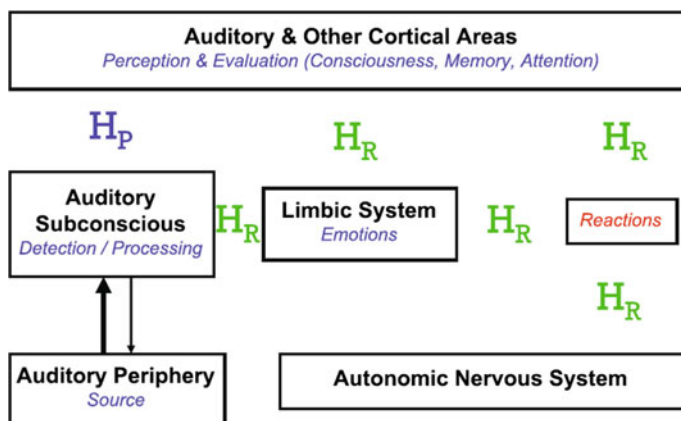


Fig. 2.3 The illustration of habituation of reactions (HR) and perception (HP) [MLDK10]

selects and blocks signals at a subconscious level on the basis of previous experience. Retraining/extinction of conditioned reflexes cannot be done on the cognitive level.

Habituation of tinnitus based on neurophysiologic model (Fig. 2.3) has two main goals: to habituate reactions of the limbic and autonomous nervous systems (to block tinnitus-related neural activity from reaching these systems) and to habituate perception (to block tinnitus-related neural activity before reaching the level of awareness). The first goal aims at relieving patients from negative reactions of their brain and the body associated with tinnitus. Counseling should be performed individually (tailored to individual needs), not as a group therapy. The final goal of the treatment, is that tinnitus ceases to have an impact on the patient's life.

Habituation is achieved by a variety of methods, including counseling and sound therapy. In order to be called Tinnitus Retraining Therapy, the treatment must involve both counseling and sound therapy (which involves providing the auditory system with enriched stimulation to decrease the contrast between tinnitus-related and background neuronal activity and consequently decreasing the strength of tinnitus signal). The classical approach for an extinction of conditional reflex would be to expose the subject to the same signal (tinnitus), while removing reinforcement. As tinnitus-related signals cannot be manipulated directly, another method is to decrease both the tinnitus signal (by sound therapy) and reinforcement (by reclassifying tinnitus to neutral stimuli—counseling) at the same time.

2.3 Treatment Protocol

The treatment protocol within TRT is composed of several steps:

- the initial appointment,
- audiological evaluation,
- medical evaluation,

- diagnosis with decision as for treatment,
- counseling.

The initial contact with a patient is made through a form (see Appendix A), which is then further expanded by an interview. The interview helps in identifying resulting problems, determining the impact of tinnitus on the patient's life and assessing the level of emotional distress. The audiological evaluation is performed starting with an otoscopic examination of the ear canal and tympanic membrane and a series of hearing tests, from which the most important outcomes are audiogram and LDL (loudness discomfort level). The medical evaluation of the patients aims, in the first place, at excluding any known medical condition that has tinnitus as one of its symptoms (the most common such conditions are: acoustic neuroma, Meniere's disease and otosclerosis).

2.3.1 Patient Categories

After the evaluation, a patient is placed into one of five categories, based on four factors (Table 2.1):

- the extent of impact tinnitus has on one's life (reflecting the strength of functional connections between the auditory system and the limbic and autonomous nervous systems),
- patient's subjective perception of hearing loss,
- presence or absence of hyperacusis (increased sensitivity to sounds),
- prolonged worsening of hyperacusis and/or tinnitus following exposure to moderate or loud sounds.

Category 0

Denotes patients with neither hyperacusis nor significant hearing loss, and whose tinnitus has little impact on their lives. In these cases, counseling sessions are sufficient and there is no need for any instrumentation.

Category 1

Patients (the most common category) have significant tinnitus, but without hyperacusis and hearing loss. They are treated, besides full counseling, with the use of sound generators set at the level close to "mixing" or "blending" point.³

³The level where partial suppression ("partial masking") starts to occur [MLDK10].

Table 2.1 Determining categories of tinnitus patients [JJ00]

Category	Hyperacusis	Prolonged sound-induced exacerbation	Subjective hearing loss	Impact on life	Treatment
0	–	–	–	Low	Counseling only
1	–	–	–	High	Sound generator set at mixing point
2	–	–	Present	High	Hearing aid with stress on enrichment of the auditory background
3	Present	–	Not relevant	High	Sound generators set above threshold of hearing
4	Present	Present	Not relevant	High	Sound generators set at threshold; very slow increase of sound level

Category 2

Consists of patients with the characteristics of *Category 1*, but additionally significant subjective hearing loss. These are advised to wear hearing aids, while enriching their sound environment. Currently, due to changes in hearing aids industry, the combination instruments (hearing aid and sound generators in one shell) become widely available and are predominant devices used for this category of patients.

Category 3

This category is used for patients with a significant hyperacusis that is not enhanced for a prolonged period of time. Sound generators are recommended for treating these patients. The sound level should be set below a level which would induce discomfort.

