

## Review Article

# Hearing Disorders and Sensorineural Aging

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The physiological age-related hearing loss is defined as presbycusis and it is characterized by reduced hearing sensitivity and problems in understanding spoken language especially in a noisy environment. In elderly the reduced speech recognition is generally caused by a reduction of the cochlear cells in the organ of Corti and degeneration of the central auditory pathways. In order to have a complete management strategy of central and peripheral presbycusis the diagnostic evaluation should include clinical ENT examination, standard audiological tests, and tests of central auditory function. Treatment should include not only the appropriate instruments for peripheral compensation but also auditory rehabilitative training and counseling to prevent social isolation and loss of autonomy. Other common hearing disorders in elderly are tinnitus and hyperacusis which are often undervalued. Tinnitus is characterized by the perception of a “phantom” sound due to abnormal auditory perception. Hyperacusis is defined as a reduced tolerance to ordinary environmental sounds. Furthermore auditory, visual, nociceptive, and proprioceptive systems may be involved together in a possible context of “sensorineural aging.” The aim of this review is to underline the presence of hearing disorders like tinnitus and hyperacusis which in many cases coexist with hearing loss in elderly.

## 1. Introduction

Hearing loss affects approximately one-third of adults over 60 years [1].

Typical changes in presbycusis start with a hearing loss on high frequencies with a progression toward the lower frequencies and a deterioration of the hearing threshold [2]. Many factors contribute to presbycusis like morphological alterations in the stria vascularis, loss of hair cells in the cochlea, and degeneration of the central auditory pathway [3, 4], depending on a genetic basis, smoking, vascular changes, metabolic disorders, and environmental exposure to noise [5]. However, the originating signals that trigger these mechanisms remain unclear. Changes within the cochlea are responsible for age-related hearing loss typically linked with low speech understanding especially in presence of competing sound sources. The phenomenon of low speech understanding in elderly is related to modifications in central brain processes.

Associations between hearing loss and blood lipids in older adults have been studied for many years. Currently the association is considered controversial [6]. Despite some limitations in data collection methods, interesting findings were proposed by Verschuur et al. about the significant association between hearing loss in older people and higher levels of four markers of inflammation: white blood cell count, neutrophil count, IL-6, and C-reactive protein [7].

Central auditory disorders are common in neurodegenerative diseases, including dementia and Alzheimer's disease [8]. In these cases the evaluation of auditory threshold and the identification and characterization of associated symptoms like tinnitus or hyperacusis can be difficult and objective measures are requested. Recognition of tinnitus and decreased sound tolerance in elderly must be also considered because in many cases they are still undervalued or confused especially with somatosounds, epilepsy, or psychotic illusions.

Tinnitus is defined as a perception of a sound without an external acoustic source. It can be persistent, intermittent,

or throbbing, depending on the cause. It is important to distinguish between subjective and objective tinnitus. Subjective tinnitus (95% of cases) has a neurophysiological origin whereas objective tinnitus (5% of cases) can be generated from vascular, muscular, or respiratory sources and also from the temporomandibular joint. Another classification of tinnitus is in pulsatile and not pulsatile. There are many hypotheses to explain the origin of tinnitus even if none has yet been proven. Many conditions are associated with tinnitus and they are reported in Table 1. Tinnitus becomes more prevalent in association with aging and hearing loss, with an estimated prevalence of 12–18% over the age of 60 years [9].

Audiologists describe decreased sound tolerance using the terms “hyperacusis,” “phonophobia,” “misophonia,” and “recruitment.” Hyperacusis is defined as “unusual tolerance to ordinary environmental sounds” [10] or as “consistently exaggerated or inappropriate responses to sounds that are neither threatening nor uncomfortably loud to typical person” [11]. The prevalence of chronic hyperacusis in the general population aged 51–79 years has been estimated as up to 9% [12]. It is widely noted that patients suffering with tinnitus also present with hyperacusis in 40–79% of cases [13–15]. Instead, in patients with hyperacusis, tinnitus has been reported in 86% [16].

