Original Article

Feasibility of Personal Sound Amplification Products in Patients with Moderate Hearing Loss: A Pilot Study

Running title: Feasibility of PSAPs in Patients with MHL

Ga-Young Kim, BS$^{18}$; Jong Sei Kim, MD$^{28}$; Mini Jo, BS$^1$; Hye Yoon Seol, AuD$^1$; Young Sang Cho, MD$^{1,2}$; Il Joon Moon, MD, PhD$^{1,2}$

$^1$Hearing Research Laboratory, Samsung Medical Center, Seoul, Korea
$^2$Department of Otorhinolaryngology-Head and Neck Surgery, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea

Co-first authorship

$^	ext{8}$These authors contributed equally to this work.

Address for correspondence
Il Joon Moon, MD, PhD
Department of Otorhinolaryngology-Head & Neck Surgery,
Samsung Medical Center, Sungkyunkwan University School of Medicine,
81 Irwon-ro, Gangnam-gu, Seoul, 06351, Korea
Tel: +82-2-3410-3879
Fax: +82-2-3410-3579
E-mail: moon.iljoon@gmail.com
Sources of Financial Support

"This research was supported by a grant of Patient-Centered Clinical Research Coordinating Center funded by the Ministry of Health & Welfare, Republic of Korea (grant number: HI19C0481, HC19C0128)."

ORCID (Open Researcher and Contributor ID)

Ga-Young Kim: https://orcid.org/0000-0002-8945-4927
Jong Sei Kim: https://orcid.org/0000-0002-1798-817X
Mini Jo: http://orcid.org/0000-0002-8197-811X
Hye Yoon Seol: https://orcid.org/0000-0002-7040-1884
Young Sang Cho: https://orcid.org/0000-0002-4040-7206
Il Joon Moon: https://orcid.org/0000-0002-3613-0734

Author Contributions

Conceptualization: G-YK, JSK, MJ, HYS, YSC, IJM.
Data curation: G-YK, JSK, MJ.
Formal analysis: G-YK, KSK.
Funding acquisition: YSC, IJM.
Methodology: G-YK, JSK, MJ, HYS, YSC, IJM.
Project administration: G-YK, JSK, IJM.
Visualization: G-YK, JSK.
Writing – original draft: G-YK, JSK, MJ, IJM.
Writing – review & editing: G-YK, JSK, HYS, IJM.
Feasibility of Personal Sound Amplification Products in Patients with Moderate Hearing Loss: A Pilot Study

Abstract

Objectives: To confirm the feasibility of personal sound amplification products (PSAPs), the study was conducted for three purposes: 1) to investigate electroacoustic characteristics of PSAPs, 2) to identify whether PSAPs provide adequate gain and output for three common hearing loss configurations, and 3) to compare the benefit of one representative PSAP (RPSAP) to a conventional hearing aid (HA) based on clinical hearing outcomes as a pilot study.

Methods: The study consisted of three phases: electroacoustic analysis, simulated real-ear measurements (REMs), and clinical hearing experiments. Electroacoustic analysis and simulated REMs were performed in three basic (BeethoSOL, EarJJang, and Geniesori2) and three high-end PSAPs (Hearing Able, Olive Smart Ear, and SoriIn) using the Aurical Hearing Instrument Test box with a 2cc coupler. With regards to electroacoustic analysis, four electroacoustic characteristics (maximum output sound pressure level at 90 dB SPL, frequency range, equivalent input noise, and total harmonic distortion) were investigated. By simulated REMs, the appropriate level of the six PSAPs for three common hearing loss configurations (mild-to-moderate high-frequency hearing loss, moderate to moderately severe sloping hearing loss, and moderate flat hearing loss) was determined. Clinical experiments were carried out for the purpose of comparing the performance of RPSAP to HA. Before conducting clinical experiments, both RPSAP and HA were fitted by audiologists using REMs. Clinical experiments were administered using functional gain, a word recognition test, and the Korean version of the Hearing in Noise Test in six participants with bilateral
Results: With regards to electroacoustic analysis, two high-end devices met all tolerances. In the case of simulated REMs, one basic and two high-end PSAPs showed appropriate level for three common hearing loss configurations. As for the clinical experiments, the RPSAP showed better performances than unaided, but slightly worse than HA under all test conditions.

