Development of a Medical Kiosk for Hearing: Implementation of an Artificial Intelligence-Based Early Diagnosis System for Hearing Loss

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INTRODUCTION

- The rapid advancements in Artificial Intelligence (AI) that are transforming various sectors have yet to be fully utilized in the field of audiology. Traditional hearing assessments, such as pure-tone audiometry (PTA), rely on labor-intensive processes that limit accessibility, particularly for early detection of hearing loss.
- In this context, integrating AI into hearing tests, such as pure-tone audiometry, represents a significant technological innovation within the field. Therefore, the present study aims to develop a AI audiometry device based on kiosk, referred to as WithHearing, for the purpose of hearing test, and to conduct comprehensive verification and validation of the device.
- WithHearing is an audiometry solution designed to improve early detection of hearing loss and accessibility to audiometry through AI-powered self-monitoring and screening. It combines automated pure-tone audiometry(PTA), AI-based tympanic membrane(TM) analysis, and standardized questionnaire(RHHI-K; Revised Hearing Handicap Inventory) to provide comprehensive hearing tests. The user-friendly kiosk design can be placed anywhere, not just in medical settings, making hearing tests readily available without the need for audiologist or equipment.
- WithHearing introduces three key innovations to hearing healthcare:
  1) **Accessible and Comprehensive Hearing Assessments**: WithHearing integrates multiple diagnostic tools—automated PTA, AI TM analysis, and questionnaires—into a single, user-friendly device. This integration enables reliable hearing tests in various environments without the need for specialized personnel.
  2) **Early detection of hearing loss with AI:** Based on hearing bigdata, WithHaring combines audiometric data with AI-driven TM analysis to facilitate early detection of hearing loss, enabling timely intervention and effective hearing management.
  3) **Real-Time AI-Powered Guidance:** The AI chatbot provides instant, personalized consultations on hearing loss and hearing aid options, offering expert advice on demand to empower informed decisions and facilitate access to further support.

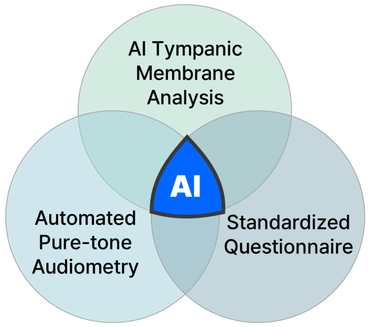

Fig 1. Key Features and Components of WithHearing

RESULTS

WithHearing Process

- The product, WithHearing, is an AI-based hearing test device that operates on a kiosk (or tablet) platform. It was developed as a hearing screening and monitoring tool through dedicated software and equipment (standard audiometric headphone, e.g., DD65v2). Users interact with the device via a touchscreen on the kiosk (or tablet) where the software is installed, proceeding through steps that include personal information input, standardized questionnaire, automated pure-tone audiometry, and AI-driven tympanic membrane examination. After all tests are completed, the user can receive the test results in PDF format via a message.

Automated pure-tone audiometry

- Based on the Type 4 Audiometer defined in IEC 60645-1: 2017, we ensured and verified performance in terms of frequency and intensity. Specifically, the performance criteria were secured as follows: Frequency range: 0.25-8 kHz, Intensity range: 0-110 dB, Frequency accuracy: ±2.5%, Intensity accuracy: ±3.7-6.2 dB (0.25 to 4 kHz: ±3.7 dB, 6,000 and 8,000 Hz: ±6.2 dB). The threshold measurement method follows the Ascending Method as described in ISO 8253-1: 2010, where the intensity of the stimulus sound automatically increases (or decreases) based on the subject's response, allowing automatic measurement of the hearing threshold for each frequency.

AI tympanic membrane analysis

- We derived the receiver operating characteristic (ROC) curve to assess the optimal conditions for detecting eardrum diseases based on individual substructures or their combinations. The combination of the malleus, cone of light, and umbo yielded the highest area under the curve (AUC) at 0.911, outperforming the AUC values of 0.737 to 0.873 obtained for each substructure individually. Therefore, an algorithm incorporating these five key normal anatomical structures demonstrates potential for both explainability and effectiveness in screening for abnormal tympanic membranes.

Questionnaire (RHHI-K; Revised Hearing Handicap Inventory for Korean)

- In the study, 201 participants were categorized based on hearing impairment levels, and descriptive statistics were reported for each group. The RHHI-K demonstrated high internal consistency (Cronbach's α=0.968) and strong test-retest reliability (r=0.814, p=0.00). Construct validity was confirmed through significant correlations with audiometric measures, including PTA (r=0.682–0.683), SRT (r=0.626), PBmax (r=-0.569), and MCL (r=0.619). Exploratory factor analysis identified a single dominant factor, "self-reported hearing handicap," with high factor loadings (0.783–0.913). ANOVA revealed significant differences in RHHI-K scores across hearing loss categories (F=30.611, p=0.000), with post hoc analysis showing significant pairwise differences between groups (normal to profound).

