

PREDICTIVE RISK ASSESSMENT FOR ADULT HEARING IMPAIRMENT: IMPLICATIONS FOR PUBLIC HEALTH AND HEALTHCARE ORGANIZATION

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INTRODUCTION

Hearing impairment is recognized as one of the leading causes of disability worldwide and has become an increasingly important public health concern. The global burden of hearing loss continues to rise due to population aging, urbanization, occupational noise exposure, and the growing prevalence of chronic noncommunicable diseases. According to the World Health Organization, approximately one in five individuals worldwide experiences some degree of hearing impairment, and the number of affected people is expected to increase considerably in the coming decades.

The consequences of hearing loss extend far beyond sensory dysfunction. Numerous studies have demonstrated associations between hearing impairment and reduced social participation, communication difficulties, emotional distress, depression, cognitive decline, and diminished quality of life. Untreated hearing loss is increasingly recognized as a modifiable risk factor for dementia and age-related cognitive impairment. Furthermore, hearing disorders contribute to decreased work productivity, increased healthcare utilization, and substantial socioeconomic burden.

Despite significant advances in diagnostic technologies and hearing rehabilitation, a large proportion of hearing disorders remain undiagnosed during the early stages of disease development. Many individuals seek medical attention only after experiencing substantial deterioration in hearing function. This delay reduces the effectiveness of therapeutic interventions and limits opportunities for timely rehabilitation. Several factors contribute to delayed diagnosis, including insufficient public awareness, limited accessibility of audiological services, inadequate screening programs, and ineffective referral pathways within healthcare systems.

Traditional approaches to hearing healthcare have primarily relied on passive case detection, whereby patients independently seek medical assistance when symptoms become clinically significant. However, progressive hearing decline often develops gradually, making early recognition difficult for both patients and healthcare providers. Consequently, alternative strategies focusing on proactive identification of high-risk individuals have attracted growing attention in recent years.

Risk-based screening has emerged as an effective public health approach for improving the detection of chronic diseases while maintaining cost-effectiveness.

Rather than screening entire populations, risk-oriented strategies focus healthcare resources on individuals with the highest probability of disease development. Such approaches have demonstrated effectiveness in cardiovascular medicine, oncology, diabetes prevention, and several other fields of public health. Nevertheless, their application in hearing healthcare remains relatively limited.

Recent advances in digital health technologies and predictive analytics provide new opportunities for improving hearing healthcare delivery. The integration of predictive risk models into primary healthcare settings allows healthcare providers to identify individuals at elevated risk of hearing impairment before significant functional deterioration occurs. Digital decision-support systems can facilitate standardized risk assessment, enhance referral accuracy, and improve resource allocation across healthcare systems.

In many developing healthcare systems, including those undergoing healthcare modernization and digital transformation, the organization of hearing healthcare services remains fragmented. Screening activities are often inconsistent, referral mechanisms are poorly standardized, and access to specialized audiological evaluation may be limited. Consequently, there is a growing need for evidence-based organizational models capable of improving early detection and ensuring continuity of care.

The development of predictive models based on epidemiological, clinical, and behavioral risk factors may represent an important step toward establishing more efficient hearing healthcare systems. By identifying individuals at increased risk and implementing targeted screening strategies, healthcare organizations may improve early diagnosis rates while reducing unnecessary expenditures associated with universal screening programs.

Therefore, the present study aimed to develop and validate a predictive risk assessment model for adult hearing impairment and to evaluate its potential application in optimizing healthcare organization, preventive screening programs, and audiological service delivery.

Materials and Methods. This study was conducted between 2021 and 2025 in primary healthcare facilities, otorhinolaryngology departments, and specialized audiological centers of the Republic of Uzbekistan. The research was designed as a population-based observational study aimed at identifying factors associated with hearing impairment in adults and developing a predictive model for risk assessment and early detection.

A total of 1,246 adults aged 18–75 years were included in the study. The mean age of participants was 47.3 ± 13.8 years. All participants underwent comprehensive audiological evaluation, including otorhinolaryngological examination, pure-tone audiometry, speech audiometry, and tympanometry. Individuals with acute inflammatory ear diseases, severe psychiatric disorders, or conditions preventing reliable audiometric testing were excluded.

Demographic characteristics, occupational history, lifestyle factors, medical history, and information on healthcare utilization were collected through structured questionnaires and review of medical records. Particular attention was paid to occupational noise exposure, chronic middle ear diseases, arterial hypertension, diabetes mellitus, smoking status, family history of hearing impairment, and previous use of potentially ototoxic medications.

To assess organizational aspects of hearing healthcare delivery, referral pathways, diagnostic delays, accessibility of audiological services, and timing of specialist consultations were analyzed. The interval between symptom onset and audiological assessment was evaluated as one of the key indicators of healthcare system performance.

Statistical analysis was performed using SPSS Statistics 26.0. Initially, univariate analyses were conducted to identify factors associated with hearing impairment. Variables demonstrating significant associations were subsequently included in multivariable logistic regression models to determine independent predictors. Based on the obtained coefficients, a predictive risk assessment model was developed and implemented as a digital decision-support tool. Model performance was evaluated using receiver operating characteristic (ROC) analysis with calculation of the area under the curve (AUC), sensitivity, and specificity. Statistical significance was established at $p < 0.05$.