Conclusion: Our results demonstrated that certain PSAPs met all specified tolerances for electroacoustic analysis and had ability to approximate prescriptive targets in a well-controlled laboratory condition. The pilot clinical experiments explored the possibility that RPSAP could be served as a hearing assistive device for patients with moderate hearing loss.

Keywords: Hearing Loss, Hearing Aids, Personal Sound Amplification Products, Electroacoustic Analysis, Real-Ear Measurements.
HIGHLIGHTS

1) High-end personal sound amplification products (PSAPs) satisfied most of the tolerances for specifying electroacoustic data.

2) PSAPs showed sufficient amplification towards the prescriptive targets when their gain could be adjusted across frequencies through a smartphone application.

3) The pilot clinical hearing experiments explored the possibility that PSAP could be served as a hearing assistive device for patients with moderate hearing loss.
According to World Health Organization estimates, over 5% of the world’s population suffers from hearing loss and the numbers are expected to increase to one for every ten people by 2050 [1]. The number of patients with hearing loss in Korea increased from 277,000 in 2012 to 349,000 in 2017; this represents a 25% increase over a period of five years [2]. Untreated hearing loss is a major health and social problem. Moreover, hearing loss can be associated with cognitive functions [3]; therefore, proactive hearing rehabilitation is needed for people with hearing loss.

The uptake rate of hearing aids in patients with hearing loss remains relatively low all over the world in spite of the negative consequences of hearing loss. The uptake rate of hearing aids in Korea was 17.4% based on the data from a national survey [4]. Reasons reported in the study conducted by the Korean National Evidence-based Healthcare Collaborating Agency (NECA) are as follows: inconvenience in wearing hearing aids (49.1%), hearing aid purchase and maintenance cost (46.4%), and stigma associated with hearing aids (37.1%) [5].

Among these reasons, cost is a critical barrier for hearing aid acquisition. While the average cost for a hearing aid is currently around $2,000, individuals are willing to pay less than the average cost when purchasing the devices [5]. Thus, over-the-counter (OTC) hearing devices, including personal sound amplification products (PSAPs), may have a potential as a less expensive alternative for hearing aids.

To accommodate this rise in interest, in the United States, the President’s Council of Advisors on Science and Technology (PCAST) recommended that the Food and Drug Administration (FDA) should approve hearing devices for OTC sale to promote access to hearing technology for people with hearing loss [6]. FDA plans to develop regulations for
publicly available OTC products for consumers with mild to moderate hearing loss by the year 2020 [7]. However, under current regulations, PSAPs should not be advertised as a device that can compensate for hearing loss.

PSAPs, one of the OTC hearing devices, were originally designed for the purpose of amplifying ambient sounds for hunting, bird watching, and listening to long distance lectures. However, it has recently been used to manage hearing loss. There have been several studies showing PSAPs as alternatives to conventional hearing aids for mild to moderate hearing loss [8-10]. However, these previous studies investigated that PSAPs were not prescribed using best-practice protocols, such as real-ear measurements (REMs). All hearing assistive devices perform the best when appropriately fitted by hearing experts. Therefore, it is important to properly fit PSAPs with the purpose of hearing compensation. The objectives of this study are three-fold: 1) to investigate electroacoustic characteristics of PSAPs, 2) to identify whether PSAPs provide adequate gain and output for three common hearing loss configurations, and 3) to compare the benefit of one representative PSAP to a conventional hearing aid based on clinical hearing outcomes as a pilot study.

MATERIALS AND METHODS

Phase 1. Electroacoustic analysis

Six PSAPs were selected based on the following inclusion criteria: The PSAPs needed to 1) be distributed in Korea, 2) be readily accessible to the public, and 3) have measurable electroacoustic characteristics. The PSAPs were divided into two price groups based on the retail cost for a pair: a basic group consisting of three devices (BeethoSOL, EarJJang, and Geniesori2) and a high-end group consisting of three devices (Hearing Able, Olive Smart Ear,
and SoriIn). All PSAPs used in this study are presented in Table 1.

