Speech perception enhancement in elderly hearing aid users using an auditory training program for mobile devices

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Aims: The goal of the present study was to develop an auditory training program using a mobile device and to test its efficacy by applying it to older adults suffering from moderate-to-severe sensorineural hearing loss.

Methods: Among the 20 elderly hearing-impaired listeners who participated, 10 were randomly assigned to a training group (TG) and 10 were assigned to a non-training group (NTG) as a control. As a baseline, all participants were measured by vowel, consonant and sentence tests. In the experiment, the TG had been trained for 4 weeks using a mobile program, which had four levels and consisted of 10 Korean nonsense syllables, with each level completed in 1 week. In contrast, traditional auditory training had been provided for the NTG during the same period. To evaluate whether a training effect was achieved, the two groups also carried out the same tests as the baseline after completing the experiment.

Results: The results showed that performance on the consonant and sentence tests in the TG was significantly increased compared with that of the NTG. Also, improved scores of speech perception were retained at 2 weeks after the training was completed. However, vowel scores were not changed after the 4-week training in both the TG and the NTG.

Conclusions: This result pattern suggests that a moderate amount of auditory training using the mobile device with cost-effective and minimal supervision is useful when it is used to improve the speech understanding of older adults with hearing loss. Geriatr Gerontol Int 2017; 17: 61–68.

Keywords: auditory training, elderly with hearing loss, hearing aids, mobile device-assisted therapy, neural plasticity, speech perception.

Introduction

The number of older adults is expected to increase dramatically worldwide, resulting in increased prevalence of chronic diseases and higher disability rates. Among the chronic diseases, hearing impairment, called presbycusis, is the third most common, and the condition has steadily increased with a larger older population.3 This pattern has resulted in more older adults using hearing aids, and more research focused on hearing performance,2,3 benefits of aural rehabilitation,4,5 and social and emotional aspects related to hearing loss.6 As the characteristics of presbycusis are irreversible and progressive, active intervention for aural rehabilitation are required for older adults who wear hearing aids.

The main purpose of aural rehabilitation for hearing-impaired listeners is to help compensate for degradation in the auditory signal from the damaged auditory system so as to minimize difficulties from hearing disability and thus, ultimately enhance communication ability in everyday life.7,8 To achieve successful aural rehabilitation, the degree and type of hearing loss should be evaluated, appropriate amplification should be selected and fitted, and sufficient amounts of auditory training should be provided.9 In particular, systematic auditory training is critical to improve listening and
understanding skills. In reality, however, most opportunities for auditory training are provided to young children who have congenital hearing loss, because their ages are a critical period of language acquisition. However, older adults also show significant improvement in speech understanding in the early stage of intervention. According to Chateline et al., 65 older adults who received a cochlear implant showed dramatically improved scores in both word and sentence tests, from 9% and 18% correct in the preoperative condition to 31% and 58% correct at 3 months after the implant, respectively. However, the scores did not change at 6 months after the implantation in comparison with a control group that consisted of 101 implanted young adults. Thus, we assume that older adults who have hearing loss and newly wear hearing aids might have a critical period for improving their speech perception as a result of neural plasticity, which indicates that early intervention with auditory training for older adults is necessary. Furthermore, compared with any other age group with hearing loss, older adults experienced significant difficulty in social functions because of their hearing loss. Older adults with only moderate hearing loss have large individual variance in psychological ripple effects, so that some people significantly reduced outside activities and restricted interaction with peers. In short, early, sufficient and continuous auditory training has a positive influence on the ability to enjoy their life for older adults with hearing loss. Nevertheless, from a practical perspective, sufficient auditory training cannot be provided for older adults with hearing loss, because it requires great expense and is time-consuming. Thus, new hearing aid users are often not satisfied, and do not have any motivation to wear the hearing aid. For this reason, many contemporary researchers have developed a home-based auditory training system and have proven its efficacy.

