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REVIEW ARTICLE

# Applications of extended high-frequency audiometry: a narrative review

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## Abstract

**Background and Aim:** Hearing loss assessment is typically done using the conventional pure tone audiometry (125 Hz to 8000 Hz). Extended high-frequency audiometry (EHFA), which covers the frequency range of 9000 Hz to 20000 Hz, is a very useful tool for detecting early hearing loss before engaging middle and low frequencies. The involvement of these frequencies significantly affects hearing sensitivity. The purpose of the present study was to review the literature on the early diagnosis of hearing impairment using EHFA.

**Recent Findings:** EHFA has been suggested as a low utilization tool in clinical evaluation. However, in recent years, a great deal of information has been provided in this area. This evaluation has proven to be useful in a variety of areas, including ototoxicity, noise-exposed individuals, and users of personal music devices, hidden hearing loss (HHL), middle ear infections, rheumatoid arthritis, and Sjogren's syndrome.

**Conclusion:** Given the importance and application of this clinical tool in the early detection of hearing loss and its use in conjunction with other evaluations, better care planning and prevention can be offered to patients in some areas.

**Keywords:** Extended high-frequency audiometry; middle ear infections; hidden hearing loss; ototoxic medications; noise exposure; personal music player

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## Introduction

The early diagnosis and prevention of diseases that cause irreversible damage to the normal function of the body are among the important trends of the modern healthcare system [1,2]. Preventions against these damages can also be attributed to the auditory system [1].

Conventional pure tone audiometry assesses auditory thresholds at frequencies between 125 to 8000 Hz. The upper limit of the human audible range reaches 20000 Hz. Also, according to research conducted, frequencies above 8000 Hz are referred to extended high-frequency (EHF) [1-4]. Despite advances in technology, due to lack of facilities and expensive equipment, assessment of extended high-frequencies is not routinely performed in clinical test batteries [2,3].

Acoustic energy of EHF plays an important role in bolding speech cues such as speech perception, especially in noisy environments and sound

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localization [1,2]. In addition, hearing ability will decrease by aging, starting from the highest frequencies and progressively spreading to lower frequencies. In this regard, the evaluation of EHFs can be useful as an early diagnosis approach of hearing loss caused by aging [1,2,5].

The extended high-frequency audiometry (EHFA) covers the frequency range of 9000 Hz to 20000 Hz, therefore, studies have shown that in many cases this assessment can be helpful in the early detection of hearing loss [2,6-12].

## Methods

To collect data for the present study, a total of 49 articles in PubMed, Science Direct, Springer, Elsevier, and Google Scholar databases were reviewed from 2001 to 2020. According to the purpose of the study, the articles were categorized into seven main groups used in diagnosis which include hearing loss diagnosis in users of personal music players, acoustic trauma, otitis media, noise exposure, use of ototoxic medications, hidden hearing loss (HHL), rheumatoid arthritis, and Sjogren's syndrome. The categories and the advantages of EHFA in their diagnosis were reviewed.

## Discussion

### *Noise induced hearing loss*

Hearing loss has been the most common neurological disorder to date [13]. Noise induced hearing loss (NILH) is recognized as the most common preventable disability and the second leading cause of hearing loss after presbycusis. NIHL is permanent and irreversible but preventable [14]. A common method for evaluating NIHL is performing pure tone audiometry at frequencies of 250 to 8000 Hz [11,14]. Other suggested methods for early detection of NIHL are EHFA and otoacoustic emissions (OAEs) [11,15]. Nonetheless, according to Mehrparvar et al. study EHFA is the most sensitive test for detection of hearing loss in persons exposed to hazardous noise compare with conventional audiometry and distortion product acoustic [14]. It has recently been suggested that frequencies above 8000 Hz are more sensitive to noise or ototoxic medications than lower frequencies. Therefore, hearing loss at these frequencies after noise exposure may predict NIHL at lower frequencies (250 to 8000 Hz), particularly in the speech range [15,16]. The first comprehensive audiometric study of the noise exposure effects on high-frequency hearing thresholds was conducted by Sataloff et al. in 1967 [17]. Later, Fillipo used high-frequency hearing measurements to show early signs of hearing loss in young workers [18]. Wang et al. investigated the use of EHFA in the early detection of NIHL in China. In this study, one thousand personnel exposed to noise were evaluated by conventional pure tone audiometry (500 to 8000 Hz) and EHFA (10000 to 20000 Hz). Compared with the control group, subjects exposed to noise showed slight changes in the conventional frequency thresholds, while the hearing thresholds increased at the EHF. Therefore, in ears that are exposed to noise, the change in thresholds in EHF occurs earlier than the conventional frequency range. The absence of responses to maximum output and the changes in thresholds in the EHF can be used as a criterion for early diagnosis of NIHL in assessing people suspected of having noise damage [19]. Many studies have suggested the usefulness and potential role of EHFA as an early indicator of work-related hearing loss [14,15,17,19-21].

