Chapter 1
Introduction

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Keywords Tinnitus • Objective tinnitus • Subjective tinnitus • Impact of tinnitus • Treatment • Neural plasticity • Hyperacusis • Phonophobia

Abbreviations

CNS	Central nervous system
EEG	Electroencephalography
PAG	Periaquaductal gray

Introduction

Tinnitus can affect the entire life of an individual, can prevent intellectual work, and impair the quality of life in general; in some instances, tinnitus can cause suicide. Severe tinnitus is often accompanied by hyperacusis and affective disorders such as phonophobia and depression.

Tinnitus and auditory hallucinations are perceptions of sounds in the absence of external noise. Subjective tinnitus and hallucinations are phantom sounds. Tinnitus is different from hallucinations and objective tinnitus that is caused by sounds generated in the body and conducted to the ear. Tinnitus is hearing of meaningless sounds. Hallucinations consist of meaningful sounds such as music or speech and occur in schizophrenia, after intake of certain drugs, and it may occur (rarely) in temporal lobe disorders. This book will not cover hallucinations.

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There are two main kinds of tinnitus, namely, objective and subjective tinnitus. Objective tinnitus is caused by sounds generated in the body and conducted to the ear. It may be caused by turbulence of blood flow or muscle contractions. Individuals with subjective tinnitus have no visible signs of disease, and the disease has few detectable physical correlates. Objective tinnitus may be detected by an observer using auscultation, whereas subjective tinnitus can only be observed by the person who has the tinnitus.

Subjective tinnitus can have many forms: it can be high frequency sounds similar to the sounds of crickets, like a high- or low-frequency tone, and constant or pulsatile. Tinnitus can be present at all times or can appear only sometimes. However, it is usually not possible to relate a specific event to the appearance of tinnitus.

Patients' description of their symptoms is the only cue, and this may be misleading because they point to the ear, which is rarely the site of the pathology. It is abnormal neural activity in the brain that causes subjective tinnitus. This abnormal neural activity may originate in the ear but it is more likely generated somewhere in the brain.

There are two ways in which abnormal neural activity that may be interpreted as a sound can occur in the brain. One is through neural activity in the periphery of the auditory system that emulates the activity elicited by sound, which reaches the ear. The other way is through abnormal neural activity generated somewhere in the ascending auditory pathways. The way the neural activity that causes tinnitus is generated is not known in detail, but recent studies indicate that the activity is different from that elicited by sound stimulation, which means that the different forms of tinnitus may be generated in different ways.

There is evidence that tinnitus, after some time (chronic tinnitus), becomes fundamentally different

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from acute tinnitus. This change over time is important for treatment of tinnitus, and there is evidence that treatments are less effective after tinnitus has persisted for more than 5 years [1].

Tinnitus is not perceived in the same way as normal physical sounds, and there are indications that the way tinnitus is perceived has to do with perception of "self" (see Chap. 73) [2].

It is not known where in the nervous system sensory activation reaches conscious awareness, and neural activity in other parts of the CNS than that of normal sounds may give rise to the tinnitus sensation. It is not known what features of neural activity are important for eliciting awareness of a sensory signal, and even less is known about which kind of neural activity causes awareness of tinnitus (see Chap. 10) [3].

Contemporary understanding of which qualities of neural activity gives awareness of sensory stimulation includes neural synchrony, coherence of activity in many neurons in cortical or other structures, and neural connectivity. There is considerable evidence that activation of neural plasticity plays an important role in many forms of tinnitus (see Chap. 12). These characteristics of tinnitus have similarities with equally variant forms of pain. In particular, central neuropathic pain has many similarities with severe tinnitus, as will be discussed in this book (Chap. 14). Tinnitus and neuropathic pain are typical examples of "plasticity disorders" [4], where the symptoms are caused by plastic changes that are not beneficial to an individual person.

Sensory awareness and affective reactions (distress) are probably caused by different kinds of neural activity and probably occur in different parts of the CNS.

Such separation of perception is known for pain, where the lateral tract of the spinothalamic system produces awareness while the medial system produces the affective and emotional reaction to pain and activates distress networks.

More recently, some abnormal physiological signs have been found to be abnormal in individuals with some forms of tinnitus. One abnormality is with regard to the high-frequency component of electroencephalographic (EEG) recordings, known as gamma activity (see Chap. 21). The amplitude of the gamma activity is increased while the amplitude of another common component of the EEG, the alpha activity, is decreased (see Chap. 17). Animal experiments have shown that some forms of evoked potentials are altered (often increased) after exposure to sounds of an intensity that in humans causes tinnitus, and which has shown signs of hyperactivity in recordings from specific nuclei [5, 6].