Category 4

This category denotes patients who have tinnitus and hyperacusis that is getting worse, when exposed to the sound. This category is the most difficult to treat. In this case, the sound generators, used in the treatment, are set to the threshold of hearing. As the treatment progresses, the sound level is increased slowly.

2.4 Motivation for RS Project

In summary, the TRT proves to be a very effective method, for both tinnitus and hyperacusis, and provides many other benefits [JJ00]:

- can be used to treat all patients,
- does not require frequent visits,
- does not interfere with hearing,
- there are no negative side-effects.

For majority of patients treated with this method, tinnitus constituted no longer a problem in their lives.

2.4.1 *Treatment Results*

TRT works independent of the cause of the tinnitus and can be successfully used for any type of tinnitus. The neurophysiological model of tinnitus has been proved in practice by results of clinical studies [MLDK10]. Many studies have been published on the effect of TRT, including systematic clinical trials and showed improvement in over 80% of the patients, and what is more, the improvement has proved to be persistent.

The treatment requires a significant amount of time (from 9 to 24 months) to provide steady development of plastic changes in the nervous system (habituation of tinnitus). It still does not guarantee 100% success rate. For the treatment to be effective it is necessary to retrain the feedback loops formed between the auditory, limbic and autonomous systems during consecutive follow-up visits. As a result, habituation decreases the strength of those connections. Patients are asked to assess their tinnitus awareness, annoyance and effect on life on a scale of 0–10 before and after treatment, as well as after each visit. The changes can be observed by comparing the initial form with the follow-up forms (see Appendices A and B). According to our medical expertise, the process of habituation is slow and characterized by fluctuations. Patients experience temporary tinnitus relief (due to partial habituation), but when it returns to its previous state, they perceive it as worsening. Initial improvement can be seen within few months, then follows the constant, gradual improvement. Clearer results can be seen on average after 3 months of therapy, but the doctor recommends

that the treatment lasts at least 9 months. Doctor Jastreboff reported the effects of treatment on sample of 263 patients [JJ00]. About 90% of them received instruments (82.5% sound generators and 7.6% hearing aids). 9.9% received one session of counseling (and did not typically follow TRT). Results obtained from treatment on the patients revealed that 75% of them reported significant improvement. And the results (80%) were even more optimistic for patients who also were prescribed noise generators or hearing aids. On the average, the values for awareness, annoyance and life impact metrics decreased by half in comparison to their pre-treatment values. Also the patients from Categories 3 and 4 (that is those, who also suffered from hyperacusis) showed even greater improvement than patients with tinnitus only (categories 1 and 2). The method provided steady improvement after even after 3 or 5 years from ending the treatment [JJ06].

However, we must remember, that TRT is not a cure, but a treatment that allows patients to control their tinnitus and thus live a normal life and participate in everyday activities. TRT has been used clinically since 1988 and underwent many modifications since its first description. The method has not a stagnant protocol, but continues to evolve on the basis of information gathered from both treatment of patients and animal search findings [MLDK10].

2.4.2 Patient Dataset

The progress of treatment with Tinnitus Retraining Therapy (habituation of tinnitus) was monitored and collected in Tinnitus and Hyperacusis Center at Emory University School of Medicine. Original sample of 555 patients, described by forms during initial or follow-up visits, collected by Dr. Jastreboff, was used. Additionally, the Tinnitus Handicap Inventory (see Appendix C) was administered to individuals during their visits to the Center. The second database was extended to 758 patients [Tho11] (not made available), containing also a new form called *Tinnitus Functional Index*, or TFI, in shortcut. These databases, consisting of tuples identified with patient and visit numbers, have been developed over years by inserting patients' information from paper forms (developed by Dr. Jastreboff).

2.4.3 Problems with Human Approach

There remain some challenges in using the method with human approach. Evaluating results of tinnitus treatment is a challenge itself, because there exists no objective method for detecting the presence, the extent and severity of tinnitus, and there is also a high level of "placebo effect" [JJ06]. Furthermore, the methodology has to be highly individualized to specific patient's profile and needs, sound generators must generate sounds that would not cause annoyance for a particular patient. Besides, it is often not clear, why particular technique proved to be successful in one case,

while not in another case. The evaluation of any tinnitus treatment outcome is based on subjective evaluation of the problem. As a result of it, this treatment requires a lot of time and involvement from the personnel side, who has to be also specifically trained. Taking into account time restrictions in today's medical practice and the need for more efficient evaluation of different treatment methods, a proposal to develop a decision support tool besides forms, seems encouraging. It could also potentially provide more precision and objectivity, when dealing with tinnitus problem.

TRT is a complex treatment process, which generates a high volume of matrix data over time: some attributes have relatively stable values while others may be subject to change as the doctors are tuning the treatment parameters while symptoms of patients are altering [ZRJT10]. The medical dataset is sparse and has large volumes of missing variables for each patient. Many important clinical conditions are also poorly understood and associated with complex, multi-factorial conditions. Taking into account the requirement for making personalized recommendations and care to patients, the proposed computer-assisted treatment approach seems promising. Modern computing techniques, including machine learning, intelligent data analysis and recommender systems technologies, provide a new promising way to better understand, further improve and support the treatment. Understanding the relationships between patterns among treatment factors would help to optimize the treatment process.

Decision Support System for Diagnosis and Treatment
of Hearing Disorders

The Case of Tinnitus

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