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A Systematic Classification of Tinnitus Generator Mechanisms

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Abstract: Largely unknown causes and innumerable assumed mechanisms conceivably could be involved in the generation of tinnitus. Indeed, tinnitus is so complex and so manifold that a systematic classification could prove helpful. Here represented is a systematic classification that is suitable for scientific communication, for explaining tinnitus models to affected patients in the course of tinnitus counseling, and as a basis for rational diagnosis of and therapy for tinnitus.

The systematic classification outlined in this article differentiates conductive from sensorineural and central tinnitus. Sensorineural tinnitus is subdivided into motor (type I), transduction (type II), transformation (type III), and extrasensory tinnitus (type IV), central tinnitus being subclassified as primary and secondary (centralized) tinnitus.

Tinnitus is a symptom of the auditory system. In the same way that the visual system can react to disturbances only symptomatically by reducing the ability to see or by "seeing stars", all disorders of the auditory system lead to a reduction in hearing ability or to tinnitus (or to both) without exception. For this reason, a broad number of mechanisms can be responsible for the onset of tinnitus, as has been discussed in the literature. Nevertheless, just as one cannot deduce the pathophysiology from the symptom of hearing loss alone, without case history or further medical evidence, the symptom of tinnitus alone does not allow one to deduce the mechanism involved in its generation. Furthermore, results obtained from therapies that apply specific forms of treatments, such as certain drug therapies or retraining therapy, do not necessarily allow a firm conclusion to be drawn from the host of pathological mechanisms that might be responsible.

In addition, the very common, subjective tinnitus cannot be assessed objectively; thus, no concrete evidence at all corroborates the large number of individual mechanisms that supposedly lead to tinnitus, as described in the literature. As a consequence, numerous tinnitus models have already been proposed [1–15]. Even some apodictic statements have claimed that one model is responsible for (nearly) all forms of tinnitus: Circulatory disturbances represent one example of this form of misuse.

In the present situation, a systematic classification based on the anatomical and functional aspects involved in the generation of tinnitus should prove useful. The various models can then be incorporated into the classification, regardless of their scientific evaluation.

The present systematic classification, parts of which actually have been discussed since 1993 [16,17], is described here in further detail, taking both the methods of functional and anatomical systematics into account. It will enable physicians to classify the large number of causative mechanisms for tinnitus by a more simplified means, to reach a basis for general understanding.

The first stage in the systematic classification of tinnitus (Table 1) is the conventional division into objective and subjective tinnitus. To comprehend *subjective tinnitus*, Figure 1 schematically depicts the individual functional and anatomical steps involved in sound processing, with the middle ear, inner ear, and brain roughly outlined. The signal can be made out, which begins at the point when sound enters the ear and leads to vibrations of the ossicles in the middle ear, which then are transferred to the inner ear. The *sensorineural component* of the hearing process follows, comprising three functional, anatomical steps. First, the sound signal is amplified by the motor (i) of the cochlear amplifier of the outer hair cells (OHCs); then the amplified signal is transformed into an electrical signal by the final

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Table 1. Systematic Tinnitus Classification

Objective tinnitus
Subjective tinnitus
Conductive tinnitus*
Sensorineural tinnitus*
Type I (motor tinnitus)
Type II (transduction tinnitus)
Type III (transformation tinnitus)
Type IV (extrasensory tinnitus)
Central tinnitus
Primary central tinnitus
Secondary central (centralized) tinnitus

*Conductive tinnitus and sensorineural tinnitus form the peripheral tinnitus.

mechanoelectrical (ii) transduction of the inner hair cells (IHCs). The signal then is transferred synaptically from the IHCs to the afferent nerve fibers as a so-called (iii) transformation before being transferred by means of the auditory nerve. The sensory functional elements, including amplification motor, transduction, and transformation, are supported by such (iv) extrasensory elements as the stria vascularis, which is amply supplied with blood and provides a source of energy. By way of the auditory nerve, the sound signal reaches the central nervous system, where perception and cognition take place.

