1

Introduction

Tinnitus is a symptom recognized for thousands of years. However, most definitions presently in use are neither sufficiently specific nor physiological in basis. Many definitions include objective sounds originating in the head and neck areas (*somatosounds*) and auditory hallucinations. This has frequently misdirected research clinical approaches. A definition of tinnitus as an auditory phantom perception was proposed in the early 1990s (Jastreboff, 1990, 1995); it is discussed here and used throughout this book. Decreased sound tolerance and its components hyperacusis and misophonia are defined and discussed. They frequently accompany tinnitus, similarly to hearing loss, but they do not have significant recognition in the literature.

1.1 Definitions of tinnitus

1.1.1 Commonly used definitions of tinnitus

Tinnitus is defined by the American National Standards Institute (ANSI, 1969) as "the sensation of sound without external stimulation." Another common description was proposed in the Committee on Hearing, Bioacoustics and Biomechanics (CHABA) report *Tinnitus Facts, Theories, and Treatments*, which defines tinnitus as "the conscious experience of sound that originates in the head" (McFadden, 1982). Both definitions include the auditory hallucinations of schizophrenia, a variety of somatosounds such as palatal myoclonus, abnormal opening or patency of the eustachian tube, temporomandibular joint disease, spontaneous otoacoustic emissions and sounds (bruits) of vascular origin (see Ch. 6; Champlin, Muller & Mitchell, 1990; Harris, Brismar & Cronqvist, 1979; Hazell, 1990b; Hentzer, 1968; Jastreboff, Gray & Mattox, 1998; McFadden, 1982) as well as sensation resulting from a malfunction of the cochlea or auditory nerve (Jastreboff, 1990; Moller, 1984). Obviously, this broad definition invites a discussion of many different phenomena unrelated to tinnitus problems. Traditional definition of tinnitus as any sound generated within the head, without regard for underlying mechanism(s) or possible origin, invites discussion of phenomena unrelated to tinnitus problems and promotes categorization of tinnitus by symptoms alone.

Traditional definition of tinnitus as any sound generated within the head, without regard for the underlying mechanism(s) or possible origin, invites discussion of phenomena unrelated to tinnitus problems and promotes categorization of tinnitus by symptoms alone.

In the past tinnitus has been classified by various divisions, such as subjective/objective and peripheral/central tinnitus (McFadden, 1982). However, these categories were not clearly defined, and they involved significant overlap. Let us look at the most common division into *subjective* and *objective* tinnitus. Objective tinnitus (or some component of it) could be heard by an observer, and subjective tinnitus was heard by the sufferer alone. With better knowledge of the auditory system and better measurement techniques, some cases of tinnitus previously considered to be subjective can now be measured in an objective manner and heard after appropriate processing and amplification, for example patients with spontaneous otoacoustic emissions. These cases therefore become objective or at least have an objective component.

Another problem is that, while so-called objective tinnitus may be strongly associated with an audible generator, nevertheless, the perception resulting from such a source may be quite different, and in some cases not even detected by the owner. Certain spontaneous otoacoustic emissions can be detected by an external observer but are not perceived by the person generating them. It is impossible to predict if a given spontaneous otoacoustic emission is perceived or not, and a complex psychoacoustical approach is needed to associate spontaneous otoacoustic emission with perception of a sound (Penner, 1992; Penner & Burns, 1987). Classification into objective/subjective tinnitus is completely dependent on the sensitivity of the methods used to detect the somatosounds.

The definition proposed in the CHABA report results in a paradox. If it is understood as referring to sound originating in the head, then the majority of tinnitus cases would be excluded since there is no sound that can be detected. If the definition is understood as referring to the perception originating in the head, then all external and internal sounds would be included since all perception occurs in the head. While this definition attempts to restrict the origin of the sound to the head of the owner, it includes both real sounds, which can be detected by an external observer (somatosounds), and hallucinations related to schizophrenia, in addition to tinnitus. The sound perception generated by cochlear implants would also need to be included.

Other definitions were equally broad and not very precise. For example, the definition proposed during the CIBA symposium on tinnitus in 1981 stated, "The sensation of sound not brought about by simultaneously applied mechano-acoustic or electrical signals" (anon., 1981a) and, therefore, includes somatosounds generated anywhere in the whole body.

Another definition "Tinnitus is an aberrant perception of sound reported by a patient that is unrelated to an external source of stimulation" (Shulman, 1988) is similar to the previous one, with the additional assumption that tinnitus perception is abnormal. This is contradicted by the fact that tinnitus can be induced in 94% of the population by a few minutes of sound deprivation (Heller & Bergman, 1953).