### *Hearing loss caused by personal music players*

Noise induced hearing loss (NIHL) is one of the most common occupational injuries [14,15,21]. Occupational hearing loss may be caused by noise, ototoxic medications, and noise exposure [15]. Noise exposure can damage cochlear cells both metabolically and mechanically [22,23]. Repeated exposure to high intensity sounds over long periods can induce a gradual NIHL, probably due to exposure to occupational or recreational noises [10,13]. Many reports have shown the detrimental effects of using a personal music player on hearing. NIHL, after prolonged exposure to broadband noise, has a specific audiometric pattern with a gap in the range of 3000 to 6000 Hz, which is consistent with the initial resonance frequency of the external ear canal

[11].

Personal music player devices such as smartphones, music players, laptops, iPods, and tablets with headphones on or in the ear have made life easier and more enjoyable. The maximum sound output level of music players can reach 100 to 120 dB with a scale of A (dB A), which is equal to the sound level produced by a pneumatic hammer or a chainsaw [13,24].

It is estimated that 5 to 10% of music player users suffer from permanent hearing loss at certain frequencies after several years of use. Since hundreds of millions of music player devices have been sold worldwide, even if a small percentage of devices are used at an unauthorized level, it is likely to expose millions of people to hearing loss caused by noise and make a public health concern [25].

The purpose of the hearing protection program is to detect the cochlear changes caused by noise in the quickest way possible. The question that arises is whether pure tone audiometry has a high sensitivity in the conventional frequency range. Several studies have discussed the use of EHF bands as an alternative or alongside conventional audiometry [11].

With the growing number of personal music player devices among teens, concerns about hearing loss by improper use of these devices have been on the rise. Precise information on the adult use of these devices and their possible effects on hearing sensitivity is limited [25]. The level of intensity of the music played has a major role in the extent of damage to the auditory system. Many music player devices can deliver a maximum output level of 79 dB A to 120 dB A. The deleterious effects of these high output levels are evident. In this respect, National Institute for Occupational Safety and Health (NIOSH) and Occupational Safety and Health Administration (OSHA) as criteria for hearing impairment recommended standard values at 85 dB A and 90 dB A for eight hours per day, respectively. Therefore, adults who use music players at maximum intensity for 15 minutes are likely exposed to the same level of industrial noise as workers may expose 85 dB for eight hours of work per day [13,24]. The intensity of music listened by people depends on various factors such as the type of music, music player device, headphones, and the amount of ambient noise [13].

Kumar et al. conducted a study on 100 participants in age group of 15–30 years. Participants were divided into two groups, the first group consisting of 30 subjects with no history of personal music devices use and the second group having 70 subjects with history of use of personal music devices. The latter group had minimum one h/day use of personal music devices for one year and no exposure to loud noise two days preceding the EHFA. Both conventional pure tone audiometry and EHFA was performed in all the participants. As a result of this study, the duration and volume of using personal music player devices can affect the hearing system. Significant changes have been observed in the auditory thresholds of people who have been using personal music players for more than five years and at least one hour per day based on EHFA (especially at frequencies of 10000 and 13000 Hz). Moreover, there were no significant changes in hearing thresholds in personal music player devices users before 5 years of using these devices [13]. Long-term use of music players may have adverse effects on hearing thresholds [10].

EHFA assesses frequencies in the range of 9000 to 20000 Hz. Therefore, it can be used as a tool for early detection of changes caused by noise from music players. Since music players are used globally by millions of people, even a small percentage of those at risk can become a global hearing problem [13,24].

