

Original Article

# Behavioral Evaluation of 3 Smartphone-Based Hearing Aid Apps for Patients with Mild Hearing Loss: An Exploratory Pilot Study

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**BACKGROUND:** The aim of this study was to evaluate the behavioral performance of a selection of currently available hearing aid apps in patients with mild hearing loss.

**METHODS:** We investigated 3 user-friendly hearing aid apps (EarMachine, Sound Amplifier, and Petrallex) with real-ear measurement, warble-tone audiometry, word recognition testing in unaided and aided conditions, and hearing-in-noise tests in quiet and noise-front conditions in a group of users with mild hearing impairment (n = 7) as a pilot for a future long-term investigation. Results from the apps were compared with those of a conventional hearing aid.

**RESULTS:** Hearing aids showed greater gain at 1 and 3 kHz than hearing aid apps in real-ear insertion gain of real-ear measurements. Hearing aids tended to have greater gain than hearing aid apps at 2 and 3 kHz in the sound field audiometry test. The clinical performance of the listeners tended to be better when using a hearing aid and Petrallex (13% and 6% improvement in word recognition score, respectively), while EarMachine and Sound Amplifier conferred limited user benefit. The hearing aid apps did not improve signal-to-noise ratio in comparison with the unaided condition in the hearing-in-noise test.

**CONCLUSIONS:** Some hearing aid apps were beneficial for patients with mild hearing loss in terms of amplification, but participants using the apps showed no improvements in hearing-in-noise tests.

**KEYWORDS:** Hearing aid apps, hearing loss, smartphone, hearing aids, hearing disability

## INTRODUCTION

In 2018, the World Health Organization estimated that there were 466 million people worldwide with hearing loss and that this would be likely to increase up to 900 million by the end of 2050.<sup>1</sup> Despite considerable evidence of the benefits of using conventional hearing aids,<sup>2</sup> much of the hearing-impaired population has not undergone any hearing rehabilitation. Numerous barriers to hearing aid adoption still remain in different parts of the world, including cost,<sup>3</sup> lack of availability of trained professionals,<sup>4</sup> the acceptance of hearing loss stigmatization, and lack of internal or external motivations.<sup>5</sup> It follows that many with hearing impairment wait a long time before seeking treatment (8.9 years on average).<sup>6</sup> Despite the need for a better understanding, the literature has already highlighted relationships between hearing disabilities and the incidence of dementia and other later-life disorders.<sup>7,8</sup> Therefore, early intervention may be crucial to reduce the influence of hearing impairment on these adverse events. Currently, numerous devices are available for people with mild-to-moderate hearing loss; however, this population is more likely to wait for their hearing to worsen before seeking interventions.

A number of diverse solutions are being developed to reach larger numbers of hearing-impaired people. Governments are aware that hearing impairment is an important public health concern, and some are participating in improving accessibility to hearing care,

for example, by training specialists and by helping patients to finance these services. Nevertheless, these initiatives are mostly insufficient and a considerable proportion of people with hearing impairment remain underserved. As an intermediate step in the process of hearing care, there have been a number of advances in hearing loss prevention and awareness globally. For example, hearing test apps (e.g., HearWHO, HearZa, Ear scale, and Hearing Test) allow self-screening and provide information and advice to users. Studies have shown that such apps can be useful in settings where conventional pure-tone audiometry is not available<sup>9</sup> or for large-scale hearing screening.<sup>10</sup> Hearing-based apps are also considered to have the potential as gaming and exercise tools to improve cognitive performance, which can decline with age and other adverse events.<sup>11</sup> Furthermore, there is a diversification of devices for hearing enhancement. Access without a medical prescription to low-cost hearing amplifiers, such as personal sound amplification products or over-the-counter hearing aids, is now widespread.

In hearing care or other fields, direct-to-consumer devices set aside the requirement of a specialist, to increase accessibility to health care. This raises the question of whether they can maintain a suitable degree of quality. The development of wearable health devices is increasing, and they show great potential to benefit the aging population despite numerous concerns about data privacy and management, controlled standards, and quality requirements.<sup>12</sup> Therefore, there is a need to investigate the effectiveness of hearing aid apps as an intermediate solution for people without access to hearing care or people who wait a long time to seek help.<sup>13</sup> However, these studies showed that there were many perceptible differences between the different apps, with some attempting to be as close as possible to what a hearing aid can provide, while others position themselves only as basic hearing amplifier apps.<sup>13–16</sup> Moreover, few apps have been investigated, which makes the current overall conclusion about their benefits difficult to generalize.

