Evaluation Method for Hearing Aid Fitting under Reverberation: 
Comparison between Monaural and Binaural Hearing Aids

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Abstract  Some hearing-impaired persons with hearing aids complain of listening difficulty under reverberation. No method, however, is currently available for hearing aid fitting that permits evaluation of hearing difficulty caused by reverberations. In this study, we produced speech materials with a reverberation time of 2.02 s that mimicked a reverberant environment (a classroom). Speech materials with reverberation times of 0 and 1.01 s were also made. Listening tests were performed with these materials in hearing-impaired subjects and normal-hearing subjects in a soundproof booth. Listening tests were also done in a classroom. Our results showed that speech material with a reverberation time of 2.02 s had a decreased listening-test score in hearing-impaired subjects with both monaural and binaural hearing aids. Similar results were obtained in a reverberant environment. Our findings suggest the validity of using speech materials with different reverberation times to predict the listening performance under reverberation of hearing-impaired persons with hearing aids. J Physiol Anthropol Human Sci 23(6): 255–258, 2004 http://www.jstage.jst.go.jp/browse/jpa

Keywords: hearing impairment, reverberation, monaural hearing aid, binaural hearing aids, binaural advantage, evaluation method, speech material

Introduction

We usually hear various sounds and speech in an environment with noise and reverberation. Persons with normal hearing frequently experience difficulty in speech recognition in noisy and/or reverberant conditions, like subways or large halls. It has been reported that effects of noise and reverberation on speech recognition for hearing-impaired persons are particular large compared with normal-hearing persons (Nabelek and Pickett, 1974; Gelfand and Hochberg, 1976; Harris and Swenson, 1990). To predict the listening performance of hearing-impaired person with hearing aids in noisy environments, a speech test in noise has been clinically used for persons with and without hearing aids. No method, however, is currently available for hearing aid fitting that permits evaluation of hearing difficulty caused by reverberations. Previous studies suggest that the main problem is that a specially constructed room with a controllable reverberation time (RT) is needed, for changing the absorption at the boundary walls and the ceiling (Nabelek and Pickett, 1974; Nabelek and Robinette, 1978; Nabelek and Mason, 1981; Harris and Swenson, 1990). For clinical testing, this is a difficulty because such a room is very expensive and compels researchers to take time and effort for changing the RT precisely. An alternative is to prepare several rooms with different RTs to record speech materials (Hawkins and Yacullo, 1984). This method is not clinically appropriate for hearing aid fitting. Because of above reasons, a clinically easy method which can be carried out in a soundproof booth is desirable for investigating effects of reverberation on speech recognition for hearing-impaired persons with monaural and binaural hearing aids.

In this study, we propose a method to evaluate listening performance by using speech materials with different RTs. We compared the effects of RT on listening performance with the speech materials for normal-hearing subjects and for hearing-impaired subjects with monaural and binaural hearing aids.

Materials and Methods

The subjects were six hearing-impaired subjects with sensorineural hearing loss, from mild hearing loss in the high frequencies to severe hearing loss, ranging in age from 34 to 73 years. The audiograms of each hearing-impaired subject are shown in Fig. 1. Ten university students with normal hearing, five men and five women ranging in age from 19 to 24 years, served as a control group. All subjects gave informed consent to participate in the experiments with a reward.
Listening tests for the normal-hearing and hearing-impaired subjects with monaural and binaural hearing aids were carried out in a soundproof booth, and a classroom with an RT of 2.02 s. Only speech materials with an RT of 0 s were used in the classroom. Each speech material was presented from a single speaker placed at a distance of 1 m from the subjects. The non-test ear in the monaural condition was masked by a weighted noise from an audiometer delivered by an inserted earphone.

**Results**

The recognition scores obtained from the normal-hearing subjects nearly reached the upper limit of 100%. All proportions from the normal-hearing and hearing-impaired subjects were normalized by an arcsine transformation before statistical analysis (Harris and Swenson, 1990). If the score was 100%, a correction was used when less than 50 trials were finished before transforming to angles (Snedecor and Cochran, 1989). The recognition scores were analyzed by a three-way ANOVA with hearing aid configuration (monaural and binaural), RT (0 s, 1.01 s and 2.02 s in a soundproof booth, and 2.02 s in a classroom), and subject (normal-hearing and hearing-impaired) as independent variables.