Electroacoustic measurements were performed for all devices using the Aurical Hearing Instrument Test (HIT) box and the OTOsuite software (GN Otometrics A/S, Denmark). An HA-1 2cc coupler was used to measure all devices, except for one device. One BTE (behind the ear) device (SoriIn) was analyzed using an HA-2 coupler.

Tolerances for specifying electroacoustic data were established based on previous studies [11,14]. Maximum output sound pressure level at 90 dB SPL (OSPL 90 Max) represents the maximum output of a device when the input SPL is 90 dB with the gain control of the device set to its full-on position. The OSPL 90 Max tolerance was set to be no greater than 120 dB SPL. The frequency range refers to the range between the minimum and maximum frequencies given an input of 60 dB SPL with the reference test setting of the gain control (RTS). The frequency range includes the speech frequency range of 250-6000 Hz. The equivalent input noise (EIN) refers to the noise produced by the device during amplification with the gain control in the RTS. A tolerance of EIN was less than 28 dB SPL. The total harmonic distortion (THD) is measured at the gain control in the RTS using a pure-tone input signal at three different frequencies: 70 dB SPL at 500 Hz and 800 Hz and 65 dB SPL at 1,600 Hz. The THD was not to exceed 3% at any given frequency.

Phase 2. Simulated real-ear measurements

In the second phase of the study, simulated REMs were performed with a 2cc coupler. Three common configurations of hearing loss (mild-to-moderate high-frequency hearing loss, moderate to moderately severe sloping hearing loss, and moderate flat hearing loss) were used according to previous study [11]. The devices were placed in the Aurical HIT box and aided responses were measured at moderate input signal of 65 dB SPL. The appropriate level of the devices was adjusted to match as closely as possible the National Acoustics
Laboratories-Non-Linear prescription, 2\textsuperscript{nd} generation (NAL-NL2) targets. The appropriate level of device was determined by whether the difference between the NAL-NL2 target and aided response at seven frequencies (0.25, 0.5, 1, 2, 3, 4, and 6 kHz) was within 10 dB SPL.

Five out of seven frequencies or above was considered “appropriate level” for that hearing threshold [11].

Phase 3. Clinical outcomes

Lastly, we conducted clinical experiments to identify the utility of one representative PSAP by comparing their performance to a conventional hearing aid for patients with bilateral moderate hearing loss (pure tone average of the 4-frequency averages at 0.5, 1.0, 2.0, and 4.0 kHz, 41-55dB of hearing loss). The hearing aid used were ReSound LiNX 3D LT962-DRW, denoted as the HA. Olive Smart Ear, denoted as the RPSAP, was selected as the representative PSAP for these experiments based on three reasons. First, the RPSAP met all tolerances in electroacoustic analysis. Second, the RPSAP showed appropriate gains for three common hearing loss configurations. Third, the RPSAP could adjust gains across frequencies using a corresponding smartphone application. Before conducting clinical experiments, both the HA and RPSAP were fitted by audiologists using REMs. The RPSAP had a corresponding smartphone application that allows users to adjust the device’s frequency response and volume. The test was first performed in unaided condition, and then the HA and RPSAP were put on in order and measured immediately without acclimatization period.

Six participants (one man and five women) were recruited from the outpatient clinic of the department of otolaryngology. Individuals who met the following eligibility criteria were included: patients who are under 70 years of age, who have bilateral moderate sensorineural hearing loss, and who are judged to have no abnormalities in the eardrum through otoscopy with a type A tympanogram. The mean age of the participants was 58.17 (SD = 6.18) years.
The individual audiogram of each six patients were described in Figure 1. All but one participant (Subject5) had no experience wearing hearing aids. The demographics and characteristics of the individual patients were shown in Table 2.