The mechanisms of hyperacusis generation could involve a peripheral origin, principally the cochlea, the central auditory pathways, endogen endorphins, or central disorders. In the hypothesis of a peripheral origin, the hyperexcitability of the outer hair cells (OHC) of the cochlea would overstimulate the action of inner hair cells (IHC) so a moderate sound may be amplified and will be annoying. Distortion-product otoacoustic emissions (DPOAEs) are an objective indicator of normally functioning OHC. DPOAEs in some patients with hyperacusis show increased values [15]. The central auditory origin may be related to the impairment of the lateral olivocochlear bundle (LOCB) which could generate hyperacusis because the LOCB terminals can evoke either slow enhancement (cholinergic transmission) or suppression (dopaminergic) of auditory nerve response [17]. On the other hand, mood disorders as anxiety and chronic stress lead to increased release of endorphins in the IHC-auditory nerve synapses. These substances increase the excitatory effect of the glutamate. The inhibitory neurotransmitter GABA acts at several levels on the acoustic pathways so a decrease of GABA will increase neural activity and could be correlated with hyperacusis.

Hyperacusis may be associated with ear pathologies like Ménière’s disease, perilymphatic fistula, sudden sensorineural hearing loss, acoustic trauma, otosclerosis, Bell’s facial palsy, and Ramsay Hunt syndrome (Table 2). The conductive hyperacusis is associated with dehiscence of the superior semicircular canal [18] which simulates the effect of a “third window”. In this condition the patient may have normal air conduction thresholds on pure audiometry with a bone conduction better than normal. The consequence is a hyper-awareness of somatosounds. In addition, CNS disorders like migraine, depression, posttraumatic stress disorders, multiple sclerosis, benign intracranial hypertension, Tay-Sachs

TABLE 1: Etiopathology of tinnitus.

|                                       |   |
|---------------------------------------|---|
| Vascular                              | Atherosclerotic disease (carotid and subclavian)            |
|                                       | Dural arteriovenous fistulas                                |
|                                       | Carotid-cavernous fistula                                   |
|                                       | Aneurysm (giant)  |
|                                       | Fibromuscular dysplasia of carotid artery                   |
|                                       | Carotid artery dissection                                   |
|                                       | Aberrant internal carotid artery                            |
|                                       | Hyperdynamic states (anemia, thyrotoxicosis, and pregnancy) |
|                                       | Hypertension  |
|                                       | Internal auditory canal vascular loops                      |
|                                       | Glomus jugulare tumor                                       |
|                                       | Benign intracranial hypertension                            |
|                                       | Sigmoid or jugular diverticulum                             |
|                                       | High jugular bulb   |
| Transverse or sigmoid stenosis        |   |
| Condylar vein abnormalities           |   |
| Somatosensory                         | Palatal and middle-ear myoclonus                            |
|                                       | TMJ alterations (synchrony with joint movements)            |
| Neurologic                            | Cerebellopontine angle tumors                               |
|                                       | Neurodegenerative diseases (dementia)                       |
|                                       | Epilepsy  |
|                                       | Auditory hallucinations                                     |
|                                       | Migraine  |
| Auditory                              | Ear wax   |
|                                       | Acute otitis media  |
|                                       | Otitis media with effusion                                  |
|                                       | Chronic otitis media  |
|                                       | Cholesteatoma   |
|                                       | Otosclerosis  |
|                                       | Ossicular chain trauma                                      |
|                                       | Ossicular malformations                                     |
|                                       | External- or middle-ear cancer                              |
|                                       | Labyrinth malformations                                     |
|                                       | Genetic hearing loss (syndromic and nonsyndromic)           |
|                                       | Immune mediated inner-ear disease                           |
|                                       | Cochlearototoxicity   |
|                                       | Ménière disease—cochlear endolymphatic hydrops              |
|                                       | VIII cranial nerve tumor                                    |
|                                       | Acoustic trauma   |
|                                       | Sudden deafness   |
|                                       | Barotrauma  |
|                                       | Labyrinthitis (bacterial, viral, tuberculosis, and fungal)  |
| Auditory neuropathy                   |   |
| Central auditory processing disorders |   |
| Psychiatric                           | Depression  |
|                                       | Anxiety   |
|                                       | Somatoform disorders  |
|                                       | Obsessive compulsive disorder                               |
|                                       | Posttraumatic stress disorder                               |
|                                       | Psychosis   |

syndrome, Williams syndrome, and Lyme’s disease may be related to hyperacusis (Table 2).