Main effects were noted in the hearing aid configuration (monaural and binaural) $[F(1, 98)=21.35, p<0.001]$, the RT $[F(3, 98)=13.54, p<0.001]$, and the subject $[F(1, 14)=62.46, p<0.001]$. There were statistically significant interactions between the hearing aid configuration (monaural and binaural) and the subject $[F(1, 98)=15.91, p<0.001]$, and the RT and the subject $[F(3, 98)=8.39, p<0.001]$. Further analyses were carried out for which subjects were divided into the normal-hearing group and the hearing-impaired group.

**Normal-hearing subjects**

The recognition scores obtained from the normal-hearing subjects were analyzed by a two-way ANOVA with hearing aid configuration (monaural and binaural), and RT as independent variables. The main effects were not significant, with $[F(1, 63)=0.90, p=0.35]$ and $[F(3, 63)=1.60, p=0.20]$ for the hearing aid configuration and for the RT, respectively. No significant differences were noted between the recognition scores for the speech material with an RT of 2.02 s in a soundproof booth and those with the same RT in a classroom.

**Hearing-impaired subjects**

The recognition scores obtained from the hearing-impaired subjects were analyzed by a two-way ANOVA with hearing aid configuration (monaural and binaural), and RT as independent variables. Significant differences in the main effects were observed in the hearing aid configuration $[F(1, 35)=13.08, p=0.001]$ and the RT $[F(3, 35)=7.61, p<0.001]$. Mean recognition scores as a function of the increased RT for the normal-hearing subjects and hearing-impaired subjects are shown in Fig. 2. The values of the observed binaural advantage
The increase in RT of the speech materials from 0 to 2.02 s in a soundproof booth was accompanied by a decrease in mean recognition scores from 82.0 to 68.7% for the monaural condition, and from 86.3 to 75.7% for the binaural condition, respectively. In a classroom with an RT of 2.02 s, the mean speech recognition score was 69.3% for the monaural condition, and 77.0% for the binaural condition, respectively.

The speech recognition score for each hearing-impaired subject and their averaged scores are shown in Fig. 3. Multiple comparisons (Tukey–Kramer) were carried out for the recognition scores of four conditions (the three different RTs of 0 s, 1.01 s and 2.02 s in a soundproof booth and the RT of 2.02 s in a classroom). There were significant differences between the recognition scores with RTs of 0 s and 1.01 s in the soundproof booth \((p=0.03)\), 0 s and 2.02 s in the soundproof booth \((p=0.001)\), and 0 s in the soundproof booth and 2.02 s in the classroom \((p=0.003)\). No significant difference was observed between the recognition scores for the speech materials with an RT of 2.02 s in the soundproof booth and the speech materials in the classroom with the same RT of 2.02 s \((p=0.94)\).

Discussion

For the normal-hearing subjects with both monaural and binaural hearing aids, there was no difference between the recognition scores for the speech materials with an RT of 0 s in a soundproof booth and the recognition score for the speech materials with an RT of 0 s in a classroom. For the hearing-impaired subjects, however, the deterioration of the speech recognition scores in the same conditions was observed. This was apparently caused by masking of the proceeding speech on the acoustic characteristics of the following speech. These results indicate that a speech recognition score for hearing-impaired persons with hearing aids in quiet and less reverberant environments, such as a soundproof booth, do not reveal real performance under reverberation. The major finding of this study was that no difference between the speech recognition score with an RT of 2.02 s in a soundproof booth and that obtained in a classroom was statistically observed regardless of hearing aid configuration (monaural and binaural).