Sweetow and Sabes suggested that Listening and Auditory Communication Enhancement (Neurotone, Redwood, CA, USA) is a cost-effective and easy-to-access training program that relies on a personal computer. Listening and Auditory Communication Enhancement is also an interactive system in that it gives appropriate feedback to trainees while taking individual differences in performance into consideration. Compared with a control group, hearing-impaired adults who trained by themselves using the eARena program (SIEMENS, Berlin, Germany) for 4 weeks showed higher satisfaction with using their hearing aids, and improved speech perception scores in both quiet and noisy conditions. The Computer-Assisted Speech Training program (House Ear Institute, Los Angeles, CA, USA) was also applied to adult cochlear implant patients. After training in a 4-week program, their scores on speech tests were significantly improved. Recently, a study by Stacey et al. indicated that 11 adult cochlear implant recipients showed a significant improvement in consonant discrimination scores after a 3-week program of computer-based auditory training. In short, we expect that a computer-based auditory training program at home for a certain period provides motivation for auditory training, effectively improves speech perception and communication ability, yields high satisfaction among hearing aid users, and ultimately causes an increase in self-confidence in older adults who have hearing loss, but are not eligible to regularly visit an audiology clinic. However, hitherto developed computer-based auditory training programs are still limited in that an environment equipped with a computer and speakers is required for the training. While keeping pace with the times by launching simple mobile services for older adults all over the world, we developed a hands-on auditory training program for older adults with hearing loss using a mobile application that is more portable and easier to access at any time and any place. The goal of the present study was to develop a training program using a mobile device that can overcome the limitations of space and time with minimal costs, and to evaluate whether the developed program can improve the speech understanding of older adults who are new users of hearing aids.

Methods

Participants

A total of 20 hearing-impaired older adults (12 men and 8 women) participated in the present study. All of them were new hearing aid users who had 1 month of experience in wearing the hearing aid, considering their critical period of speech perception. Their average age was 75.6 years, and the age range was 68–84 years. They all passed the normal criteria of the Korean version of the Mini-Mental State Examination (MMSE-K) to eliminate possible bias of training effect. Among the 20 participants, 10 were randomly selected into an experimental group for self-auditory training using a mobile device for 4 weeks, referred to as the training group (TG), whereas the other participants were assigned to a control group that had received only traditional auditory training in the clinic once a week for 4 weeks, referred to as the non-training group (NTG).

The mean age in the TG and NTG was 75.4 and 75.8 years, respectively. In the unaided condition, the TG and NTG demonstrated 58.5 and 60.8 dB HL, respectively, for the right ear and 58.3 and 59.7 dB HL for the left ear at average hearing threshold. The mean of word recognition scores in the TG and NTG were 53.2% and 57.6% in both ears with a symmetric pattern. Bilaterally aided thresholds for the TG and NTG were 38.2 and 38.4 dB HL, respectively. All participants were native Korean speakers and signed an informed consent form.
Auditory training program of mobile device

before the experiment. They voluntarily participated in the experiment after understanding the design of present study in the consent form, without any refusal, dropout and interrupted training.

Testing materials and procedure

As a baseline, all participants’ speech recognition scores were derived by measuring material containing consonants, vowels and sentences from the Developmental Assessment of Speech Perception. The monosyllables were produced by one male talker through a speaker (0°degree, 1 m) generated by an audiometer (GSI 61; Grason-Stadler, Eden Prairie, MN, USA) in a sound isolation chamber. When the participant listened to each monosyllable, he/she produced it with accuracy. The presentation level of the monosyllables was set to each participant’s most comfortable level. After completing the 4-week training, both the TG and the NTG carried out the same tests in the same conditions, so as to compare with their scores from the baseline test. To avoid the learning effect, lists of sentences were randomly assigned within and across participants. In order to see whether the TG retained the training effect, the follow-up measure was carried out 2 weeks after the 4-week training period ended (Fig. 1).

Training materials and procedure

Using Eclipse software (ver. 4.3; Eclipse Foundation, Ottawa, Canada) based on an Android application, a customized mobile auditory training program had been developed. The speech materials, which consisted of 10 Korean consonants (k, n, t, l, m, p, s, tʰ, s*, h) followed by the /a/ vowel, were spoken by a female speaker and recorded using a recording function of the sound level meter (Model 2250; Bruel & Kjær, Nærum, Denmark) in a sound-isolated chamber, resulting in a stimulus set of 10 nonsense tokens. All speech stimuli were sampled at a 44-kHz sampling frequency and 16 sampling bit, and adjusted in root mean squared by Adobe Audition (ver. 3.0; Adobe, San Jose, CA, USA). Each level included 3 628 800 blocks (factorial 10 as 10 standard stimuli) initially. On each trial, a stimulus token was chosen randomly and presented to the participant. When a set of standard and paired example stimuli was correct, the set was not presented during the level.

Among four typical levels of auditory training, two levels, such as discrimination and comprehension, were applied for the auditory training program of the present study. These two levels were extended and specialized to four levels: discrimination level, advanced discrimination level, identification level with close-set condition and identification level with open-set condition. For the discrimination level executed in the first week of the training program, when listening to three consecutive sounds, the participant was asked whether the three sounds were the same or different and responded by pressing one of two buttons (labeled “Same” and “Different”). For the advanced discrimination level executed in the second week of the training program, the participant listened to three sounds in sequence in which two of the three sounds were identical and the other was different. The participant was asked to find which sound was different and responded by pressing one of three buttons (labeled “Sound 1,” “Sound 2” and “Sound 3” in a mobile screen). Visual feedback was provided as to whether the response was correct or incorrect, because we wanted the participant to be trained in similarity and difference of the sounds in the level of discrimination.