Clinical experiments were administered using functional gain, a word recognition test, and the Korean version of the Hearing in Noise Test (K-HINT). Functional gain is defined as the difference in dB HL between aided and unaided sound-field thresholds at test frequencies (0.25, 0.5, 1, 2, 3, 4, and 6 kHz). The results of functional gain testing are equal to real-ear insertion gain (REIG) [12]. Functional gain was assessed using a front loudspeaker in a quiet sound-treated booth. Aided sound-field thresholds using FM (frequency modulation) signals centered at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz were obtained using the ASHA-recommended procedure [13]. Subjects were seated in a sound booth 1 m from a loudspeaker at 0˚ azimuth. All tests were performed at bilateral aided state. The functional gain is obtained by subtracting the unaided threshold from the aided threshold. Unaided thresholds are measured to tones presented through the loudspeaker 1m front of the patient. Aided thresholds are made using the same stimuli. The differences between the two represent the functional gain provided by HA and PSAP.

The word recognition test in sound-field was measured at 50 dB HL to obtain word recognition scores (percentage of correct recognition). Participants were asked to repeat 25 words from one of the Korean Standard-Monosyllabic Word Lists for Adults (KS-MWL-A) [15]. K-HINT [16] was used to measure reception thresholds for speech both in quiet and in front noise conditions. The unit of measure for threshold in the quiet condition is dB[A]. The unit of measure for threshold in the noise condition is the dB S/N ratio.

This study was approved by the institutional review board (IRB) at [Samsung] in accordance with the Declaration of Helsinki (IRB file No. SMC 2020-05-052-001).
Statistical Analysis

The statistical language R was used for the data analysis (version 4.0.2, R foundation for Statistical Computing, Vienna, Austria). Wilcoxon signed-rank test was used to compare functional gain of the HA and PSAP.

RESULTS

Phase 1. Electroacoustic analysis

With regards to OSPL 90 Max, five devices (BeethoSOL, EarJJang, Geniesori2, Hearing Able, Olive Smart Ear, and SoriIn) were within the tolerance limits (< 120 dB SPL). As for the frequency range, four (EarJJang, Geniesori2, Olive Smart Ear, and SoriIn) out of the six devices met the tolerance (250-6000 Hz). In the case of EIN, three devices (Hearing Able, Olive Smart Ear, SoriIn) were within the acceptance tolerance (< 28 dB SPL). In THD, only the BeethoSOL device showed less satisfactory performance, generating a value of 3% or higher at 800 Hz (4.5%). In summary, two high-end devices (Olive Smart Ear and SoriIn) met all tolerances. All results are presented in Table 3.

Phase 2. Simulated real-ear measurements

In the case of mild-to-moderate high-frequency hearing loss, the output was not adequate for three devices. The two basic devices (EarJJang and Geniesori2) featured excessive amplification in low and middle frequencies. One high-end device (SoriIn) displayed a lack of amplification at frequencies above 3 kHz. As for the moderate to moderately severe sloping hearing loss, the basic devices exhibited a tendency to excessively amplify low
frequencies and insufficient gain at high frequencies. The high-end devices also showed a lack of amplification at the high frequencies. In terms of moderate flat hearing loss, most devices bore adequate levels at all frequencies. However, one device (EarJJang) had excessive amplification in the low and medium frequencies. In summary, one basic (BeethoSOL) and two high-end PSAPs (Hearing Able and Olive Smart Ear) showed appropriate level for three common hearing loss configurations. All results are presented in Table 4.

**Phase 3. Clinical outcomes**

**Functional gain**

The differences in functional gain between HA and PSAP was analyzed. There were no statistically significant differences between HA and PSAP in functional gain for each frequency. The functional gain of was presented by box plot with individual data in Figure 2. Although not statistically significant, hearing aid showed better performance than RPSAP under most of conditions.

**Word recognition test**

The mean percentage score of the word recognition test was 48.7% in the unaided conditions, 82% in HA conditions, and 78% in RPSAP conditions. However, there were no statistically significant differences between HA and RPSAP (Fig. 3).