From this schematic course of events, which presents a simplified form of the entire auditory system according to its functional and anatomical aspects, an uncomplicated classification can be deduced for subjective tinnitus (see Table 1). This allows every conceivable proposition for a pathophysiological, causative mechanism of tinnitus to be classified in the same way that the physiological courses of events divide the entire auditory system.

According to function and anatomy, the following three divisions can be made: *conductive* tinnitus, *sensorineural* tinnitus, and *central* tinnitus [11,13]. These three groups can be distinguished along the same lines as can hearing difficulties.

In the case of sensorineural tinnitus, one of the three sensory functional elements of a resulting sensory tinnitus can be distinguished from extrasensory tinnitus [18]. In principle, sensory and extrasensory tinnitus include all possible cochlear and neural (auditory nerve) tinnitus models. To classify the tinnitus models with respect to the three sensory functional elements, an easy approach is to number them consecutively [16,17]. Thus, tinnitus associated with the first functional element, the cochlear amplification mechanism, is termed *motor tinnitus* [8,10,14,16,19] or *sensorineural tinnitus type I*. Accordingly, tinnitus associated with the electromechanical transduction of the IHCs is designated *transduction tinnitus* [9,15], or *sensorineural tinnitus type II*. Following from this, the term *transformation tinnitus* [4,5,14–16], or *sensorineural tinnitus type III*, is used to describe disorders arising during the signal transfer from the IHCs and along the afferent nerve fibers (synonyms are *cochleosynaptic tinnitus; signal transfer tinnitus*). According to this classification, the remaining extrasensory, sensorineural tinnitus mechanisms are called *extrasensory tinnitus* [18] or *sensorineural tinnitus type IV*. The first proposals for a subclassification have been made [17].

For these purposes, central tinnitus, [1,9,11,13] can be subdivided into primary central and secondary central [9] tinnitus. The pathogenesis of primary central tinnitus is to be found exclusively in the brain; it develops independently of the inner or middle ear. Secondary central tinnitus is based on the fact that conductive

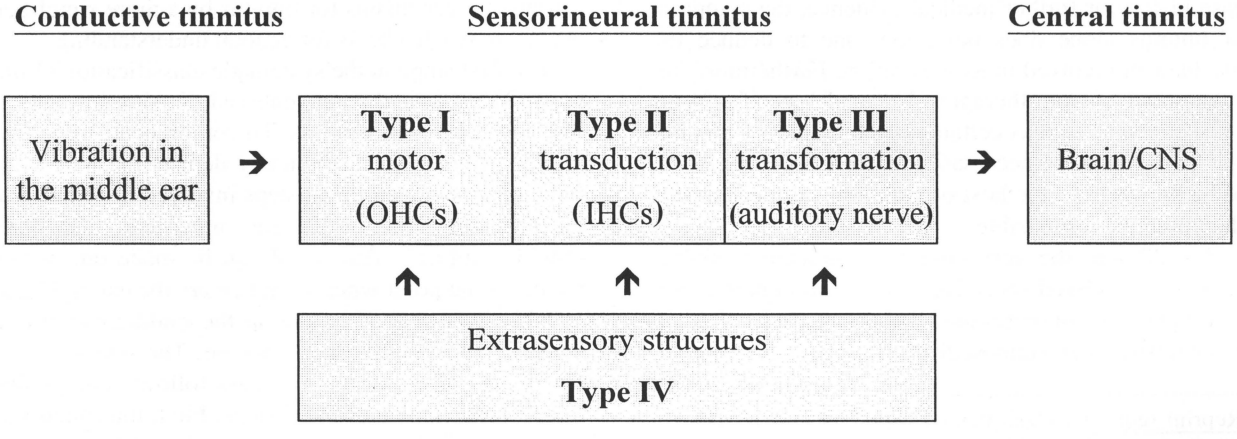

Figure 1. Systematics of possible generation mechanisms of subjective tinnitus, developed from Zenner et al. [14,15,17,18]; conductive tinnitus and sensorineural tinnitus form the peripheral tinnitus. (OHCs = outer hair cells; IHCs = inner hair cells; CNS = central nervous system.)