*Hearing loss caused by acoustic trauma*

Long-term exposure to sounds that are louder than the specified permissible range, or exposure to extremely loud sounds from blasting, etc. may cause hearing disorders. There are two types of hearing losses induced by these loud sounds. In cases that the cochlea changes appear gradually and over time, the hearing loss is called NIHL, but in sudden occurrences of a sound blast, the hearing problem is called an acoustic trauma [26].

Cellular after-effects usually occur 2 min after the acoustic stroke, meaning that they are not instantaneous. Also, the degree of damage and its extent depends on the severity and duration of the noise exposure [26].

NIHL usually results in the loss of outer hair cells (OHCs) in successive rows, and eventually the destruction of the inner hair cells and the loss of their nerves over time.

In acoustic trauma, depending on the severity of the injury, cell damage varies from disrupting stereocilia array to a partial or complete breakdown of sensory hair cells, swelling of the outer hair cells, swelling and rupture of the inner hair cells, the partial or total damage to the tectorial membrane, and organ of Corti destruction [6,26]. Balatsouras et al. found that high-frequency audiometry cannot detect acoustic trauma. This study was performed on 39 young soldiers with hearing loss and tinnitus as a result of working with weapons. Evaluations of conventional frequencies (250 to 8000 Hz) and EHFA (10000 to 20000 Hz) were conducted. The most significant differences compared with the control group in pure tone thresholds were in the frequency range of 250 to 11200 Hz and in particular in the range of 4000 to 8000 Hz. According to the information obtained, EHF does not provide additional data than audiometry of conventional frequencies in the assessment and monitoring of acoustic trauma [6].

*Hearing loss due to otitis media*

Middle ear effusion is a common disease that affects about 80% of children who have experienced at least some periods of otitis media. The most common feature of this problem is hearing loss, which can range from slight to 60 dB HL [26]. Previous studies have been limited to evaluating conventional frequency audiometry (250 to 8000 Hz) in chronic middle ear otitis media [12,27-29].

Several studies have suggested that sensorineural hearing loss (SNHL) may be due to middle ear infection, which has shown associations between chronic middle ear purulent infection and SNHL. Other studies have also suggested that the presence of cochlear hearing loss is due to chronic middle ear purulent infection. It is generally accepted that chronic otitis media leads to cochlear dysfunction [27,28]. A few studies have focused on evaluating hearing status by EHFA in patients with otitis media with effusion [12,29-31]. Dieroff and Schuhmann reported persistent high-frequency hearing loss in a small number of patients with otitis media with effusion [31]. McDermott et al. reported the permanent high-frequency hearing loss at extended high-frequencies (8000-20000 Hz) in patients with injuries in the middle ear or long-term middle ear diseases in compare with control group. Although middle ear effusion may be temporary, in most cases, it is recurrent or fluctuate and may be asymmetric [30].

Sharma et al. conducted a study on high-frequency audiometry in individuals with otitis media with effusion in order to identify the status of EHFs. The results showed a significant difference in the study group among the three frequency bands (low, high, and EHF), suggesting that hearing sensitivity is more affected at certain frequencies (10000, 12000, and 16000 Hz). Thus, the evaluated thresholds in the conventional high frequencies audiometry (2000, 4000, and 8000 Hz) had the least change; but, the conventional low frequencies and extended high frequencies had the most changes, respectively. One of the discussions about high-frequency hearing loss in the study of Sharma et al. was that surgical trauma during inserting the ventilation tube, suction, or its noise may cause damage to the inner ear fluid. Suction’s noise can be loud but short-lived and its frequency is mostly in the range of 1700 to 6000 Hz. The main finding of this study was the increase in extended high-frequency thresholds in individuals with a history of otitis media with effusion [12].

A recent study conducted by Li et al. on 146 patients with acute otitis media (AOM) (69 had an infection in the left ear and 77 in the right ear) found that AOM was closely related to EHF thresholds. During the healing process, symptoms and audiometric thresholds of normal frequencies improve, but EHF thresholds need time to be improved [29].

The EHF thresholds in this disease changes, which cannot be easily detected using conventional frequency audiometry. This study showed that the recovery time of EHF in patients with AOM was later than the audiometric thresholds of conventional frequencies. Therefore, patients with AOM should be identified immediately and their course of treatment started. Long-term follow-up should be considered for these individuals to monitor changes in their EHF thresholds [29].