TABLE 2: Peripheral and central conditions associated with hyperacusis.

|                                  |                               |
|----------------------------------|-------------------------------|
| Cochlear diseases                | Meniere's disease             |
|                                  | Perilymphatic fistula         |
|                                  | Sudden deafness               |
|                                  | Acoustic trauma               |
|                                  | Otosclerosis                  |
| After surgical procedures        | Poststapedectomy              |
|                                  | Transtympanic tube placement  |
| Stapedial reflex disorders       | Ramsay Hunt syndrome          |
|                                  | Bell's facial palsy           |
| Central disorders                | Migraine                      |
|                                  | Depression                    |
|                                  | Posttraumatic stress disorder |
|                                  | Head trauma                   |
|                                  | Lyme's disease                |
|                                  | Williams syndrome             |
|                                  | BZD dependence                |
|                                  | Serotonin dysfunction         |
|                                  | Tay-Sachs syndrome            |
|                                  | Multiple sclerosis            |
| Benign intracranial hypertension |                               |

A recent study underlined the relationship between tinnitus and hyperacusis in patients with semantic dementia. MRI data from patients with semantic dementia and auditory symptoms evidenced preservation of grey matter in the posterior superior temporal lobe and reduced grey matter in the orbitofrontal cortex and medial geniculate nucleus. Atrophy of the orbitofrontal cortex was associated with tinnitus while atrophy of the medial geniculate nucleus (auditory thalamus) was associated with hyperacusis [19]. These data confirm the involvement of cortical and subcortical auditory pathways and extratemporal areas concerned with the evaluation of sensory stimuli and support previous work indicating the role of alterations in inhibitory central neurons and limbic and autonomous activity [20]. There are specific tests for hyperacusis such as the determination of the loudness discomfort level (LDL), which is generally considered pathological below 90 dBHL [21]. Questionnaires for decreased sound tolerance are useful in the clinical diagnosis and have been developed in these years [22]. With these questionnaires it is possible to evaluate cognitive reactions to hyperacusis, behavioral changes, and emotional responses to external sound [23]. The questionnaire published by Khalfa evaluates attention, social interaction, and emotions [24].

Hyperacusis should be distinguished from phonophobia (fear of sound) and misophonia (dislike towards specific sounds) [25], which are associated with a strong negative emotional response.

Pure phonophobia is rare and is often associated with migraine.

Misophonia is described as a negative reaction to sounds and it results from an enhanced limbic and autonomic response without abnormal enhancement of the auditory system. Misophonia was recently classified as a new psychiatric disorder and considered as an obsessive compulsive spectrum disorder [26]. Edelstein et al. studied behavioural

and physiological characteristics in patients with misophonia. Behavioural aspects were evaluated with interview and they evidenced that the worst trigger sounds are eating, chewing, and crunching sounds [27]. Subjects with misophonia were also studied with skin conductance response (SCR) to measure arousal of the sympathetic nervous system. This is the first experimental investigation on misophonia and interestingly subjects with misophonia showed SCR ratings greater than controls; but it's conceivable an enhanced connectivity between auditory cortex and limbic structures.

It is suggested that the term hyperacusis is used for various types of hearing hypersensitivity and not for a specific range of sounds. Recruitment is frequently confused with hyperacusis; it is an increased loudness perception [28] caused by a dysfunction of the OHC with cochlear hearing impairment. Recruitment is defined as an abnormal increase in the sensitivity to increasing loudness of sound in the affected ear. This phenomenon of recruitment can be used to distinguish between cochlear and retrocochlear impairment. If the hearing is normal, hypersensitivity is always due to hyperacusis (plus or minus misophonia) and never due to recruitment. The differential diagnosis between recruitment and hyperacusis is based on audiological routine tests like tonal and speech audiometry, tympanometry, and acoustic middle ear reflex study. Acoustic brainstem responses (ABR) are useful for a differential diagnosis for retrocochlear diseases, vestibular schwannoma, and neurovascular conflict, together with MRI and angio-MRI.