In general, speech from a talker in a room, a direct sound from the source and numerous reflections in all directions from walls, ceilings, and floors (reverberation) reach both ears of a listener with a delay in time. Like this, the reverberation contains not only temporal information but also spatial information. However, our results show that using speech materials processed with an RT from a speaker in front of a listener closely resembled a real reverberant condition in a classroom. Also, our results from the hearing-impaired subjects were consistent with previous reports that revealed that speech materials with increased RT showed decreased recognition scores for hearing-impaired subjects (Nabelek and Pickett, 1974; Gelfand and Hochberg, 1976; Harris and Swenson, 1990). From the above results, we strongly believe that our proposed method carried out in a soundproof booth is useful for evaluating speech recognition with hearing aids under reverberation for clinical testing. This easy method has advantages which it is not necessary to prepare a special room with controllable RTs and which it is possible to produce speech materials with an arbitrary RT by signal processing (i.e. convolution).

One of the uninvestigated problems for hearing aid fitting for clinical testing is the length of the distance from a talker to a listener necessary to record an impulse response. In our experiment, the distance was 1 m. Listening-performance in a room depends on the critical distance (Dc) where the energy level of direct sound and reverberant sounds is equal. The more a room is reverberant, the shorter the critical distance and the higher the level of reverberant sound energy (Ross, 1992). Another uninvestigated problem is the type of room that should be mimicked. Although a classroom was used in this experiment, for aged people with hearing losses, it might be desirable to investigate the acoustic characteristics of common places such as living rooms or large halls in community centers.

Advantages of binaural hearing aids are better localization, better speech understanding in noise, greater ease of listening, and better balance of sound. Our binaural scores from the
hearing-impaired subjects showed a significant superiority compared to the monaural scores at each RT in the soundproof booth and the actual RT of 2.02 s in the classroom. The results were consistent with previous reports (Nabelek and Pickett, 1974; Nabelek and Robinette, 1978; Hawkins and Yacullo, 1984).

It is worth considering the difference between the binaural scores with an RT of 2.02 s in the soundproof booth and the binaural scores in the classroom. A small increased score for binaural hearing aids in the classroom compared to that in the soundproof booth was observed, although this difference was not statistically significant. The phenomenon of “binaural masking level difference” (BMLD) comprises an improvement in the detectability of a signal under binaural listening conditions in noise (Hirsh, 1948; Johansson and Arlinger, 2002). There is a difference in the threshold of the signal (in dB) in cases where the signal and masker have the same phase and level relationships at the two ears, and in case where the interaural phase and/or level relationships of the signal and masker are different (Moore, 2003). In the classroom used in our experiment, numerous reflections (reverberation) in all directions from the walls, the ceiling and the floor were out of phase. Conversely, in the soundproof booth, reverberation for the processed speech material from the speaker in front of the subject reached both ears in phase. Licklider (1948) found that the intelligibility of speech was higher when the speech was in phase and the noise was out of phase in the two earphones, compared with the cases where both the speech and noise were either in or out of phase.

From the above research on the BMLD, the speech recognition score with binaural hearing aids in the classroom might have been superior compared to that in the soundproof booth. One reason why no statistically significant difference between these two listing conditions was found in this study might be the small number of hearing-impaired subjects. Another reason might be the large differences in the binaural advantage between individuals as Nabelek and Robinette (1978) reported. If significant, the method in this study would be limited to the evaluation of monaural hearing aid fitting under reverberation. Further investigation with more hearing-impaired subjects with binaural hearing aids is therefore necessary.

Conclusion

The outcome of our listening tests in a soundproof booth with an RT of 2.02 s was similar to that obtained in an actual listening environment, such as a classroom. Our results suggest that listening tests using speech materials with different reverberation times are useful for hearing aid fitting and for predicting the hearing ability of persons with hearing impairment who wear a hearing aid in daily life. However, a further investigation with more hearing-impaired subjects with binaural hearing aids seems necessary to reveal the possibility on effect of BMLD under a real reverberation.

Acknowledgements This research was supported in part by Grant-in-Aid for Scientific Research (B) (1) No.15300203 from the Japan Society for the Promotion of Science, and the 21st Center of Excellence (COE) program of the Japanese Government, entitled ‘Design of artificial environments on the bases of human sensibility’, Kyushu University, Japan. We wish to thank Dr. Gerard Remijn and Dr. Jonathan Goodacre for their English correction.

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Received: September 6, 2004
Accepted: September 24, 2004
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