This was a pilot study designed for a future evaluation of hearing aid apps under real-world conditions. The objective of the study was to evaluate their potential immediate benefits to users with mild hearing loss in a controlled environment.

## METHODS

### Hearing Aid Apps, Devices, and Test Equipment

Three authors independently searched for hearing aid apps with the aim of providing information on the apps most likely to be found and used around the world. Therefore, as a first approach, we focused the search using the most commonly represented operating systems. The search was conducted in April through the App Store from Apple and Google Play using the keywords “hearing aid apps,” “sound amplifier,” and “hearing amplifier.” At the same time, we searched for apps on the search engines Google, Safari, and Naver with the addition of “smartphone” and “mobile” to the list of keywords. The search engines allowed us to determine which apps were the most cited and to identify those providing information about their developers and their structure. After the search using keywords, we identified the different apps that would match the criteria of the smartphone-based app. That is, apps that record sound from the environment using a microphone on the smartphone, process and amplify those sounds, and then transmit them through the earbuds to the user. Based on the apps that appeared most frequently at the top of the search results and the number of downloads when available, we selected 14 among a total of 27 apps initially identified. Seven were available on iOS and 7 were available on Android, with only 1 app (Petralex) available on both operating systems (Table 1).

We selected Sound Amplifier, Petralex app for Android, which was most popular among android apps and is updated regularly, and EarMachine app for iOS. We used an iPhone 8 (Apple Inc., Cupertino, Calif, USA) for iOS apps, a Galaxy S8 (Samsung, Seoul, South Korea) for

**Table 1.** Hearing Aid Apps, Listed by Mobile Operating System, Number of Installations, Provider, and In-App Purchase Information

Apps	No. of Installations	Provider	Optional In-App Purchases
iOS			
EarMachine	N/A	EarMachine LLC	Free
Jacoti		Jacoti	Free
Mobile ears		Listen AS	Free
Hearing aid: sound enhancer		Emre Turgay	\$1.99/week, \$6.49/month
Fennex		Adam Palmquist	\$4.99/month, \$49.99/year
Listening device, hearing aids		Alexander Bredikhin	\$9.99/week, \$15.99/month \$59.99/year
Petralex		IT4YOU	\$5.99/month, \$59.99/year
Android			
Sound amplifier	10 000 000+	Google LLC	Free
DaMic	1 000 000+	SoomSoft	Free
Petralex	500 ,000+	IT4YOU	\$5.99/month, \$59.99/year
Super ear	500 000+	Liberation studio	Free
EarShot	50 000+	Raja Muhammad Abdullah	Free
Hearing aid master	50 000+	Sennikpro	Free
Hearing aid maximizer	10 000+	SinCUR	Free

android apps, and 2 wired earbuds with built-in microphones provided with the smartphone by each manufacturer: Apple A1748 earpods with lightning connector and Samsung EO-IG955 earbuds tuned by AKG. We considered these devices to be among the most common types available to users because they were bundled with the mobile device. In addition, the earbuds were initially calibrated according to the corresponding smartphone, thereby accurately transmitting the sound level delivered by the device and controlling the output. We placed the earbuds into the participant's ear canals toward to eardrum and it would represent an everyday listening setting. For the hearing aid, we tested the Siya 1 miniRITE coupled with two 85 dB receivers and single closed-ear tips (Oticon, Smorum, Denmark) with advanced features turned off, and the microphone directivity was omni microphone setting. All measurement materials were calibrated before the tests.