The signs of tinnitus at a local anatomical level are often different from those of a global brain level, and there are indications that non-auditory regions of the brain are activated abnormally in some forms of subjective tinnitus (see Chap. 17) [7]. Many different parts of the CNS are involved with tinnitus and there is evidence that parts that normally are not activated by sounds may also be involved in generating the sensation of tinnitus (see Chap. 73).

Also, animal experiments have shown evidence of non-auditory structures, for example, the hippocampus, being involved [8, 9]. Studies in humans have shown evidence of involvement of limbic structures [10]. Other studies have indicated that nonclassical pathways are abnormally involved in some forms of tinnitus [11, 12].

The degree and the impact of tinnitus on an individual person vary widely for the different kinds of tinnitus and also from person to person. It often fluctuates over time and with differing circumstances. Tinnitus is common, but only in a relatively few individuals does it cause distress or other problems. Many people who do not have tinnitus under normal environmental circumstances will experience tinnitus when placed in a room that is silent, such as the test rooms used for audiological testing.

Tinnitus is a phantom sensation of different kinds of sounds, but rarely are these sounds comparable with natural sounds or even with sounds that can be synthesized electronically.

Different methods have been used to estimate the intensity (loudness) of tinnitus. Visual analog scales have been used to estimate the strength of tinnitus, but methods such as loudness balance often give results that are unrealistically low [13]. The results of loudness matching show that most forms of tinnitus have loudness in the range of 20 dB even in situations where the tinnitus is regarded to be unbearable.

The effect of tinnitus on an individual person varies, and the degree of annoyance is not directly related to the perception of tinnitus. Like the impact of severe pain depends on whether it is regarded to be escapable or inescapable, also the impact of tinnitus on a person's quality of life largely varies. Studies have indicated that inescapable and escapable pain involved different lamina of the PAG [14] and the hypothalamic–midbrain neural circuits [15].

While tinnitus is described as a sound, similar sensations cannot be evoked by sound stimulation and it is assumed that the neural activity that causes tinnitus is different from that evoked by sound stimulation. The abnormal neural activity that causes tinnitus cannot be detected by imaging methods that are available. Some physiological methods can provide some insight in abnormal neural activity, but most of these methods are restricted to use in animals.

Tinnitus, especially severe tinnitus, is often accompanied by abnormal perception of (physical) sounds such as hyperacusis (lowered tolerance for all kinds of sounds) (see Chap. 3) and phonophobia (fear of sound). Hyperacusis also occurs in connection with other diseases such as autism.

In some individuals, tinnitus is associated with distress of affective (emotional) symptoms. These two qualities, perception and distress, are caused by activation of different parts of the nervous system. This is similar to pain where the lateral spinothalamic system is engaged in the perception of pain, whereas the medial spinothalamic system mediates the distress or affective component of pain. Animal experiments have indicated that pain that is perceived as escapable involves anatomically different parts of the periaquaductal gray (PAG) than pain that is perceived as inescapable. It is not known if there are similarities regarding tinnitus.

It is particularly true that when limbic structures (the emotional brain) become activated, tinnitus becomes a problem [2] (see Chaps. 10 and 73).

Treatment of Tinnitus

Subjective tinnitus is the most challenging of common disorders of hearing. So far, the available forms of treatment have had little to moderate success. Many different treatments are in use and even more have been tried and discarded. Often the goal of treatment of severe tinnitus has been to eliminate the symptoms, but this is rarely achieved. However, it is often possible to reduce some of the effects of the tinnitus, so that a patient gains quality of life and would perhaps be able to work in spite of the remaining effects of the disorder. This means that it is often possible to gain quality of life for the patient by such management of the tinnitus. Setting the goal to eliminate tinnitus will often make the patient disappointed when this goal is not met, and the patient may try to find another treatment option, which most likely will be equally disappointing.

There are no known objective tests that can determine the severity of tinnitus and even detect whether tinnitus is present or not. Treatment must therefore rely on the patient's own assessment of his/her tinnitus. Some functional abnormalities have been detected in some individuals with tinnitus using functional imaging methods that can relate the abnormalities to specific brain regions. However, these methods are still in development and are not yet available for general clinical diagnosis of tinnitus.

Research on tinnitus has lagged behind similar disorders such as pain. There are two kinds of sound perception that are not caused by sounds reaching the ear from outside the body: tinnitus and auditory hallucinations.

Tinnitus Can Occur Together with Other Diseases

Tinnitus may occur together as one of the symptoms of a specific disease, such as Ménière's disease (see Chaps. 38 and 60), where tinnitus is one of the three (or four) symptoms that define the disease (the others are paroxysmal vertigo and fluctuating low-frequency hearing loss). Vestibular schwannoma are almost always accompanied by tinnitus (see Chap. 39). Individuals with Wilson's disease often have tinnitus. Tinnitus is often one of the symptoms of intracranial hypotension [16]. Traumatic injuries to the auditory nerve often result in tinnitus. Down's syndrome may also be associated with a higher incidence of tinnitus than non-Down's syndrome individuals. It has been reported that autistic individuals have an abnormal perception of loudness [17], but little is known about tinnitus.