and sensorineural tinnitus can be perceived only as such when the signal is processed in the brain. Mechanisms leading to a response in which the perception of tinnitus first triggered peripherally but then manifesting itself in the brain independently of the original source in the ear can be subsumed within the group termed *secondary central tinnitus* (centralized tinnitus, or the less scientific but comprehensible term *phantom tinnitus*, being synonyms). The subdivision into primary and secondary central tinnitus, therefore, concludes every conceivable, central tinnitus model.

Thus, the systematics presented here provide us with the framework for classifying all known causative models of the symptom tinnitus. Some examples of the classification are listed in Table 2. Systematics can be used clinically in cases in which case history, etiology (if known), and the accompanying audiological examinations allow conclusions of clinical relevance to be made. Conclusions regarding possible causative mechanisms or the suspected location of the source certainly are relevant when (i) exogenous causes are involved, or a (ii) symptomatic tinnitus is diagnosed or (iii) tinnitus is not the only symptom of the respective disorder of the hearing system (e.g., when a hearing impairment also is present). The probability that defective hearing and tinnitus are the result of the same causative mechanism is rated much higher than the probability that they have different origins [7]. Furthermore, the (iv) subjective localization of tinnitus [7] might be helpful also.

Examples include the following. Noises perceived in the outer auditory canal with a microphone or a stethoscope are an indication of objective tinnitus. During one of the initial steps, noise leads to physiological damage of the molecular structure of the stereocilia of the OHCs, thus disrupting their motor function. The etiology would seem to indicate a sensorineural tinnitus type I. If the noise has led simultaneously to a change in the otoacoustic emissions or even to a complete loss of hearing with positive recruitment, the probability of a sensorineural type I tinnitus being diagnosed is much higher.

Tinnitus occurring with and in the same frequency range as a hearing disorder, whereby the psychoacoustic loudness is some decibels above the hearing threshold and the hearing disorder is accompanied by a partial or complete loss of TEOAE and a positive recruitment phenomenon, results in a high degree of probability from a disturbed motor function of the OHCs. If, as did Feldmann [7], one assumes a uniform disruptive mechanism to be responsible for both the hearing disorder and tinnitus—in cases of noise induction of aminoglycosides, this is virtually certain; in other cases, it suggests a high probability—a sensorineural tinnitus type I can be diagnosed.

Currently, diagnosing a sensorineural tinnitus type II in exceptional cases only is possible.

If an acoustic neurinoma is detected, a sensorineural tinnitus type III is the most likely diagnosis. A circulatory disturbance of the inner ear (proving difficult for detection) indicates sensorineural tinnitus type IV (reduced blood circulation in the stria vascularis); in cases involving dramatic hypoxia, this leads to a tinnitus type III (swelling of the nerve fiber endings).

Tumors and inflammation of the brain (e.g., multiple sclerosis) accompanied by tinnitus confirm the classification of a primary central tinnitus. The fact that a secondary central tinnitus can be diagnosed is exemplified by phantom tinnitus, which still continues even after neurectomy. Apart from these rare events, an additional centralized component of a sensorineural tinnitus can

Table 2. Comparison of Tinnitus Classification and a Selection of Pathogenetic Models

Classification	Pathogenetic models (examples)
Objective tinnitus	Glomus tumor, angiostenosis, protruding bulbus off jugular vein
Subjective tinnitus	
Conductive tinnitus	Disturbance of tubal ventilation, middle ear myoclonia
Sensorineural tinnitus	
Type I	Hypermotility, DC tinnitus, edge-effect tinnitus, efferent tinnitus caused by regulatory disturbances of the nerves, noise trauma, ion channel disorders of the outer hair cells
Type II	Continuous depolarization of ion channel disorders of the inner hair cells, disturbance of the stereocilia of the inner hair cells
Type III	Release of transmitters, flooding with synaptic transmitters, swelling of the afferent nerve fibers, excitotoxic tinnitus
Type IV	Disorders (e.g., of the ion channels) of the stria vascularis, circulatory disorders of the cochlea, resorption disorders and osmolarity change of endolymph, endolymph hydrops
Central tinnitus	
Primary	Brain tumors, multiple sclerosis
Secondary	Phantom tinnitus