## 2. Discussion

*Presbycusis* is widely studied also in the elderly with particular focus on risk's factors and predisposing conditions.

Mao et al. studied for the first time audiological characteristics in a centenary population of 74 participants. They found prevalence of "As" type tympanogram, suggesting reduced compliance of the tympanic membrane, a moderate to severe hearing loss below 2000 Hz, and profound hearing loss at 4000 and 8000 Hz. Otoacoustic emissions, which indicated the integrity of cochlear OHC, were undetectable in the majority of listeners [29].

Neurological insults, including hypoxic ischemic stroke, prolonged convulsions, head injury, spinal cord injuries, and profound hypoglycemia, result in neurotoxicity, neuronal death, and neurodegenerative diseases [30].

Some researchers suggested that hearing loss is a risk factor for dementia [31]. The hypothesis is that both hearing loss and progressive cognitive impairment are caused by a common neuropathological process. Supporting this hypothesis, tests of central auditory function, like Dichotic Sentence Identification test and Dichotic Digits tests, have been found to be significantly altered in patients with Alzheimer's disease and also in early stages of cognitive decline like in subjects with mild cognitive impairment [8, 32].

The majority of older people had presbycusis and someone had auditory perceptual abnormalities specially in noise. In the elderly the ability of speech discrimination may be reduced in consequence of modified temporal processing.

Neurophysiological evidence of delayed neural timing and decreased temporal processing ability with age may be consequent to decreased levels of inhibitory neurotransmitters like GABA, as reported in the dorsal cochlear nuclei [33] and auditory cortices [34] of aging animals. Profant et al. [35] demonstrated significant metabolic changes in auditory cortex of old subjects with presbycusis studied with MR spectroscopy. Elderly subjects presented with a decrease of excitatory neurotransmitter glutamate and N-acetyl aspartate (NAA) and high levels of lactate compared with young subjects. Lower levels of NAA may reflect a neuronal damage and higher levels of lactate a reduced protection against oxidative damage. Researches on animal models suggest the role of vascular endothelial growth factor (VEGF) in cochlear vascularization. Alterations of VEGF in elderly may be implicated in reduced angiogenesis and maintenance of tissue vascularization with consequent damages in the vascular network implicated in the maintenance of hearing [36].

Presbycusis has preclinical lesions, which manifest as asymptomatic loss of periphery auditory nerves and changes in the plasticity of the central auditory nervous system. Currently, the diagnosis of preclinical, reversible lesions depends on the detection of auditory impairment by audiological tests and functional imaging like fMRI. Hwang et al. demonstrated in 12 elderly subjects studied with fMRI early functional changes associated with central presbycusis occurring mainly in the posterior part of the left superior temporal gyrus [37].

The medical significance of the symptom of *tinnitus* has been identified as a soft sign of neurodegeneration in the central nervous system (CNS). A neurovascular dysfunction of the central nervous system may trigger or influence the clinical course of the tinnitus itself [38]. It is hypothesized that patients with the occurrence and localization of ischemia and inflammation in regions of the CNS like medial temporal and frontal lobes and the primary auditory cortex may clinically manifest with symptoms of idiopathic subjective tinnitus [39].

The concomitant occurrence of decreased sound tolerance disorders with hearing loss is today object of new lines of research.

In many cases there is not a specific and identifiable cause of *hyperacusis* and the central auditory system is considered the likely culprit. Syndromic hyperacusis is present when it is associated with specific conditions of the central nervous system like allodynia, complex regional pain, and photophobia.

In a recent study Song et al. studied retrospectively resting-state EEG of 17 tinnitus patients with hyperacusis to investigate cortical activity differences in the hyperacusis brain [40]. They evidenced increased beta power in the dorsal anterior cingulate cortex and orbitofrontal cortex. Interestingly, similar alterations are also present in patients with allodynia and hyperalgesia [41]. The principal limitation of the study is the coexistent presence of tinnitus on cortical activity.