In the identification level with the close-set condition (third week), the participant was asked to select one of three sounds using three alternative forced choices while selecting one of three examples on the mobile screen (labeled “ka,” “na” and “ta,” for instance). In contrast, in the open-set condition, the participant was asked to type a sound directly on the mobile screen without an example as a clue when listening to the sound. Visual feedback was provided as to whether the response was correct or incorrect, and the correct answer was also shown if an incorrect answer was typed, because the purpose of the identification level is to train the participant to identify which sound was perceived.

The training program was installed on the participant’s personal mobile device by an audiologist. The presentation level of the syllables was set to each participant’s most comfortable level on the mobile device, having good sound quality at 24 bits and a frequency range of 60–7000 Hz to cover the speech frequency. Thus, wearing their hearing aids, the participants listened to the training stimuli through the mobile device at the level of 55–65 dB without any distortion of sound. All participants started to train on the discrimination level regardless of their individual baseline performance on the first day of the first week of training. However, the training program kept each participant’s record in their training session, including the total time spent in training and the correct percentage of each block as a memory function. The participant continued to train only on the incorrect blocks the next day (i.e. blocks were considered correct when participants achieved 100% correct per a standard stimulus and paired example sounds). Thus, the participant was able to focus on training on difficult and confusable sounds. All participants were instructed to train for at least 40 min per day 6 days per week for four successive weeks.

Statistical analysis

Statistical analysis was carried out using SPSS software (version 20; IBM, Armonk, NY, USA). To see a training effect for 4 weeks, scores of the initial evaluation as the
Figure 1  Flow chart of test and training procedures used in this experiment.
baseline and the post-training evaluation were compared with $2 \times 2 \times 3$ mixed-model analysis of variance (ANOVA). For a comparison of the speech perception scores in three time measurements of the TG, a two-way repeated-measures ANOVA was used to evaluate the data. If necessary, Bonferroni corrections were applied with multiple comparisons. The criterion used for statistical significance in this study was $P < 0.05$.

**Results**

ANOVA confirmed a significant main effect of training ($F[1, 18] = 34.480, P = 0.000$), kind of speech test ($F[2, 36] = 95.411, P = 0.000$) and group ($F[1, 18] = 98.425, P = 0.000$). Figure 2 shows bar graphs for the mean of the total error percentage of consonant, vowel, and sentence in both the TG and NTG. For consonant scores, there was a significant difference in mean error percentage between pre- and post-training ($F[1,18] = 22.749, P = 0.000$) and significant interaction of training and group ($F[1,18] = 14.157, P = 0.02$). That is, the TG showed significantly decreased error percentage from 31.67% (SD 8.05) in pre-training to 20.00% (SD 3.85) in post-training. Performance of the NTG was 30.67% (SD 7.82) for pre-training and 25.33% (SD 11.99) for post-training. The consonant performance difference of pre- and post-training was 11.67% for the TG and 5.34% for the NTG. For vowel scores, there was no significant difference in mean error percentage between pre- and post-training, and no significant interaction. In the TG, the mean error percentage was 10.48% (SD 8.63) in pre-training and 4.76% (SD 5.02) in post-training. The NTG showed a mean error percentage of 8.81% (SD 4.73) for pre-training and 3.81% (SD 5.41) for post-training. The TG and NTG showed only a 5.72% and 5% difference between pre- and post-training, respectively. For sentence scores, there was a significant difference in mean error percentage between pre- and post-training ($F[1,18] = 22.984, P = 0.000$), and significant interaction of post-training and group ($F[1,18] = 17.490, P = 0.001$). The TG showed a mean error percentage of 20.49% (SD 11.16) in pre-training and 9.76% (SD 6.19) in post-training, resulting in a 10.73% decrease in the training effect. However, the NTG showed a small change in performance in 18.62% (SD 10.40) for pre-training and 15.92% (SD 11.64) for post-training.