Berrios *et al.*, have chosen a different approach and defined tinnitus as a formless hallucination (Berrios, 1991; Berrios & Rose, 1992). They pointed out that tinnitus belongs to the physiological/medical otological field rather than the psychological/psychiatric area. During the twentieth century, the subject has been passed from psychiatry to otolaryngology (where it was known as *tinnitus aurium* – tinnitus of the ear) and back several times. However, none of the models of tinnitus developed by surgeons, or psychiatrists, was successful in helping the patient. One difficulty in achieving agreement regarding the mechanisms of tinnitus and its definition might be the bias towards the hallucinatory type of phantom perception, more frequently encountered by psychiatrists, as opposed to the simpler (tonal or noise-like) perceptions seen by otolaryngologists. The labeling of tinnitus as either tinnitus aurium or hallucination had a powerful impact on thinking about mechanisms of tinnitus and was responsible in large part for the past approaches to treatment.

As a consequence of traditional definitions of tinnitus as any sound generated within the head, classifications were based on lists of mutually exclusive types of tinnitus with clear separation of their boundaries, for example eustachian tube tinnitus, palatal tinnitus, stapedial tinnitus, 8 kHz hearing loss tinnitus, Ménière's tinnitus, VIII nerve tinnitus, vestibular schwannoma tinnitus, cochlear nuclei tinnitus, vascular compression tinnitus, caffeine tinnitus, presbycusis tinnitus, etc. This approach creates complex, multilevel definitions that frequently require redefining as we increase our knowledge of the functioning of the auditory system and the brain.

1.1.2 Tinnitus as a phantom perception

The proposed new definition of tinnitus used here restricts the use of the word tinnitus to one unique phenomenon: a phantom auditory perception (Jastreboff, 1990, 1995). The definition is "The perception of sound that results exclusively from activity within the nervous system without any corresponding mechanical, vibratory activity within the cochlea, and not related to external stimulation of any kind" (Jastreboff, 1995). If there is a vibratory component in the cochlea, which can be related to the perception of sound, it is categorized as a *somatosound* (Jastreboff & Jastreboff, 2003a).

Tinnitus is the perception of sound that results exclusively from activity within the nervous system without any corresponding mechanical, vibratory activity within the cochlea, and not related to external stimulation of any kind.

From a historical perspective it is quite interesting that the above definition of tinnitus is the exact opposite of the first scientific attempt proposed in 1683 by Duverney to define tinnitus as "True," perceived by external observer, and "False," heard only by the subject (Stephens, 1984).

1.1.3 Justification of proposed definition

The proposed definition is based on several lines of evidence. One comes from the dissimilarity of tinnitus perception from the perception of external sounds. The results of psychoacoustical evaluation (audiometric testing) of tinnitus patients show that they perceive tinnitus as a sound completely different from anything previously experienced in their external environment. Hazell used a music synthesizer in an attempt to match tinnitus perception in 200 patients (Hazell, 1981). Although near matches were achieved, it was never possible to imitate the tinnitus sound the patient heard exactly. This finding was later confirmed by a careful research study (Penner, 1993). Subjects in this study were attempting to resynthesize their tinnitus and complex external sounds using combinations of pure tones with varying frequency, amplitude and phase. This study fully confirmed Hazell's finding of the inability to match tinnitus perfectly with any combination of external tones. Notably, using the same technique, Penner achieved perfect matching of complex external sound by a combination of pure tones. These results indicate that tinnitus patients perceive tinnitus as a sound completely different from anything previously experienced in their external environment.

Tinnitus patients perceive tinnitus as a sound completely different from anything previously experienced in their external environment.

If tinnitus has a vibratory correlate in the cochlea then suppression of its perception should follow the rules of acoustical masking. The psychoacoustical masking of sound is defined as "the amount by which the threshold of audibility for one sound is raised by the presence of another (masking) sound" (Moore, 1995). Masking is commonly understood as the total disappearance of perception of a sound owing to the presence of a masking sound. Pure tones of varying frequency and intensity are used to characterize the properties of masking. Two tones (one that is masked, and the other acting as masker) have to be within a certain frequency range, which is referred to as a critical band, for masking to occur. The critical band is defined as a narrow band of frequencies surrounding the masked tone contributing to the

masking of the tone (Moore, 1995). Predominant opinion is that the masking results from mechanical interaction of the vibration of two adjacent parts of the basilar membrane in the cochlea. Two tones that are separated by more than the critical band width cannot mask each other, however loud the masker. When the masking tone is within the range of the critical band, the frequency distance of one tone from the other determines the extent of the increase in a threshold of detection of the masked tone in the presence of the second (masker), with stronger masking occurring when the tones are closer. As a result, there is a V-shaped masking curve of intensity of the first tone required to "cover" the second when the intensity and frequency of the masked tone are kept constant (Moore, 1995; Zwicker & Schorn, 1978). This rule applies to all external sounds and to sounds made by the body (somatosounds).

