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Efficiency of sound masking system for elderly people with degraded auditory properties

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1. Introduction

Recently, sound masking systems have been receiving a lot of attention as a method of protecting speech privacy [1]. However, the majority of studies have been designed for normal-hearing people. This study investigated a sound masking system for elderly people in terms of masking efficiency and annoyance. In particular, the study focused on the effect on elderly people with degraded auditory properties. The results were compared with those for young people.

2. Stimuli

Target and masker sounds were added together and used as stimuli. They were combined with various target-to-masker ratios, TMRs.

2.1. Target

The target in sound masking systems is the sound to be masked, i.e., the contents of a conversation that are not wished to be heard by other people. We selected 144 Japanese four-mora words from the FW03 corpus [2] as target sounds. The target sounds were presented to participants at a level of 50 dB in L_{Aeq}.

2.2. Maskers

A masker is a sound that is added to prevent comprehension of the target. The maskers used in the current experiment were classified broadly into two groups: noise maskers and a speech masker. These maskers were created by using the methods described below. The sound pressure level of each masker was changed in 3 dB steps from 47 to 56 dB in L_{Aeq}, i.e., TMRs of −6, −3, 0, and 3 dB.

2.2.1. Noise maskers

As noise maskers, pink noise and babble noise were used. The pink noise was created using MATLAB. The babble noise was taken from NOISEX [3].

2.2.2. Speech masker

It is known that maskers created from a speech signal yield informational masking. The present study refers to this type of masker as a "speech masker." The speech masker used in this study was created using the algorithm of Ito *et al.* [4]. We made two replicas of every target. Each of the replicas was processed in the following manner. Firstly, the temporal frames (160 ms) of an each replica were time-reversed. Next, the time-reversed frames were replaced randomly. Then, a speech masker was created by adding one of the manipulated replicas to the other with an 80 ms time delay.

2.3. Combination and presentation

We used a total of 1,728 stimuli: 3 maskers (pink noise, babble noise, and speech masker) × 4 TMRs (−6, −3, 0, and 3 dB) × 144 words. For each participant, the stimuli were counterbalanced among the combinations of words and processing types. The stimuli were randomly presented to each participant.

3. Experiment

3.1. Participants

Two groups of listeners participated in this study: a young group and an elderly group. Each participant's native language was Japanese. The young group consisted of 12 college-aged (mean age = 21.2 years) listeners (5 males and 7 females) with normal pure-tone thresholds. The elderly group consisted of 24 listeners (12 males and 12 females) ranging in age from 63 to 82 years (mean age = 68.5 years). The pure-tone thresholds of the elderly participants varied from normal hearing (En) (7 listeners) to degraded hearing (17 listeners). Degraded hearing included three different types of hearing problems: 1) Ed1 (10 listeners), where the hearing of high frequency sounds is deteriorated compared with low-frequency sounds, 2) Ed2 (5 listeners), where shows a rapid increase in the hearing threshold occurs above 2 kHz, and 3) Ed3 (2 listeners), who were categorized into neither of the above types. Table 1 indicates the number of participants in each group.

3.2. Procedure

The experiment was conducted in a soundproof room. The stimuli were presented monaurally from a loudspeaker (YAMAHA MSP3) through a USB audio system interface (Roland EDIROL UA-25EX). The loudspeaker was located directly in front of the participant at a distance of 1.8 m and at the height of the participant's head, i.e., approximately 1.2 m.

The participants listened to each stimulus once and were asked to answer two questions: 1) what word did you hear? (a word intelligibility test), and 2) was the masking sound annoying? (an annoyance assessment test). For the annoyance assessment test, listeners were instructed to rate the stimuli using a scale from 1 (not at all annoying) to 5 (extremely annoying). The young participants typed answers for 1) into a computer; for 2), they responded by clicking on a box

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Table 1 Number of participants in each group.

Young	Elderly			
	En	Ed1	Ed2	Ed3
12	7	10	5	2

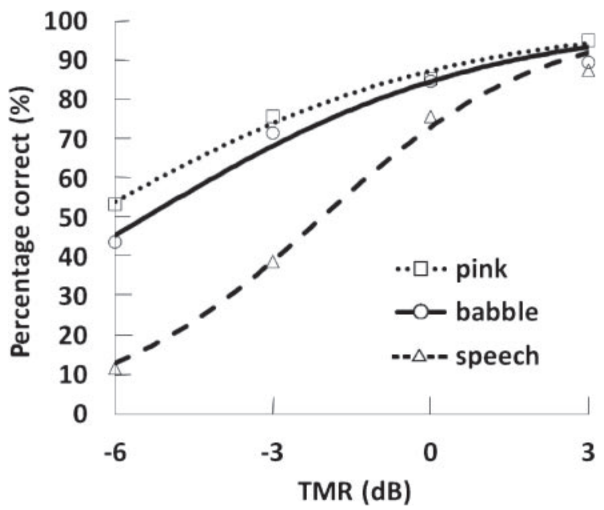

Fig. 1 Results of the word intelligibility test for the young group. Symbols show the average percentage of correct answers in the word intelligibility test for each TMR; squares indicate pink noise, circles indicate babble noise, and triangles indicate the speech masker.