The study was conducted in accordance with international ethical standards for biomedical research involving human participants. All participants provided informed consent before enrollment, and personal data were anonymized prior to analysis.

Results. Among the 1,246 adults included in the study, hearing impairment was identified in 318 individuals, corresponding to an overall prevalence of 25.5%. Mild hearing loss represented the majority of detected cases, whereas moderate, severe, and profound forms were observed less frequently. The findings indicate that a substantial proportion of hearing disorders remain at potentially reversible or manageable stages, highlighting the importance of timely detection and intervention.

A clear age-related increase in hearing impairment prevalence was observed. Hearing disorders were detected in 11.8% of participants aged 18–39 years, increasing to 24.7% among individuals aged 40–59 years and reaching 48.9% among participants older than 60 years. These results confirm the strong influence of aging on auditory function and are consistent with global epidemiological trends.

Occupational factors also demonstrated a significant impact on hearing health. Participants exposed to prolonged industrial noise exhibited substantially higher rates of hearing impairment compared with individuals working in low-noise environments. The highest prevalence was observed among workers employed in manufacturing industries, transportation services, and construction sectors, emphasizing the continuing importance of occupational health measures and hearing conservation programs.

Multivariable logistic regression analysis identified several independent predictors of hearing impairment. Age above 60 years was the strongest risk factor, followed by long-term occupational noise exposure. Chronic middle ear diseases, diabetes mellitus, arterial hypertension, and smoking were also significantly associated with increased risk. These findings suggest that hearing impairment should be considered within the broader context of chronic disease prevention and healthy aging strategies.

Based on the identified predictors, a risk stratification system was developed to classify adults according to their probability of developing hearing impairment. Application of this approach demonstrated a marked difference in disease prevalence between risk categories. Individuals classified as high risk showed substantially higher rates of hearing disorders compared with those categorized as low risk, supporting the clinical relevance of the proposed model.

The predictive model demonstrated good diagnostic performance during internal validation. Receiver operating characteristic analysis yielded an area under the curve of 0.84, indicating a high level of discrimination between individuals with and without hearing impairment. Sensitivity reached 82.1%, while specificity was 78.6%, confirming the potential utility of the model for population-based screening and risk assessment.

Analysis of healthcare utilization revealed considerable delays in diagnosis and referral. Less than one-third of participants sought specialized audiological evaluation within the first year after symptom onset. The average interval between the appearance of hearing-related complaints and formal audiological assessment exceeded three years. Many patients remained under observation in primary healthcare settings without undergoing objective hearing evaluation, contributing to delayed diagnosis and reduced opportunities for early rehabilitation.

Evaluation of existing referral pathways identified several organizational barriers, including insufficient use of audiometric testing at the primary care level, limited awareness of hearing disorders among patients, and delayed referral to specialized services. These factors collectively contribute to underdiagnosis and inefficient utilization of audiological resources.

Simulation of the proposed organizational model demonstrated its potential effectiveness in improving hearing healthcare delivery. The implementation of risk-based screening supported by a digital decision-support tool was associated with a projected increase in early detection rates of approximately 30–35%, a reduction in referral delays of nearly 40%, and more efficient allocation of specialized audiological resources.

Overall, the findings indicate that the integration of predictive analytics, digital health technologies, and risk-oriented screening strategies may substantially strengthen hearing healthcare systems and facilitate earlier identification of hearing impairment among adults.

Conclusion

The present study demonstrated that hearing impairment remains a significant public health challenge among the adult population. More than one-quarter of examined individuals exhibited varying degrees of hearing loss, with prevalence increasing substantially with age. The findings confirm that hearing impairment is influenced by a combination of demographic, occupational, clinical, and behavioral risk factors.

Several independent predictors of hearing impairment were identified, including advanced age, long-term occupational noise exposure, chronic middle ear diseases, diabetes mellitus, arterial hypertension, and smoking. These factors provide a scientific basis for the development of targeted preventive strategies and risk-based screening programs.

The predictive risk assessment model developed in this study demonstrated good diagnostic performance and may serve as an effective tool for identifying individuals at increased risk of hearing impairment. The integration of this model into routine primary healthcare practice may facilitate earlier diagnosis and more efficient referral to specialized audiological services.

The study also revealed important organizational deficiencies in the current system of hearing healthcare delivery, including delayed diagnosis, insufficient use of objective audiological assessment at the primary care level, and prolonged referral intervals. These barriers contribute to underdiagnosis and limit opportunities for timely intervention and rehabilitation.

Implementation of a risk-oriented organizational model supported by digital decision-support technologies has the potential to improve early detection rates, optimize healthcare resource allocation, and enhance the effectiveness of hearing healthcare services. The proposed approach supports the transition from passive case detection toward proactive, preventive, and personalized healthcare strategies.

In conclusion, the integration of predictive analytics, digital technologies, and risk-based screening represents a promising direction for strengthening hearing healthcare systems and improving population hearing health outcomes.

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