### Recruitment

Eight fluent Korean speakers (2 males, 6 females; mean age 65.6 years, range 23-79 years) were selected from among patients who visited the Department of Otolaryngology of Seoul National University Hospital. Ethical committee approval was received from the Ethics Committee of Seoul National University Hospital (approval no: 2003-028-1109). All participants provided written informed consent for the present study. The inclusion criteria were acquired symmetrical, sensorineural, mild-to-moderate hearing loss, and currently using a smartphone. They did not have any previous experience with hearing amplification. We excluded those with external and middle-ear disease or anomalies and other communication problems. One of them did not complete the study due to withdrawal of consent. Due to technical problems, word recognition score (WRS) data from another patient were excluded from the data analyses. The pure tone average (PTAs) of each ear were calculated at 0.5, 1, 2, and 4 kHz. We considered mild hearing loss as a PTA range of 26-40 dB HL (WHO, ASHA). Otoscopy, pure-tone audiometry by air and bone conduction, and tympanometry were performed to confirm sensorineural hearing loss. The study was approved by the Institutional Review Board of Seoul National University Hospital (No. 2003-028-1109), Seoul, South Korea.

### Real-Ear Measurement

Real-ear measurement was performed using Affinity 2.0 software (version 2.6.0; Interacoustics). We manually adjusted the gain control and parameters of the apps to match the targets. For hearing aids, this measurement is used to set the output based on the amplification target determined by the audiometric thresholds of the patient. All devices were set according to the NAL-NL2 targets prescribed for input levels of 65 dB SPL using the real-ear measurement to represent conversation sound level.<sup>17,18</sup>

### Warble-Tone Audiometry Thresholds and Word Recognition Scores in Unaided and Aided Conditions

Before warble-tone audiometry threshold could be tested, Interacoustics AC 40(Interacoustics, Middelfar, Denmark) were calibrated. Sound-field audiometry was administered to the listener in both unaided and aided conditions (i.e., with the hearing aid apps and hearing aid) to measure the improvement in warble-tone audiometry at 0.5, 1, 2, 3, 4, and 6 kHz. We used a warble-tone to avoid standing waves. We calculated the WRS (percentage of words correctly repeated) using Korean standard monosyllabic word lists<sup>19</sup> as

a quiet speech test, which was composed of lists of monosyllabic words unknown to the subject. Twenty-five monosyllabic words per condition were presented at 50 dB HL under unaided and aided conditions as fixed output levels to find out the effectiveness of hearing aid and smartphone-based hearing aid apps. We then calculated the mean and standard deviation for the WRS under both conditions.

### Hearing-in-Noise Test

The listener was played a list of 20 hearing-in-noise tests (HINTs) sentences per condition alongside stationary noise.<sup>20</sup> The speech and noise were initially presented at 65 dB SPL (0 dB SNR) via a loudspeaker located in front of the participant. Using the transformed up-down methods described by Levitt in 1971 which is estimated percentile points other than 50% as stimulus level is increased or decreased after specific sequences of stimuli and responses.<sup>21</sup> The level of the subsequent sentence was adjusted based on the response of the listener, while the noise levels remained constant. For the HINT, the subject was positioned 1 m in front of the speaker, and the speech reception threshold (SRT; sound level for the listener to achieve correct answers 50% of the time) in quiet and noise front conditions. The signal-to-noise ratio (SNR) needed for listeners to achieve correct answers 50% of the time was determined at a fixed level for the stimuli and by adjusting the sound level of the noise. Both measurements were conducted under unaided and aided conditions.

## RESULTS

### Real-Ear Measurement

In real-ear insertion gain, hearing aids without advanced features showed greater gain at 1000 and 2000 Hz than hearing aids apps. EarMachine and Sound Amplifier apps showed greater gain at the 250 and 500 Hz than hearing aids, respectively (Figure 1).

### Warble-Tone Audiometry Thresholds and Word Recognition Scores in Unaided and Aided Conditions

EarMachine and Sound Amplifier apps tested here tended to have lower gain than the hearing aid at 2 and 3 kHz, respectively (Figure 2). Petrallex showed a slightly inferior gain from 1 to 3 kHz. The 3 apps also had lower WRS than the hearing aid, although the difference was not significant (Figure 3). We observed average speech intelligibility of 90% and 76% with the hearing aid and the EarMachine app, respectively, with the latter being only a slight improvement over the unaided condition. Petrallex showed a better improvement of 6% over the unaided condition. The Sound Amplifier app showed no improvement compared with the unaided condition.