Contrary to the masking of external sounds, it is possible to abolish the perception of tinnitus sounds by pure tones of a similar intensity regardless of their frequency.

Contrary to the masking of external sounds, it is possible to abolish the perception of tinnitus sounds by pure tones of a similar intensity regardless of their frequency.

Contrary to the masking of external sounds, it is possible to abolish the perception of tinnitus sounds by pure tones of a similar intensity regardless of their frequency (Feldmann, 1971). This proves that "masking" of tinnitus does not involve a mechanical interaction of basilar membrane movements, does not depend on the critical band principle and, therefore, has to occur at a higher level within the auditory pathways. Consequently, the elimination of the perception of tinnitus by another sound should be labeled suppression rather than "masking," as is commonly used. Unfortunately, Feldmann's fundamental discovery has been widely disregarded, resulting in focusing attention on masking rather than suppression and in producing tinnitus instruments tuned to the dominant perceived pitch of tinnitus.

The elimination of the perception of tinnitus by another sound should be labeled suppression and not "masking," as is commonly used.

The elimination of the perception of tinnitus by another sound should be labeled suppression and not "masking," as is commonly used.

In the case of masking an external tone, a much higher intensity of masker is always needed when the masker is applied to the opposite ear than when both sounds are applied to the same ear. This is usually not the case with tinnitus suppression by a contralateral sound, which can be equally, or even more, effective in suppressing tinnitus as sound applied to the ear where the tinnitus is localized (Feldmann, 1971). The independence of tinnitus suppression from the frequency of the external tone was noticed in 1969 (Feldmann, 1969a), but the term minimal masking level was used inappropriately to describe the minimal level of external sound required to make the tinnitus inaudible. As this effect on tinnitus is one

of acoustic suppression the terms "suppression" and "minimal suppression level" should be used instead. [1]

Sound applied to the opposite ear contralaterally (can be equally, or even more), effective in suppressing tinnitus as sound applied to the ear where the tinnitus is localized.

Cyclical fluctuation of loudness of perceived sound occurs when two pure tones that are very close in frequency are presented together. This phenomenon is called *beating of tones*, and the cyclical rate of the loudness change equals the difference of the two frequencies. This phenomenon has not been achieved during attempts to produce beating with tonal tinnitus (perceived as being similar to a pure tone) and an externally applied pure tone.

Tinnitus beats with external tones do not occur.

The phenomenon of disappearance of tinnitus perception after exposure to loud sound was first described by Feldmann (1971a). This effect can last for seconds, minutes or, very rarely, hours or days and was called *residual inhibition*. It cannot be explained by any changes in cochlear function and has not been reported for external tones. It can, however, be easily explained by the rebound phenomenon. [2]

Residual inhibition is observed in some patients after tinnitus suppression.

All these properties of tinnitus strongly indicate that the interaction of tinnitus and external sounds does not occur at the level of the cochlea. Let us consider a situation where tinnitus is related to malfunction of a small area of the cochlear basilar membrane. In this case, the subject would perceive "tonal" tinnitus, as only a small group of auditory nerve fibers tuned to close-by frequencies would be stimulated. By using an external tone with frequency corresponding to the pitch of tinnitus, it should be possible to suppress the tinnitus much more easily than with tones of different frequency. Therefore, the observation that tinnitus suppression does not depend on the frequency of the external sound argues against the cochlea playing a dominant role. The absence of a beating phenomenon also argues against any kind of a mechanical tinnitus-related vibration occurring in the cochlea. In the rare condition when perception of sound results from spontaneous otoacoustic

[1] Psychoacoustically masking within the cochlea reflects the mechanical interaction of two traveling waves on the basilar membrane induced by two sounds in the cochlea. The interaction of these two waves depends upon the frequency relationship between the signal and the masking sound, and also on the frequency difference between the two. The frequency range within which the signal is affected by the masker is known as the critical band.