*Hearing loss caused by ototoxic medications*

Early diagnosis of ototoxic medications by predicting and monitoring it, makes it possible to examine therapeutic changes to minimize or prevent permanent hearing loss and balance disorders. The choice of methods for diagnosing early initial ototoxicity is still debatable, since variables such as high sensitivity, specificity and reliability, less time consumption and less labor-intensive to the patient must be considered [32]. One of the most common applications of EHFs is to monitor the side effects of ototoxic medications in people who take those [33]. Aminoglycosides (AGs) are antibiotics used for gram-negative bacteria [34]. AGs can cause irreversible damage to the inner ear. These medications include gentamicin and streptomycin, which mainly lead to vestibulotoxicity. However, other members of this group of antibiotics such as amikacin, tobramycin, neomycin, dihydrostreptomycin, and kanamycin are mainly cochleotoxic [35-37]. In a study by Al-Malky et al. hearing sensitivity of 45 cystic fibrosis children from hospital was assessed using conventional audiometry (250 to 8000 Hz), EHFA (9000-20000 Hz), and distortion product otoacoustic emissions (DPOAEs) up to 8000 Hz. In the experimental group, who had received intravenous (IV) aminoglycoside, 8 (21%) of all participants had clear signs of ototoxicity; average 8000-20000 Hz thresholds were elevated by ~50dB and DPOAE amplitudes were > 10dB lower at f2 3200-6300 Hz [36]. Cisplatin and carboplatin, which mostly are used as chemotherapy medications for childhood and adolescent cancers, can damage auditory system and the cochlear organs, eventually reducing the bilateral hearing sensitivity [38,39]. In a longitudinal study, Haugnesa et al. evaluated hearing loss and the effect of age on testicular cancer survivors (TCS) treated with cisplatin-based chemotherapy (CBCT). Forty six TCS treated with CBCT 1980-1994 were included in an audiometry (250-20000 Hz), pre-chemotherapy, and in a follow-up study after an average of 10 years (cases). Age and dose of cisplatin were significantly associated with further changes in high tone loss for frequencies 2000-8000 kHz. Cisplatin is associated with moderate hearing loss, especially at higher frequencies (both conventional audiometry and EFHA). Age seems to be an important factor in hearing loss regardless of treatment [40]. For chemotherapy-induced ototoxicity, significant threshold changes occur at the highest measurable frequencies and then continue toward lower frequencies [9,41]. In a study by Abujamra et al. 42 pediatric patients with cisplatin-induced hearing loss were examined using the HFA, and compared with the results of DPOAEs and conventional audiometry. The results show that HFA is more effective in detecting hearing loss, especially at extended high frequencies, than conventional audiometry and DPOAE [42]. Therefore, EHFA as a useful tool allows detecting hearing loss in a short matter of time. Early detection of hearing loss not only alerts clinicians but also provides an opportunity to balance the therapeutic effects of anticancer medications with the risk of permanent hearing loss.[9,41,42].

*Hidden hearing loss*

The term hidden hearing loss (HHL) was first introduced by Yeend et al. [43]. HHL refers to a decline in speech perception in noise despite normal hearing thresholds [44]. Recent studies suggest that the lesion may be due to damage to the outer hair cells or synaptic damage to the nerve fibers of the inner hair cells [44-46]. Studies have shown that OHCs deficiency may occur without an increase in hearing thresholds [43,45,46]. In another research, exposure to severe noise caused synaptopathy without affecting auditory thresholds [43-46]. Standard audiometric evaluation is not sufficient to identify HHL. OAE, electrocochleography, auditory brainstem response (ABR), and EHFA can be effective in assessing HHL [7,47]. Although EHFA cannot predict speech performance in noise, poor speech performance in noise is strongly associated with EHFA thresholds [43,45, 48]. Research has shown the decrease in wave I amplitude in ABR elicited by supra-threshold tone-burst stimuli [7,46]. OAEs, as tools commonly used to assess the natural mechanisms of OHCs, may be affected by cochlear damage earlier, even with normal audiograms [7].

The results of the relevant studies indicate that speech perception in noise is a multifunctional and complex task that is sensitive to a wide range of central and environmental factors such as memory, attention, and EHFs. All of these elements appear to be critical in determining auditory function in noisy environments [45]. EHFA may help identify individuals by reducing the number of hair cells that are not specified in conventional audiometry and provide a way to identify individuals with HHL [7].