### Hearing-in-Noise Test

Participants using the hearing aid showed consistent improvements in SNR in both quiet and noisy conditions (Figure 4). However, participants using the hearing aid apps showed no improvements in SNR compared with the unaided condition.

## DISCUSSION

Our results showed that the hearing aid generally improved the listening conditions of subjects more than the EarMachine and Sound Amplifier apps. Additional data showed that Petrallex had a higher WRS and, therefore, it could improve the intelligibility of speech.

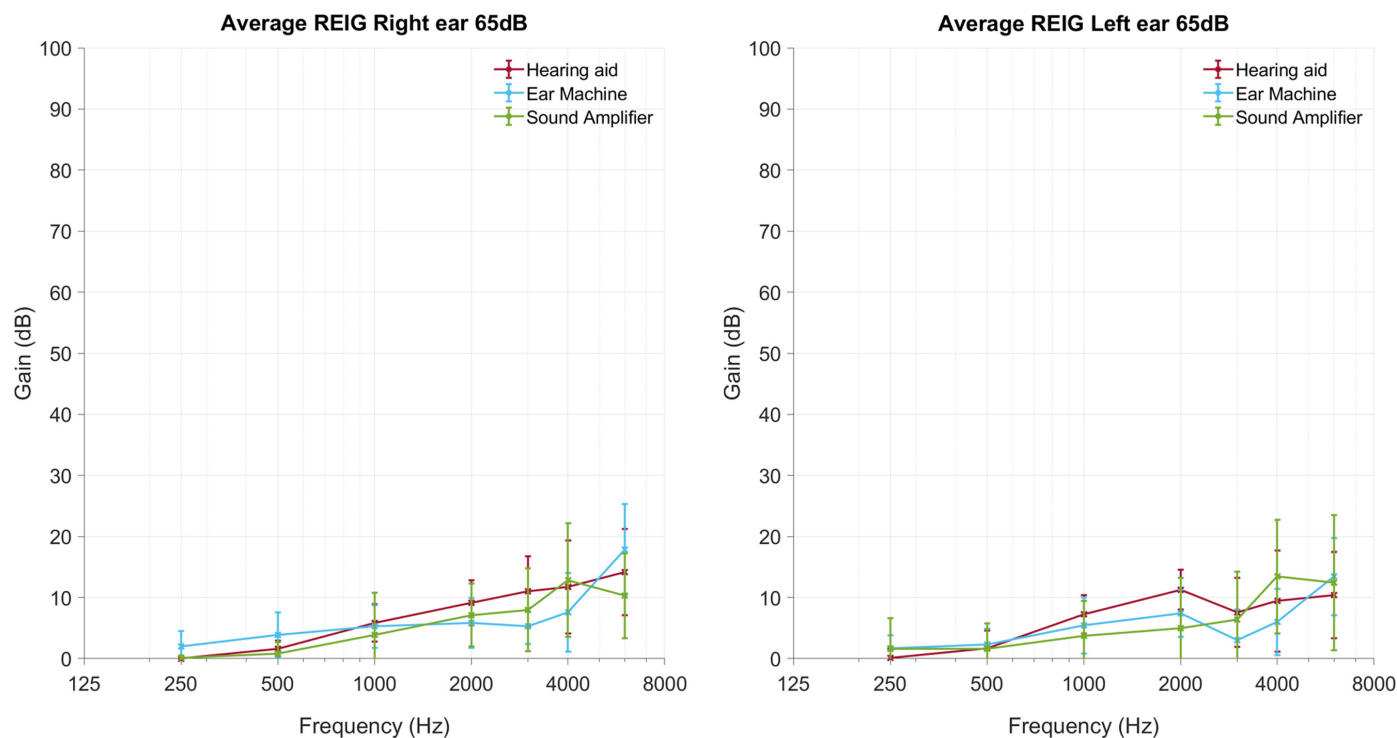


Figure 1. Real-ear insertion gain measured in subjects. REIG, real-ear insertion gains.