[2] The rebound phenomenon is well recognized in neurophysiology. If the activity of a neuron, as the result of sound stimulation, is increased, cessation of the signal frequently results in activity decreasing below the previous level of spontaneous activity occurring before stimulation. If stimulation was causing inhibition of neuronal activity, then switching off the sound results in an enhancement of spontaneous activity for some time. After a while, the neuronal activity returns to the pre-stimulus level.

emissions, frequency-specific suppression of perceived somatosound is observed (Penner, 1992; Penner & Burns, 1987).

1.2 Categories of phantom auditory perception

The definition of tinnitus that we use states that tinnitus is equivalent to a phantom auditory sensation (Jastreboff, 1990). There are a number of quite different auditory experiences that are included in this definition of tinnitus.

Tinnitus is equivalent to a phantom auditory sensation.

Tinnitus can be perceived as a formless sound, either tonal or complex in nature, that resembles (although it is never identical with) environmental sounds, for example hissing, ringing, buzzing, cicadas, escaping steam, fluorescent light, running engine, static, humming, etc. These descriptions of tinnitus are by far the most common reported. It is believed that this kind of perception occurs as a result of abnormal neuronal activity at a subcortical level of the auditory pathway. The cortex plays a predominantly passive role.

Perception of a formless sound (e.g., hissing, ringing, buzzing, cicadas, escaping steam, fluorescent light, running engine, static, humming, etc.) is by far the most common experience of tinnitus.

Auditory imagery is the phantom perception of well-known musical tunes or of voices without any understandable speech (Berrios, 1991; Berrios & Rose, 1992; Goodwin, 1980). This perception is much less frequent; nevertheless, it is well documented and occurs primarily in older people with hearing loss. It is presumably a central type of tinnitus involving reverberatory activity within neural loops at a high level in the auditory cortex.

Auditory imagery is the phantom perception of musical tunes or of voices without any understandable speech. It is presumably a central type of tinnitus involving reverberatory activity within neural loops at a high level in the auditory cortex.

The definition of tinnitus as a phantom auditory perception does not exclude phantom perception of understandable speech, frequently commanding the subject to perform specific tasks. This type of perception is a hallmark of schizophrenia (Cloninger *et al.*, 1985; Heilbrun *et al.*, 1986), and presumably results from stimulation of cortical speech centers caused by significant malfunctioning of the brain. In clinical practice, there is a tendency to separate schizophrenic from tinnitus patients because of the different approaches to treatment. Nevertheless, there are a number of reasons to include understandable speech as a form of tinnitus.

The definition of tinnitus as a phantom auditory perception does not exclude phantom perception of understandable speech, which is a hallmark of schizophrenia.

There is no clear distinction between "central" and "cortical hallucinatory" tinnitus in the classical definition, except in the complexity of perceived sound. According to the proposed definition of tinnitus, "hearing voices" indicates that abnormal cortical activity causes excitation of the cortical area involved in speech perception. There is no real difference whether speech areas of the brain are excited by electrical stimulation of the cortex or whether this is an abnormal pattern of spontaneous cortical activity affecting cortical speech areas, as happens in schizophrenia. It has been shown that complex auditory (Berrios, 1991; Hammeke, McQuillen & Cohen, 1983; Klostermann, Vieregge & Kömpf, 1992) or visual (Schultz & Melzack, 1991) hallucinations also occur without any psychiatric disorder.

Some schizophrenics experience tinnitus, perceived as a formless sound. In a group of six patients, the auditory hallucinations were unchanged despite amelioration of tonal tinnitus as a result of therapy (J. W. P. Hazell, personal communication).

1.3 Other phantom perceptions

Tinnitus is not unique in being a phantom perception. The concept of phantom perception involves both the philosophy of perception as well as everyday clinical problems. The best recognized other perceptions are phantom limb and phantom pain: the feeling of a limb "being there" or being painful after amputation (Melzack, 1989, 1990, 1992; Wyant 1979).

There are a number of other phantom perceptions, e.g., phantom limb, pain, taste and smell.

Setting aside philosophical aspects of the problem, the main question is whether phantom sensation, as perceived by a patient, differs from their perception of the external world. Melzak, in a series of elegant papers (1989, 1990, 1992), presented convincing data supporting the theory that: "*The experience of a phantom limb has the quality of reality because it is produced by the same brain processes that underline the experience of the body when intact; neural networks in the brain generate all the qualities of experience that are felt to originate in the body, so that inputs from the body may trigger or modulate the output of the networks, but are not essential for any of the qualities of experience.*" He further argued that similar mechanisms are involved in phantom seeing and phantom hearing, including tinnitus (Melzack, 1992; Schultz & Melzack, 1991). Other phantom perceptions include taste and smell (Bartoshuk *et al.*, 1994; Jastreboff, 1990; Kveton & Bartoshuk, 1994; Snow *et al.*, 1991).