**The Korean version of the hearing in noise test**

The mean threshold of K-HINT in quiet conditions was 46.4 dB[A] in the unaided conditions, 36.9 dB[A] in the HA conditions, and 38.9 dB[A] in the RPSAP conditions. The mean
threshold of K-HINT in front noise conditions was 2.0 dB S/N in the unaided conditions, 1.4 dB S/N in the HA conditions, and 1.6 dB S/N in the RPSAP conditions. However, the difference between HA and RPSAP was not statistically significant (Fig.3). Figure 4 shows the results of K-HINT for each participant.

**DISCUSSION**

This study was undertaken in order to explore the capabilities of PSAPs as a communicative assistive device and provide evidence to make appropriate recommendations to patients. Our results demonstrated that certain PSAPs met all specified tolerances for electroacoustic measurements and had ability to approximate target gain in a well-controlled laboratory condition. The pilot clinical experiments also explored the possibility that RPSAP could be served as a hearing assistive device for patients with moderate hearing loss.

Our results indicated that high-end PSAPs are comparable to conventional hearing aids in terms of their electroacoustic testing results. All three high-end PSAPs performed within three or more of the defined tolerance limits. On the other hands, basic PSAPs did not meet most of the tolerances. Manufacturers presented their devices’ electroacoustic information on their website. However, most of this information contained one or two components of electroacoustic testing and the terms were not unified. Two devices (BeethoSOL and Olive Smart Ear) offered detailed information, but had somewhat different results obtained from our study. For instance, the maximum output sound pressure level of the Olive Smart Ear was 112.8 dB SPL (± 3dB SPL) in their specification sheet, but it was 97.2 dB SPL in our study.

One reason may be that their measurement methods may have been different. There is no international standard for electroacoustic analysis of PSAPs [11, 14]. In other words, the varying range of these tested values might be due to the heterogeneity of electroacoustic
measurement procedures.

By simulating REMs, we confirmed that the gains of PSAPs were adjusted to the NAL-NL2 targets in line with three common hearing loss configurations. Regardless of the price and hearing loss configurations, frequency responses were able to meet NAL-NL2 targets when the manufacturer provided a corresponding smartphone application. It is highly important to accurately adjust hearing devices in accordance with the user’s auditory characteristics. Therefore, when considering a PSAP for auditory rehabilitation purposes, users need to confirm whether the PSAP can adjust levels for each frequency. In moderate to moderately severe sloping hearing loss, the gain was insufficient for high frequencies, even when the difference between aided responses and the targets were within the acceptable criteria (±10 dB SPL). These results are consistent with prior study showing that the functionality of PSAP is not sufficient for moderately severe hearing loss [9]. Furthermore, two basic PSAPs provided excessive low-frequency gain leading to problems with discriminating speech sounds due to the highly amplified noise [17].

Finally, we investigated whether the RPSAP was clinically suitable for patients with bilateral moderate hearing loss. For the word recognition test and K-HINT, the RPSAP and HA performed better than the unaided condition, and the RPSAP performed similarly to the HA. These findings demonstrated that the RPSAP could improve communication in quiet and noisy conditions to a similar extent as HA for patients with moderate hearing loss. This study is a preliminary study for future research, and it is difficult to significantly define the clinical outcomes owing to a small sample size. However, many previous studies have reported that PSAPs could improve communication skills in patients with mild to moderate hearing loss [8-10]. In addition, our study is significant in that the clinical experiments were conducted after performing REMs for both HA and RPSAP.

A number of studies have investigated various PSAPs in parallel with OTC hearing
devices, and have considered PSAPs as being a more affordable option for individuals with mild to moderate hearing loss [8-10]. To the best of our knowledge, this is the first study reporting that PSAPs are considered as hearing assistive devices in Korea. Considering that the majority of the individuals with hearing loss is elderly [18], it is difficult for them to purchase PSAPs that are primarily sold overseas. Hence, this study has significance in demonstrating electroacoustic properties and simulated REMs’ outcomes of the PSAPs readily available in Korea. Our results provide the preliminary data for otolaryngologists, audiologists, and other hearing care professionals when they recommend PSAPs to patients with mild-to-moderate hearing loss.