Unexpectedly, none of the tested apps consistently improved speech recognition by users, although there was a slight shift in tests with EarMachine. Hearing-impaired users with the apps showed worse performance than those with the hearing aids on warble-tone audiometry because of lower gain at mid and high frequencies, which are important for speech understanding, but higher gain at a low frequency, which may worsen the speech understanding because of the upward spread of masking.<sup>22</sup> When using the apps, no differences were observed compared to the unaided condition except with Petralelex when calculating the WRS. These results indicate that the tested low-end apps may be unsuitable, and the single high-end app tested in this study might be more appreciated for the middle

hearing loss patients. This study did not compare the advanced signal processing techniques such as noise canceling, speech enhancement, or microphone directionality. These techniques would improve the sound quality of devices. The sound quality of hearing aid apps would be another important consideration in real-world conditions.<sup>15,16</sup>

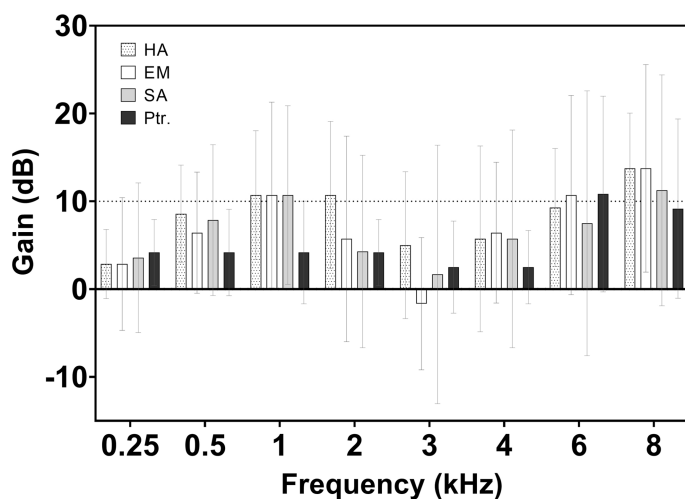


Figure 2. Average sound-field warble-tone thresholds under unaided and aided conditions via a hearing aid or one of 3 apps (Petralelex, EarMachine, and Sound Amplifier).

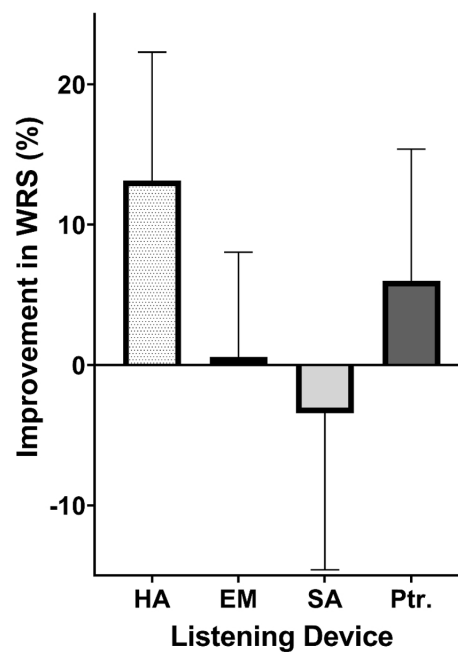
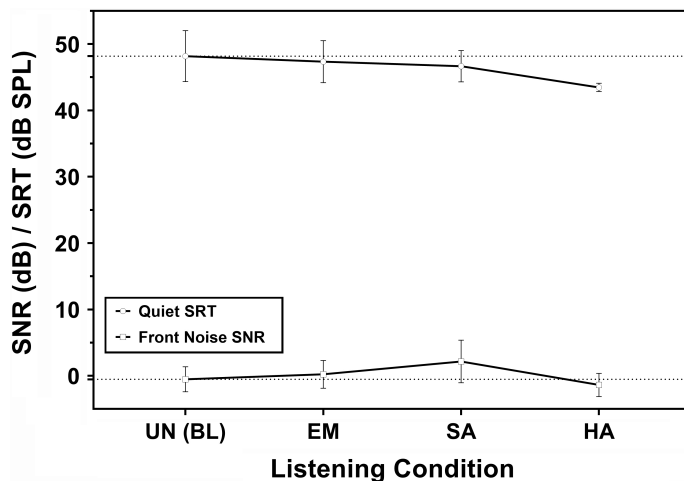


Figure 3. Improvement in word recognition scores compared to the unaided condition via a hearing aid or one of 3 apps (EarMachine, Sound Amplifier, and Petralelex). Error bars indicate standard deviation. HA, hearing aid; EM, EarMachine; SA, Sound Amplifier; Ptr, Petralelex.