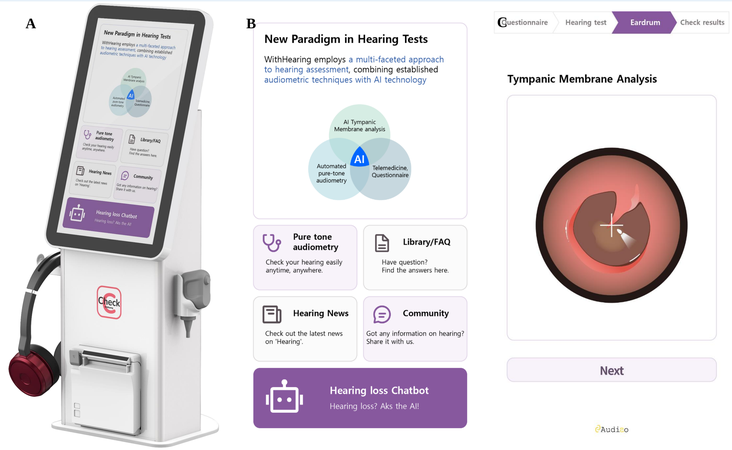

Fig 2. WithHearing Hardware and Software Structure and Functions.A: WithHearing Exterior, B: Initial Home Screen, C: Self-Ear Drum Image Capture Instruction

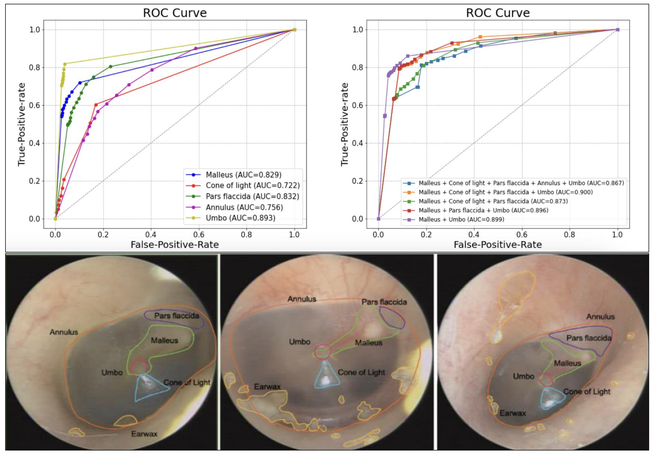

Fig 3. ROC Results and Labeling Example for the AI tympanic membrane model

METHODS

Automated pure-tone audiometry

- The automated pure tone audiometry system was developed to meet the equipment for pure-tone and speech audiometry specified in IEC 60645-1A: 2017. It automatically adjusts stimulus levels based on the subject's responses ("hear" or "can't hear") to measure hearing thresholds across various frequencies. The screening version conducted at 500, 1000, 2000, and 4000 Hz, with the option to include 250 and 8000 Hz for standard audiometry. The threshold estimation method follows the Ascending Method as described in ISO 8253-1: 2010.

AI tympanic membrane analysis

- To develop AI for tympanic membrane analysis, a retrospective study utilized tympanic membrane images from patients who attended the clinic at the Department of Otorhinolaryngology, Wonju Severance Christian Hospital, from 2015 to 2020. In total, 2,597 tympanic membrane (TM) images were considered suitable and included in the analysis.
- Labeling was conducted on five regions (Malleus, Cone of Light, Pars Flaccida, Annulus, and Umbo) for training and analysis, achieving an AUC greater than 85% in tympanic membrane image inference. The WithHeargin system enables users to capture images of their own TM with the otoscope provided by WithHearing, and receive AI-driven analysis and interpretation of the TM images.

Standadized questionnaire

- The Revised Hearing Handicap Inventory (RHHI) was adapted into a Korean version (RHHI-K), and its reliability and validity were assessed with a sample of 201 participants. To ensure reliability and validity, analyses included Cronbach's alpha coefficient, confirmatory factor analysis, test-retest analysis, and correlation with pure tone audiometry. Finally, WithHearing utilizes the Revised Hearing Handicap Inventory for Korean (RHHI-K) to measure subjective discomfort related to hearing loss.

AI hearing chat bot

- To predict the frequently asked questions (FAQs) of current and prospective hearing aid users, text-based data was gathered from publicly available sources provided by leading hearing aid manufacturers, including Beltone, Oticon, Philips, Phonak, Resound, Rexton, Signia, Starkey, Unitron, and Widex. In total, 990 responses were collected (33 questions × 3 chatbots × 10 repetitions). The authors meticulously reviewed these responses to extract the most accurate and commonly recurring answers.Following this review, a finalized list of 33 question-answer pairs was developed and subsequently presented to experts, hearing-impaired individuals, and their guardians for evaluation.

CONCLUSIONS

- The AI-based medical kiosk developed for audiometry provides several key advantages: (1) it integrates three distinct hearing assessments into a single device, (2) it eliminates the need for specialized personnel to conduct audiometry, and (3) it ensures high diagnostic reliability by utilizing AI and adhering to international standards. Consequently, the widespread adoption of these kiosk audiometers could significantly promote the early diagnosis of hearing loss while enabling systematic management and facilitating expert referrals.
- Early detection and management of hearing loss are essential for preserving quality of life and preventing social isolation. The accessibility of WithHearing's AI-powered kiosk empowers individuals to monitor their hearing health proactively, facilitating early interventions and promoting overall well-being. By making hearing assessments both readily available and user-friendly, WithHearing contributes to a more inclusive and supportive society for those experiencing hearing loss.

KEY REFERENCES

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