This study had several limitations. First, clinical experiments were only conducted on six patients diagnosed with moderate sensorineural hearing loss. Because the number of patients was so small, there was a limitation in statistical analysis. The moderate hearing loss group is expected to be the target patients for PSAPs. Nevertheless, the patients who had ski-slope type hearing loss or moderate-to-severe hearing loss would benefit less from the use of PSAPs, because several reports mentioned that PSAPs do not provide sufficient gain for high frequencies, so patients have very low satisfaction with PSAPs [19]. So, further investigations will need to include more participants with various types of hearing loss for generalization of the results. Secondly, the RPSAP was adjusted using best-practice protocols. In the majority of cases, prospective users may have to adjust the PSAPs on their own. In order to estimate the benefit of PSAPs in the real-world, it is necessary to measure clinical outcomes under self-adjusted condition. In actually, acclimatization period is necessary to identify the exact benefits of hearing aid devices. However, this was not been applied in the current study. Finally, this paper presented a comparative study between the RPSAP and HA. In the near future, additional research will need to be conducted with randomized controlled trials that contribute a higher level of evidence. PSAPs fitted by audiologists provide
sufficient aided audibility and similar speech recognition performance in quiet and in noisy conditions compared to HA condition in patients who present flat type moderate hearing loss. 

PSAPs could be served as a feasible, budget-friendly option for those who cannot afford hearing aids or are seeking a low-cost introduction to amplification.
REFERENCES


2. National Health Insurance Service (NHIS). Hearing loss. Management of hearing loss, such as amplification and aural rehabilitation, is necessary depending on regular ENT check up results. [cited 2020 Apr 03]. Available from: https://www.nhis.or.kr/bbs7/boards/B0039/25983?boardKey=14&sort=sequence&order=desc&rows=10&viewType=generic&targetType=12&targetKey=14.


FIGURE LEGENDS

Figure 1. Individual audiogram for the participants.

Figure 2. Functional gain of hearing aid (HA) and representative personal sound amplification product (RPSAP) for 6 participants by frequency; (A) 250Hz, (B) 500Hz, (C) 1000Hz, (D) 2000Hz, (E) 3000Hz, (F) 4000Hz, (G) 6000Hz, (H) 8000Hz. Functional gain is defined as the difference in dB HL between the aided and unaided thresholds. The overlapping dots and gray lines indicate the individual change. The Rhombus shape indicates the mean of results.

Figure 3. Average results of the Word Recognition Score (WRS) and Korean version of the Hearing in Noise Test (K-HINT) for Hearing aid (HA) and representative personal sound amplification product (RPSAP). The overlapping dots and gray lines indicate the individual change. The Rhombus shape indicates the mean of results.
Figure 4. Results of the Korean version of the Hearing in Noise Test (K-HINT) for each patient. (A) Individual results of K-HINT in quiet, (B) Average results at each condition of K-HINT in quiet, (C) Individual results of K-HINT in noise, (D) Average results at each condition of K-HINT in noise. The Rhombus shape indicates the mean of results.
Table 1. Demographics and Characteristics of the Individual Patients

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Sex</th>
<th>Age</th>
<th>PTA (Right)</th>
<th>PTA (Left)</th>
<th>WRS (Right)</th>
<th>WRS (Left)</th>
<th>Tinnitus</th>
<th>HA use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>60</td>
<td>53.25</td>
<td>55.00</td>
<td>80</td>
<td>76</td>
<td>Both</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>56</td>
<td>41.25</td>
<td>51.25</td>
<td>100</td>
<td>98</td>
<td>Both</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>54</td>
<td>46.25</td>
<td>42.50</td>
<td>88</td>
<td>96</td>
<td>Both</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>68</td>
<td>48.25</td>
<td>46.25</td>
<td>92</td>
<td>88</td>
<td>None</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>53</td>
<td>50</td>
<td>51.25</td>
<td>96</td>
<td>96</td>
<td>Left</td>
<td>Yes</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>61</td>
<td>41.25</td>
<td>45</td>
<td>84</td>
<td>96</td>
<td>Both</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 2. Characteristics of the PSAPs included in this study