Note: On the right, the ample variety is recognized easily. On the left, the usefulness of systematics is made obvious: It provides a clear overview and demonstrates that by no means is every tinnitus caused by a single mechanism (e.g., circulatory disturbances).

be considered, especially in cases of extreme emotional overlap with secondary symptoms.

The combination of different tinnitus types within this systematic classification generally is acceptable. This is especially true of secondary central tinnitus, which always is triggered by a different form of tinnitus.

For tinnitus sensations of up to 3–5 kHz, on the basis of the coherence theory, Feldmann [7] gives guidelines to differentiate clinically between central tinnitus and the tinnitus described here as sensorineural tinnitus. Tinnitus that can be heard in one or both ears is generated in the ear; a tinnitus perceived in the head may be regarded as central. Beyond 3–5 kHz, this simple grouping no longer is possible [7].

Some therapeutic approaches also can be grouped according to the systematic classification presented here. These are listed here before assessment: (1) resection of a glomus tumor (objective tinnitus); (2) tendotomy of the stapes tendon (conductive tinnitus); (3) permanent tinnitus suppression [7] (probably tinnitus type I after repair of the motor feedback); (4) lidocaine [15] (activation of ion channels in the cell membranes in the case of tinnitus type I, II, and IV and probable effectiveness in the case of central tinnitus); (5) caroverine [20] (blockage of the NMDA-receptor in the case of tinnitus type III); (6) improvement of blood flow (stria vascularis: tinnitus type IV); (7) beta-histidine (endolymph hydrops: tinnitus type IV); and (8) retraining therapy [9,13] (secondary central tinnitus).

If the classification is used for diagnostic purposes, the tinnitus also can be registered as compensated or decompensated. The exact description, depending on the course of the disorder, is acute, subacute, or chronic.

If tinnitus (e.g., from a gunshot) lasts for more than 12 months, is accompanied by loss of hearing threshold and TEOAE, and leads to permanent diminution in both private and professional spheres, with disturbances in the emotional and cognitive fields, accordingly it can be designated *decompensated chronic sensorineural tinnitus type I.* On the other hand, a tinnitus that is associated with multiple sclerosis and is well compensated can be called *compensated chronic "primary central tinnitus."*

If a diagnosis is reached by these means, clearly no single method of treatment can be found that would relieve all forms of tinnitus. Most tinnitus types presumably require a specific therapy. Indeed, some therapies available are designed for specific disorders: drugs for improving blood circulation (sensorineural type IV), caroverine [20] in the case of excitotoxic tinnitus (sensorineural type III), and lidocaine and calcium antagonists in the case of ion channel disorders (sensorineural types I, II, IV).

For the diagnosis of a motor disorder (OAE, recruitment), an acoustic neurinoma (ABR, NMR), and primary central disorders, specific diagnostic tools are available. A secondary central tinnitus can be diagnosed, partially at least, with psychological methods. Disorders associated with sensorineural tinnitus types II and III (apart from acoustic neurinoma) still are lacking reliable diagnostic procedures.

At present, single forms of treatment are considered appropriate without specification for nearly all patients with tinnitus. Obviously, this cannot lead to therapeutically efficient treatment. The therapeutic problem of tinnitus can be resolved only if more sophisticated diagnostic instruments become available, enabling the classified diagnosis of tinnitus. This then would form a rational basis to indicate a specific therapy for all diagnosed cases.