Many conditions have tinnitus as part of their symptoms; most noticeable are Ménière's disease and vestibular schwannoma.

Tinnitus is often associated with hearing loss of various kinds, but hearing loss also occurs without tinnitus. Individuals with tinnitus often have hearing loss, but tinnitus may also occur, although rarely, in individuals with normal or near-normal hearing. In a study by Friedland and co-authors [18], a correlation was found between low-frequency hearing loss and

risk of cardiovascular diseases. These investigators found that the shape of a person's audiogram correlated strongly with cardiovascular changes and peripheral arterial disease. Hypertension has been found to be associated with a lower incidence of tinnitus, as compared to normotension and hypotension [19].

Tinnitus often occurs after head injuries. Injury to the auditory nerve, which may occur from surgical manipulation or head trauma, often results in tinnitus. Blast injuries, such as those occurring in recent wars, result in a high incidence of tinnitus in connection with closed head injuries.

Tinnitus is more prevalent at old age, but results of epidemiologic studies vary widely, mainly because the criteria for tinnitus chosen in the different studies have been different. Most studies have concerned people who have sought professional help for their tinnitus.

Tinnitus may occur after exposure to loud noise and as complication in treatment with certain drugs such as some antibiotics (ototoxic antibiotics), aspirin, idometacin, and diuretic (furosemide) quinine (see Chap. 42).

Tinnitus often occurs together with depression [20], and it is often said that depression is a co-morbidity to tinnitus. However, it could also be possible that the physiological abnormalities that cause tinnitus are similar or that tinnitus and depression have the same risk factors. Misophonia (dislike of specific sound) may occur together with tinnitus or alone. The "exploding head syndrome" may also occur with tinnitus or alone (see Chap. 4).

Plastic Changes in the Brain Can Cause Tinnitus

Tinnitus is regarded to be a complex hyperactive disease, or rather tinnitus is a symptom with complex causes that indicate hyperactive neural activity. There is evidence that the neural activity that causes at least some forms of tinnitus is different from that evoked by sound. Earlier it was assumed that tinnitus was caused by increased firing rate of neurons occurring without sensory input. Recent studies indicate that other forms of abnormal activity somewhere in the nervous system, in particular how neural activity in populations of nerve cells are inter-related, may be the cause of some forms of tinnitus. Evidence has been presented that abnormal synchrony and temporal coherence of the activity in populations of neurons may be the important factors for causing tinnitus [21, 22]. Activation of the nervous systems with temporal (periodic or non-periodic) signals, such as those occurring from sensory stimulation with sounds, creates coherence in the neural activity in a population of neurons because many neurons are activated by the same source. There are reasons to believe abnormal communications between nerve fibers or nerve cells (ephaptic transmission) may be involved in creating an abnormally high degree of temporal coherence of neural activity without any physical sensory input (see Chaps. 10 and 13).

There is considerable evidence that activation of neural plasticity plays an important role in many forms of tinnitus (see Chap. 12). Activation of neural plasticity can alter the connectivity in the brain by unmasking dormant synapses. This is another factor that may be involved in some forms of tinnitus. There is also some evidence that the anatomically located regions activated in tinnitus are different from those that are activated by sound. There are indications that the neural activity that causes the awareness (conscious perception) of tinnitus is different from that which causes the affective (distress) reactions. Such separation in processing of sounds that represent different kinds of information may be similar to the separation of different kinds of sensory signals described as stream segregation. The separation processing that leads to conscious perception and the processing that causes distress may indicate that these occur in different parts of the thalamus: the ventral part for processing of awareness and the medial and dorsal parts for the activity that causes affective symptoms. The dorsal and medial thalamus has subcortical connections to the amygdala. All these forms of changes in the function of the nervous system have few or no detectable morphological correlates.

Many aspects of tinnitus that have lasted a long time (e.g., more than 5 years) are different from tinnitus that has only lasted a short time (less than 5 years). Perhaps most important, tinnitus that has lasted a long time is more difficult to treat than tinnitus that has only lasted a short time [1].

Impact of Tinnitus on an Individual Person

The degree and the impact on an individual person from tinnitus vary widely from person to person and often vary over time. Only rarely has it been possible to relate the character and the severity to events or specific diseases.

There are no objective tests that can determine the existence of tinnitus nor is it possible to evaluate the severity of tinnitus by any known test. The lack of objective tests may sometimes set the patients' description into question. The cause (meaning what caused the tinnitus to start) is often elusive. Only rarely has it been possible to relate the character and the severity to events or specific diseases.

The lack of objective signs to classify tinnitus according to severity has affected attempts to study the epidemiology of tinnitus. This is probably the most important reason why different studies typically show different incidence and prevalence values.

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