<table>
<thead>
<tr>
<th>Devices</th>
<th>Model No.</th>
<th>Manufacturer</th>
<th>Retail cost</th>
<th>Price group</th>
<th>Bluetooth</th>
<th>Smartphone Application</th>
<th>Channel</th>
<th>Feedback cancellation</th>
<th>Noise reduction</th>
<th>Self-fitting</th>
<th>Preset mode</th>
<th>Other features</th>
</tr>
</thead>
<tbody>
<tr>
<td>BeethoSOL</td>
<td>EM-C110</td>
<td>EM-Tech</td>
<td>$210/Pair</td>
<td>Basic</td>
<td>o</td>
<td>o</td>
<td>5</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td></td>
</tr>
<tr>
<td>EarJJang</td>
<td>VA-3000</td>
<td>ESONIC</td>
<td>$167/Pair</td>
<td>Basic</td>
<td>x</td>
<td>x</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Geniesori2</td>
<td>HA1000</td>
<td>UWICOM</td>
<td>$198/Pair</td>
<td>Basic</td>
<td>o</td>
<td>x</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Hearing Able</td>
<td>IRIS20</td>
<td>Microtech System</td>
<td>$244/$253/Single</td>
<td>High-end</td>
<td>o</td>
<td>o</td>
<td>20</td>
<td>NS</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>SVS (Smart Voice Sender) mode, Dual microphone</td>
</tr>
<tr>
<td>Olive Smart Ear</td>
<td>DHFA2FBK</td>
<td>Olive Union</td>
<td>$139/$139/Single</td>
<td>High-end</td>
<td>o</td>
<td>o</td>
<td>16</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>Equalizer</td>
</tr>
<tr>
<td>SorIn</td>
<td>YDH-B1000</td>
<td>The Yeolrim</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Price groups were determined based on the retail cost for a pair.

NS, Not stated.
### Table 2. Demographics and Characteristics of the Individual Patients

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Sex</th>
<th>Age</th>
<th>PTA (Right)</th>
<th>PTA (Left)</th>
<th>WRS (Right)</th>
<th>WRS (Left)</th>
<th>Tinnitus</th>
<th>HA user</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>60</td>
<td>53.75</td>
<td>55.00</td>
<td>80</td>
<td>76</td>
<td>Both</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>56</td>
<td>41.25</td>
<td>51.25</td>
<td>100</td>
<td>98</td>
<td>Both</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>51</td>
<td>46.25</td>
<td>42.50</td>
<td>88</td>
<td>96</td>
<td>Both</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>68</td>
<td>48.75</td>
<td>46.25</td>
<td>92</td>
<td>88</td>
<td>None</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>53</td>
<td>50</td>
<td>51.25</td>
<td>96</td>
<td>96</td>
<td>Left</td>
<td>Yes</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>61</td>
<td>41.25</td>
<td>45</td>
<td>84</td>
<td>96</td>
<td>Both</td>
<td>No</td>
</tr>
</tbody>
</table>
Table 3. Electroacoustic analysis of the PSAPs included in this study

<table>
<thead>
<tr>
<th>Devices</th>
<th>Electroacoustic analysis results</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>500 Hz</th>
<th>800 Hz</th>
<th>1600 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OSPL90 Max (dB SPL)</td>
<td>Frequency range (Hz)</td>
<td>EIN (dB SPL)</td>
<td>THD (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BeethoSOL (Basic)</td>
<td>115.9</td>
<td>293-8030</td>
<td>32.4</td>
<td>2.4</td>
<td>4.5</td>
<td>2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EarJJang (Basic)</td>
<td>119.6</td>
<td>100-7178</td>
<td>39</td>
<td>0.4</td>
<td>0.2</td>
<td>2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geniesori2 (Basic)</td>
<td>123.7</td>
<td>100-7735</td>
<td>35.4</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hearing-Able (High-end)</td>
<td>103</td>
<td>100-3717</td>
<td>26.7</td>
<td>0.9</td>
<td>1</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olive Smart Ear (High-end)</td>
<td>97.2</td>
<td>215-6650</td>
<td>27.4</td>
<td>1.8</td>
<td>0.6</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SoriIn (High-end)</td>
<td>109.6</td>
<td>100-7024</td>
<td>26.9</td>
<td>0.7</td>
<td>0.5</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bold face indicates measured values deviated from the tolerance defined in methods section.