REFERENCES

1. Arnold W, Bartenstein P, Oestreicher E, et al. Focal metabolic activation in the predominant left auditory cortex in patients suffering from tinnitus. *ORL* 58:195–199, 1996.
2. Dieler R, Sheata-Dieler WE, Brownell WE. Concomitant salicylate-induced alterations of outer hair cell subsurface cisternae and electromotility. *J Neurocytol* 20:637–653, 1991.
3. Eggermont JJ. Tinnitus: some thoughts about its origin. *J Laryngol Otol Suppl* 9:31–37, 1983.
4. Ehrenberger K, Felix D. Glutamate receptors in afferent cochlear neurotransmission in guinea pigs. *Hear Res* 52:73–76, 1991.
5. Ehrenberger K, Felix D. Receptor pharmacological models for inner ear therapies with emphasis on glutamate receptors. *Acta Otolaryngol* 115:236–240, 1995.
6. Evans EF, Wilson JP, Borerwe TA. Animal models of Tinnitus. In EF Evans (ed), *Tinnitus* (Ciba Foundation Symposium '85). London: Pitman, 1981: 108–148.
7. Feldmann H. Mechanism of Tinnitus. In JA Vernon, A Möller (eds), *Mechanism of Tinnitus.* Boston: Allyn and Bacon, 1985: 35–50.
8. Hazell JWP. A cochlear model for tinnitus. In H Feldmann (ed), *Proceedings of the III International Tinnitus Seminar.* Karlsruhe: Harsch, 1987: 121–130.
9. Jastreboff P. Tinnitus as a phantom perception: Theories and clinical implications. In JA Vernon, AR Möller (eds), *Mechanism of Tinnitus.* Boston: Allyn and Bacon, 1995: 73–87.
10. Kemp DT. Physiologically Active Cochlear Micromechanics: One Source of Tinnitus. In EF Evans (ed), *Tinnitus* (Ciba Foundation Symposium '85). London: Pitman, 1981: 54–81.
11. Lenarz Th, Schreiner Ch, Snyder RL, Ernst A. Neural mechanism of tinnitus: The Pathological Ensemble Spontaneous Activity of the Auditory System. In JA Vernon, AR Möller (eds), *Mechanism of Tinnitus.* Boston: Allyn and Bacon, 1995: 101–111.

12. Oesterreicher E, Arnold W, Ehrenberger K, Felix D. Memantine suppresses the glutamatergic neurotransmission of mammalian inner hair cells. *ORL Nova* 60(1):18–21, 1998.
13. Shulman A, Goldstein B. A final common pathway for tinnitus. Implications for Treatment. *Int Tinnitus J* 2:137–142, 1996.
14. Zenner HP. Modern Aspects of Hair Cell Biochemistry, Motility and Tinnitus. In H Feldmann (ed), *Proceedings of the III International Tinnitus Seminar.* Karlsruhe: Harsch, 1987: 52–57.
15. Zenner HP, Gitter AH. Possible Roles of Hair Cell Potential and Ionic Channels in Cochlear Tinnitus. In H Feldmann (ed), *Proceedings of the III International Tinnitus Seminar*, Karlsruhe: Harsch: 1987; 306–310.
16. Zenner HP, Ernst A. Cochlear-motor, transduction and signal-transfer tinnitus. *Eur Arch Otorhinolaryngol* 249:447–454, 1993.
17. Zenner HP, Ernst A. Three Models of Cochlear Tinnitus. In JA Vernon, AR Möller (eds), *Mechanism of Tinnitus.* Boston: Allyn and Bacon, 1995: 237–252.
18. Preyer S, Bootz F. Tinnitusmodelle zur Verwendung bei der Tinnituscounsellingtherapie des chronischen Tinnitus. *HNO* 43:338–351, 1995.
19. Plinkert PK, Gitter AH, Zenner HP. Tinnitus-associated spontaneous otoacoustic emissions: active outer hair cell movements as a common origin? *Acta Otolaryngol (Stockh)* 110:342–347, 1990.
20. Ehrenberger K. Caroverine in tinnitus treatment—a placebo-controlled blind study. *Acta Otolaryngol* 117:825–830, 1997.