*Hearing loss due to rheumatoid arthritis and primary Sjögren syndrome*

Rheumatoid arthritis (RA) is a systemic autoimmune and chronic inflammatory disease that occurs with intra-articular and extra-articular symptoms. In addition to the joints, other organs such as the heart, lung, skin, and eyes may be affected in the long term by direct effects. From this point of view, the hearing system may involve in the RA. The auditory system may be involved during RA due to complications of several pathologies. However, the results of previous studies are not fully consistent with auditory system involvement [49-51]. Primary Sjogren’s syndrome (PSS) is also an autoimmune disease characterized by endocrine dysfunction and lymphocytic infiltration. The incidence of this syndrome is 0.1 to 3%, which cause SNHL in 22.5 to 36.3% of the patient population [52,53].

The association between hearing loss and RA has been investigated in several articles and its prevalence has been estimated to be 1% in normal populations [54]. SNHL is the most common type of hearing loss in RA with an estimated prevalence of 12-80% and in PSS, which is identified by pure tone audiometry and shows a high-frequency hearing loss. These studies have reported middle ear and low-frequency involvement, that makes conductive and mixed hearing losses place in the next highest risk of hearing loss, respectively [8,49-51,55-57]. Galarza-Delgado et al. studied three groups of people with RA and PSS and the control group. According to their results, the mean frequency thresholds of 10,000 Hz to 16,000 Hz in these three groups were 40.1, 43.7, and 28.5 dB, respectively. Studying hearing thresholds in the RA group, the PSS group, and the control group, showed that people with PSS had a higher prevalence of SNHL than RA. The results reflected that there was a greater hearing loss at EHFs (10000-16000 Hz) in RA and PSS subjects compared with the healthy controls [8].

RA and PSS are autoimmune diseases in which the function of the inner ear is compromised [49,58]. The SNHLs seen in autoimmune diseases are highly different in audiometric patterns and their pathology is not clear [59,60]. The high-frequency hearing impairment caused by these diseases may be due to inflammation of the blood vessels or nerve inflammation. Such inflammations affect the cochlea and cochlear nerve and thus result in sensory-neuronal hearing loss in these patients [55-57].

Yildirim et al. identified significant correlations, especially at high frequencies, between hearing loss and RA disease activity [57]. Despite these explanations, there are also conflicting results such as greater conductive hearing loss prevalence and low-frequency hearing loss and even lack of correlation between hearing loss and RA [49,51,61]. Despite normal hearing in RA patients, OAE can be altered by RA, indicating the early stages of RA [50].

To produce DPOAEs, Lobo et al. identified a significant amplitude reduction in the frequency range of 2000 Hz compared to the control group [51]. In contrast, Rahne et al. and Ahmadzadeh et al. did not find any decrease in the OAE range [49,61].

In a case study, de la Vega et al. indicated a 33.6-time higher chance of detecting EHFA hearing loss compared to pure tone audiometry

in RA [56].
As a result of the well-known links of RA and PSS with SNHL and high-frequency involvement, EFHA can be used for the early detection of such diseases [8,62].

## Conclusion

Extended high-frequency audiometry (EHFA), as a tool covering the frequency range of 9000 to 20000 Hz, is very useful in early detection of hearing loss before the involvement of the middle and low frequencies, which significantly affect hearing sensitivity. With the advancement of technology and clinical devices and the placement of this assessment, in addition to other clinical assessments, the likelihood of early detection of diseases will increase and patient care and prevention services will be accelerated.
Recent studies have revealed the efficiency of EHFA in many applications. Some benefits of this tool are its positive impact on early detection of changes caused by noise from music players and increasing the high-frequency thresholds in people with a history of middle ear effusion. Moreover, it serves as an early indicator of occupational hearing loss, a useful tool for ototoxic drug users, and a suitable tool for clinicians to identify individuals with reduced hair cell counts that cannot be found out in conventional audiometry. EHFA also can be considered in identifying individuals with hidden hearing loss and establishing the relationship of rheumatoid arthritis and primary Sjogren's syndrome with sensorinaural hearing loss and the involvement of high-frequency hair cells. This review revealed that high-frequency audiometry does not detect hearing loss caused by acoustic trauma. Finally, it should be noted that paying more attention to this evaluation in the hearing test battery can speed up the diagnosis and increase accuracy.

## Conflict of interest

The authors declared no conflicts of interest.

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