EIN, equivalent input noise; OSPL90 Max, maximum output sound pressure level at 90 dB SPL; THD, total harmonic distortion.
<table>
<thead>
<tr>
<th>Input level: 65 dB SPL</th>
<th>Mild-to-moderate high-frequency hearing loss</th>
<th>Appropriate fit</th>
<th>Moderate to moderately severe sloping hearing loss</th>
<th>Appropriate fit</th>
<th>Moderate flat hearing loss</th>
<th>Appropriate fit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency (kHz)</td>
<td></td>
<td>Frequency (kHz)</td>
<td></td>
<td>Frequency (kHz)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>0.5</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>BeethoSOL (Basic)</td>
<td>Targeted (dB SPL)</td>
<td>57</td>
<td>57</td>
<td>53</td>
<td>60</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>Fit to prescription</td>
<td>2</td>
<td>8</td>
<td>1</td>
<td>-7</td>
<td>4</td>
</tr>
<tr>
<td>EarJiang (Basic)</td>
<td>Targeted (dB SPL)</td>
<td>57</td>
<td>57</td>
<td>53</td>
<td>60</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>Fit to prescription</td>
<td>28</td>
<td>36</td>
<td>21</td>
<td>5</td>
<td>-6</td>
</tr>
<tr>
<td>Genesio2 (Basic)</td>
<td>Targeted (dB SPL)</td>
<td>57</td>
<td>57</td>
<td>53</td>
<td>60</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>Fit to prescription</td>
<td>27</td>
<td>26</td>
<td>15</td>
<td>4</td>
<td>-6</td>
</tr>
<tr>
<td>HearingAble (High-end)</td>
<td>Targeted (dB SPL)</td>
<td>57</td>
<td>57</td>
<td>54</td>
<td>61</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>Fit to prescription</td>
<td>-2</td>
<td>1</td>
<td>-2</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>Olive Smart Ear</td>
<td>Targeted (dB SPL)</td>
<td>57</td>
<td>57</td>
<td>54</td>
<td>62</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>Fit to prescription</td>
<td>-6</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>-2</td>
</tr>
<tr>
<td>SorIN (High-end)</td>
<td>Targeted (dB SPL)</td>
<td>57</td>
<td>57</td>
<td>53</td>
<td>62</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>Fit to prescription</td>
<td>-2</td>
<td>2</td>
<td>9</td>
<td>-4</td>
<td>-12</td>
</tr>
</tbody>
</table>

Bold face indicates that the difference between the target and response levels is more than ±10 dB SPL.
**Figure 1.** Individual audiogram for the participants
Figure 2. Functional gain of hearing aid (HA) and representative personal sound amplification product (RPSAP) for 6 participants by frequency; (A) 250Hz, (B) 500Hz, (C) 1000Hz, (D) 2000Hz, (E) 3000Hz, (F) 4000Hz, (G) 6000Hz, (H) 8000Hz. Functional gain is defined as the difference in dB HL between the aided and unaided thresholds. The overlapping dots and gray lines indicate the individual change. The Rhombus shape indicates the mean of results.
Figure 3. Average results of the Word Recognition Score (WRS) and Korean version of the Hearing in Noise Test (K-HINT) for Hearing aid (HA) and representative personal sound amplification product (RPSAP). The overlapping dots and gray lines indicate the individual change. The Rhombus shape indicates the mean of results.
Figure 4. Results of the Korean version of the Hearing in Noise Test (K-HINT) for each patient. (A) Individual results of K-HINT in quiet, (B) Average results at each condition of K-HINT in quiet, (C) Individual results of K-HINT in noise, (D) Average results at each condition of K-HINT in noise. The Rhombus shape indicates the mean of results.