Similar mechanisms to tinnitus are involved in phantom seeing.

1.4 Tinnitus-related neuronal activity

The observation that tinnitus suppression does not depend on the frequency of the external sound argues against the cochlea playing a dominant role.

Another possibility is that perception of tinnitus results from neuronal activity within the auditory pathways that is similar to the activity produced by external sounds. If this were so, we should still observe frequency-specific masking, which is not the case. In addition, ipsilateral suppression (masking) should be more effective than contralateral. This makes it unlikely that the perception of tinnitus arises from neuronal activity similar to that evoked by external sounds.

Neuronal activity responsible for tinnitus perception cannot be induced by any combination of external sounds.

The logical conclusion is that the neuronal activity responsible for tinnitus perception cannot be induced by any combination of external sounds (Jastreboff, 1990, 1995). Animal research, where tinnitus-related neuronal activity from the auditory pathway has been recorded, supports this concept and shows that this activity consists of bursts of very high frequency discharges, which are typically associated with epilepsy (Chen & Jastreboff, 1995). This finding has great relevance to some of the puzzles of tinnitus that will be discussed in subsequent chapters.

Perception of tinnitus has been related to abnormal synchronization of auditory nerve activity (Moller, 1984), imbalanced activity of type I and type II afferent fibers in the auditory nerve (Tonndorf, 1987), discordant damage to outer hair cells (OHC) and inner hair cells (IHC) systems (Jastreboff, 1990, 1995) or central abnormalities (Hammeke *et al.*, 1983; Jastreboff, 1990; Moller, 1992). The final result is the same: perception of a sound without any corresponding mechanical vibrations in the cochlea.

1.5 Processing of sounds within the brain

The perception of all external sounds involves a number of brain centers outside the auditory pathways. To evaluate a sound, it is necessary to compare its pattern with other patterns stored in auditory memory. Depending on its significance and past association, perception of the sound will induce various reactions and emotions. In this respect, perception of tinnitus obeys the same general rules and mechanisms as perception of external sounds. The neurophysiological model of tinnitus, discussed later in the book, stresses this aspect very strongly. Many centers within the brain are involved in tinnitus emergence, persistence and its consequent severity.

Depending on significance and past association, perception of a sound will induce various reactions and emotions. Many centers within the brain are involved in tinnitus emergence, persistence and its consequent severity.

The processing of any type of information (including tinnitus-related activity) within the nervous system occurs at several levels and involves pattern recognition, memory and interconnection with other systems, particularly the limbic and autonomic nervous systems. As a result, this model directs our attention away from the concept of tinnitus "belonging" to a place or anatomical site and suggests that it is associated within many centers throughout the nervous system. This activity is changeable, volatile and subject to plasticity (*reprogramming*), which is reflected in patients' behavior in creating new associations, reflex responses and memories. It is this plasticity of the nervous system, properly directed and utilized, that makes it possible to provide patients with relief from their tinnitus.

1.6 Tinnitus duration and epidemiology

The proposed definition disregards tinnitus duration. The episodes of tinnitus can be very short (as in temporary tinnitus following noise exposure or very high dose of aspirin) or it may be continuous. The frequently used criterion of five minutes duration of perception of sound to be classified as tinnitus (MRC-IHR, 1981b) is arbitrary and does not have any clear theoretical or clinical basis or relevance. The time factor is irrelevant for mechanisms of tinnitus generation, regardless of what theory of tinnitus is proposed. From the patient's point of view, however, where the annoyance of tinnitus is certainly related to its duration, this is only one of many parameters determining distress.

The time duration of tinnitus is only one of many parameters determining distress.

Epidemiological studies have shown that temporary tinnitus is a very common symptom experienced by people of all ages (Coles, 1996). There are many factors recognized as most frequently associated with tinnitus: noise exposure, head trauma, some otologic problems, medical conditions and exposure to ototoxic substances. Eventually, while only 0.5–2% of people are significantly affected by tinnitus, various studies estimate that 6–30% of people experience continuous tinnitus (Coles, 1987, 1996; Davis, 1996; Davis & El Refaie, 2000; George & Kemp, 1991). The degree of distress, annoyance, emotional discomfort, sleep problems and interference with day-to-day activities are factors that differentiate people who simply experience tinnitus from those who need help and clinical attention (i.e., have clinically significant tinnitus).