In consideration of the old age and the possible comorbidity of depression, the role of serotonin in the modulation

of auditory signals must be considered. As reported by Cruz et al. SSRI may improve the results of auditory processing in elderly patients [42].

Hwang et al. studied 3 patients with hyperacusis by fMRI and they found that the frontal lobes and parahippocampus might be associated with phobic hypersensitivity to unpleasant sounds in patients with idiopathic hyperacusis [43].

Hyperacusis is common among patients with complex regional pain syndrome related dystonia. Hyperacusis in these patients may reflect the spreading of central sensitization to auditory system [44]. Finally, as reported by Hasson et al., women with emotional exhaustion become more sensitive to sound after an acute stress task and had reduced thresholds to loudness. A bereavement, a great sorrow, or a traumatic event can be the cause for the onset of hyperacusis and/or misophonia especially in elderly because of a lower adaptation and resilience.

Patients with normal ULL but seeking help for hyperacusis should be assessed for emotional exhaustion (plasma cortisol concentration and estradiol) [45].

### 3. Conclusion

The most common hearing disorder in elderly is peripheral presbycusis. Peripheral presbycusis is diagnosed with pure tone audiometry and speech audiometry. Currently there are no pharmacologic compounds available that alter the development of presbycusis and tinnitus. In many cases peripheral presbycusis is well treated with hearing aids. Hearing aids combined with sound generators may be useful for patients with tinnitus. Today hearing aids realize an amplified speech signal clear and free of distortion and they have many listening programs for maximum hearing with wideband amplification and minimal compression. However, a significant number of subjects use hearing aids only occasionally for the presence of acoustic feedback problems, excessive amplification, and disturbing background noise and for the absence of counseling to improve motivation in the use of hearing aids. Central presbycusis is associated with central auditory processing disorders and neurodegenerative disorders. Central auditory testing may be considered in the evaluation of older people with central presbycusis in order to realize an individualized program of auditory and cognitive rehabilitation. For example, a musical auditory training is suggested to engage memory and attention for improving synchrony of neural firing and central auditory processing [46]. A psychological assessment is suggested because hearing disorders in elderly are often associated with anxiety and depression, which leads to some forms of resistance to therapy. A population study on 7389 Italian participants over 60 years without dementia revealed a positive association between hearing loss and anxiety syndrome among participants over 75 years [47]. In patients with hearing loss and anxiety syndrome a cognitive rehabilitation may improve the quality of life.

The application of antiaging approaches to the prevention of presbycusis has produced inconsistent results. Future research will focus on the identification of markers for the

diagnosis of preclinical presbycusis and the development of effective interventions.

Respect on presbycusis and tinnitus, low attention is given to hyperacusis and other forms of decreased sound tolerance like misophonia and phonophobia. These disorders may be very invalidating in elderly with consequent social isolation, anxiety, and depression. An appropriate treatment results from the multidisciplinary approach by neurologists, geriatrists, ENT, and psychologists. Professionals, like general practitioners, need more training in the management of patients with hyperacusis. Also patients do not know that their problem has a name and the significance of “hyperacusis.” For this reason exhaustive information and counseling represent an important step which is needed to start the therapy. Both professionals and patients, in some cases, undervalue the disabilities related to hyperacusis and mood problems. The appropriate hyperacusis sound therapy and counseling protocol must be applied for the desensitization of the auditory system. Finally we strongly suggest paying more attention to hyperacusis and related disorders like hyperalgesia. There is close dependence between hyperacusis and hypersensitivity of other sensory systems like visual and somatosensory: in these cases we can hypothesize a multi-sensory disorder (auditory, visual, and somatosensory) or a sensorineural aging. The hypothesis of a hyperresponsiveness network will be validated with additional research on large sample size with neuroimaging.

### Conflict of Interests

The authors declare there is no conflict of interests regarding the publication of this paper.

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