After the TG completed the 4 weeks of training, the speech perception test was re-measured after 2 weeks to see whether the TG retained the training effect and confirmed the significant mean difference using a two-way repeated-measure ANOVA (see Fig. 3). For the consonant scores, a significant difference of mean error percentage existed in three time measurements ($F[2,6] = 18.039, P = 0.003$). In Bonferroni correction for multiple comparisons, the mean error percentage of the consonant test at pre-training (mean 31.67%, SD 4.91) was significantly higher than at post-training (mean 20.00%, SD 2.10; $P = 0.001$). However, the mean error percentage of post-training was not significantly different than that of the follow-up measure at 2 weeks after the training ended (mean 19.17, SD 1.60; $P = 0.638$), which means that the TG maintained decreased consonant errors as a training effect after 2 weeks. For vowel scores, no significant difference of mean error percentage existed among three time
measures. The mean error percentage was 10.48% (SD 5.50) for pre-training, 4.76% (SD 2.28) for post-training, and 5.78% (SD 3.37) for the follow-up measure. For sentence scores, there was a significant difference in mean error percentage in three time measurements ($F[2,6] = 17.678$, $P = 0.003$). A Bonferroni post-hoc test showed that the mean error percentage of the consonant test at pre-training (mean 20.49, SD 6.09) was significantly higher than at post-training (mean 9.76, SD 3.36; $P = 0.028$); however, there was no difference in mean error percentage between post-training and follow-up measure at 2 weeks after training ended (mean 6.88, SD 3.86; $P = 0.215$). Thus, sentence scores also showed that the training effect was maintained.

Discussion

The goal of the present study was to develop a self-training program using a mobile device for older adults with hearing loss, and to evaluate whether the program can improve the speech recognition performance of the older adult who is a new user of hearing aids. Compared with the NTG, the TG significantly improved performance in two speech perception tests (i.e. consonants and sentences) after 4 weeks of self-paced auditory training using a mobile device. Furthermore, the improved performance on consonant and sentence tests was largely retained at 2 weeks after the training was completed. In the previous study, Stacey et al. found that 11 cochlear implant recipients were trained by a computer training program for 3 weeks and showed significantly improved performance in the consonant test, but not in the vowel and sentence tests.19 When applying the training program using a computer for one month, Fu et al. found that 10 cochlear implant users had significantly improved from 23.7% to 39.5% for the consonant test and from 25.1% to 38.6% for the vowel test.15 Wu et al. found that seven cochlear-implanted children improved vowel and consonant perception up to approximately 10% and 20%, respectively, after the 10-week training ended.24 As one possible reason why our finding about vowel test scores contradicts the previous research, which showed no significant change in vowel scores after the training in the TG, we might explain that error scores of consonant and sentence tests were much higher than for the vowel test at the baseline. Thus, the vowel test score having a low error percentage was not much changed after the training, resulting in no significant difference of the scores between pre- and post-training measures. Also, our training program used only /a/ vowel. In other words, presbycusis has damaged hair cells in the basal part of the cochlea, and reduced the number of neurons of the cochlear nucleus, resulting in problems understanding sounds in the high-frequency regions in general.25 In addition, older adults usually have irrecoverable sensorineural hearing loss in the high-frequency regions, and are more confused in consonant perception than vowel perception.26 Therefore, older listeners who participated in the present study had high error rates in consonant and sentence scores at baseline, and showed significant improvement after the training. This training effect, thus, would be influenced not only by the device, but also by the program. If our program consisted of words or sentences instead of monosyllables, the training effect might be different, because semantic factors, such as the meaningful guess, would apply. In further study, larger numbers of older adults who have hearing loss should be classified according to degree and...
configuration of hearing loss to confirm the efficacy of the program in detail. As subgroups of presbycusis, we need to analyze which consonants have the most trouble before the training and are the most enhanced after the training.

Considerable variability remains in individual patient outcomes. For example, two out of 10 participants of the TG (i.e., S3 and S7) showed little difference in the sentence scores after training, although they were improved in consonant scores (see Appendix I for individual data). We assume this variability in training outcomes is reflected not only in individual differences in speech performance, but also in the time-course of adaptation to the novel speech patterns provided by the hearing aid. Thus, early intervention with auditory training using such a free training program can reduce this difference or variance. The present study had some limitations in terms of techniques used. As older adults tend to be less agile with their hands (or fingers) than younger people, they made some typing errors despite understanding the target sound. We need to update the mobile program applying a pencil or pen instead of relying on the subject’s ability to type. In addition, we need to upgrade the current training program, such that we might set up wireless interface system between the trainee and an audiologist so that the audiologist can apply it for fitting the hearing aid and audiological counseling.

In summary, overall the results of the present study suggest that moderate amounts of auditory training using a mobile-based rehabilitation tool can offer a convenient and cost-effective approach to improve the speech perception performance of the elderly hearing aid users. The results also show that those concerned about time constraints, expense and the proximity of patients to the rehabilitation site can benefit from this training.

Acknowledgment

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Disclosure statement

The authors declare no conflict of interest.

References


**Appendix I**

**Comparison of individual error percentage between pre- and post-training in three speech perception tests**

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<th>Pre-training evaluation</th>
<th>Post-training evaluation</th>
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Data presented as percentage. NTG, non-training group; TG, training group.