**Figure 4.** HINT results in quiet (dotted line) and noisy (full line) conditions when participants were either unaided (UN) or aided (via a hearing aid or the EarMachine or Sound Amplifier apps). Error bars indicate standard deviation. EM, EarMachine; HA, hearing aid; HINT, hearing-in-noise test; SA, Sound Amplifier; SRT, speech reception threshold; SNR, signal-to-noise ratio.

Apps are a fairly recent development, and their use is not currently widespread. Few studies have examined their sound quality or investigated their benefits to users over behavioral evaluations. Diverse electroacoustic data were collected and analyzed for some apps, while speech-in-noise was mostly used for behavioral evaluation. The general conclusion in the current literature is that hearing aid apps may be a viable intermediary before rehabilitation with a hearing aid.

To benefit the user, direct-to-consumer hearing devices first need to fulfill the requirements of usability and sound quality. Examinations of the usability parameter must answer the question: “Does it work?” De Sousa<sup>15</sup> investigated the processing delay and other functional parameters of hearing aid apps. They reported that some apps performed poorly in terms of processing delay. Indeed, hearing devices need to be able to process the sound in a time short enough to improve speech perception. Intelligibility may be altered even if the quality of amplification itself is suitable.<sup>23–25</sup> Numerous methods and parameters are available to evaluate the sound quality of a hearing device. The commonly used standards described by the American National Standards Institute (ANSI)<sup>26,27</sup> and the International Electrotechnical Commission (IEC)<sup>28</sup> are used to check the specifications of hearing aids as described by their manufacturers. These references have already been used for the electroacoustic analysis of direct-to-consumer hearing devices,<sup>29</sup> including some hearing aid apps.<sup>13</sup> Sound quality parameters related to the hardware or to certain features of apps were also investigated. Medwetsky<sup>16</sup> studied the influence of the earbuds used with a smartphone and De Sousa<sup>15</sup> analyzed the SNR improvement achieved with the NR feature. These devices do not need to pass safety tests within the scope of medical standards. However, these apps are made for hearing loss users. Therefore, we compared the behavioral performance on the basis of the commonly used methods for an aided hearing evaluation.

Compared with similar studies,<sup>13,15,16,30</sup> this pilot study had too few subjects to provide general conclusions regarding the improvement of speech intelligibility. Further investigations with a larger sample

size will allow us to compare more apps to hearing aids in terms of benefits under real-world conditions. We focused on low-end apps that were easy to use, which we considered a significant advantage for first-time users. We aimed to choose the earbuds bundle that would be most highly represented. The earbuds bundle may not provide enough high frequencies. Recently, the earbuds bundle shows better performance than the previous one in the high frequencies. In addition, high-end earphones and earbuds would provide the higher frequency gain and improve the final output.<sup>16</sup>

The accessibility and convenience of using apps are clearly advantageous, but may not offer enough benefits to use them when hearing impairment becomes significant. A number of apps have been introduced as hearing amplifiers, while others are marketed as hearing aids. Generalizing access to hearing care through smartphone-based apps also means increasing diversity without fixed standards. As in other fields of science, generalization and greater access to previously unavailable tools result in lower or missing quality control. Hearing aid apps are a response to a need for hearing care, but there is also a need for reliability. To generalize health care, a balance between the development of new tools and defined quality requirements is necessary. Apps that are regularly updated and the growing development of direct-to-consumer devices may allow hearing aid apps to play a more important role in hearing rehabilitation and awareness of the population in the future. We also expect major international companies to explore and invest in the development of access to health care, for example, Google has produced the app “Sound Amplifier,” and Apple Computer is also developing a hearing amplifier or hearing aid tool that will be accessible through their operating system.

**Ethics Committee Approval:** Ethical committee approval was received from the Ethics Committee of Seoul National University Hospital (approval no: 2003-028-1109).

**Informed Consent:** Written informed consent was obtained from all participants who participated in this study.

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