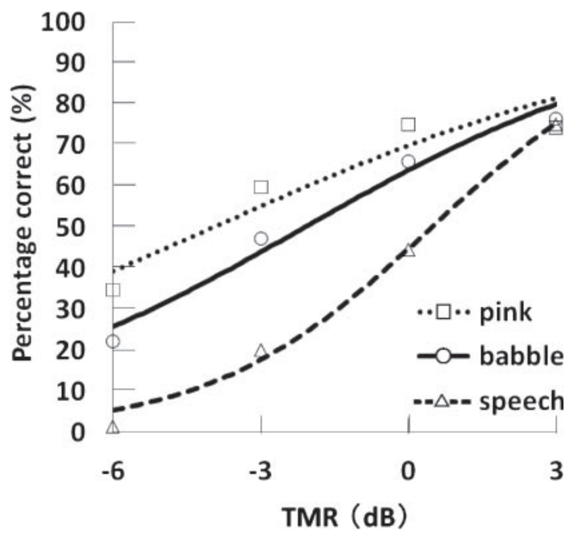

Fig. 2 Results of the word intelligibility test for the elderly group. Symbols show the average percentage of correct answers in the word intelligibility test for each TMR; squares indicate pink noise, circles indicate babble noise, and triangles indicate the speech masker.

appearing on the screen of the computer with a mouse. For the elderly participants, a sheet of paper was provided for them to write down answers for 1) and a touch panel was used for 2).

4. Masking efficiency

The results for the young group and elderly group are shown in Figs. 1 and 2, respectively. The symbols in these figures show the average percentage of correct answers in the word intelligibility test for each TMR; squares indicate pink noise, circles indicate babble noise, and triangle indicate the speech masker. Lines show the logistic functions modeled by the formula

$$y = \frac{100}{1 + e^{-k(x - x_c)}},$$

where y is the predicted percentage of correct answers, x is TMR, and x_c and k are fitting coefficients.

4.1. Young group

For the young group, two-way repeated-measures ANOVA found that the interaction between the masker and the TMR was significant ($F(6,99) = 9.433$, $p < 0.001$). A post-hoc multiple comparison test found a significant difference between the speech masker and pink noise and between the speech masker and babble noise at -6 dB TMR ($p < 0.001$). In addition, a significant difference was found for the same combinations at -3 dB TMR ($p < 0.001$). In contrast, no significant difference was found for 0 dB TMR.

4.2. Elderly group

For the elderly group, two-way repeated-measures ANOVA found that the interaction between the masker and the TMR was significant ($F(6,198) = 9.606$, $p < 0.001$). A post-hoc multiple comparison test found a significant difference among all maskers at -6 dB TMR ($p < 0.001$). Moreover, it found a significant difference between the speech masker and pink noise and between the speech masker and babble noise at -3 dB TMR ($p < 0.001$). In addition, a significant difference was found for the same combinations at 0 dB TMR ($p < 0.001$).

4.3. Young group vs. elderly group

It was observed that the performance of the elderly group was poorer than that of the young group for every TMR. For both listener groups, the average percentage of correct answers was highest for the pink noise and lowest for the speech masker. This means that the masking efficiency was lowest for the pink noise and highest for the speech masker: pink noise < babble noise < speech masker.

One-way repeated-measures ANOVA found that the main effect was between the young group and elderly group. The performance of the two groups was significantly different for all TMRs (-6 dB: $F(1,104) = 26.500$, $p < 0.001$; -3 dB: $F(1,104) = 14.221$, $p < 0.001$; 0 dB: $F(1,104) = 18.769$, $p < 0.001$; 3 dB: $F(1,104) = 12.196$, $p < 0.01$). In addition, it was significantly different for all maskers (pink noise: $F(4,31) = 2.975$, $p < 0.05$; babble noise: $F(4,31) = 3.359$, $p < 0.05$; speech masker: $F(4,31) = 10.350$, $p < 0.001$). A post-hoc multiple comparison test found a significant difference between the young group and elderly group for the pink noise at -6 dB TMR and 3 dB TMR (-6 dB: $p < 0.05$; 3 dB: $p < 0.01$). For the babble noise, the difference in performance between the two age groups was significant for all TMRs (-6 dB: $p < 0.01$; -3 dB: $p < 0.05$; 0 dB: $p < 0.05$; 3 dB: $p < 0.05$). Moreover, for the speech masker, the performance

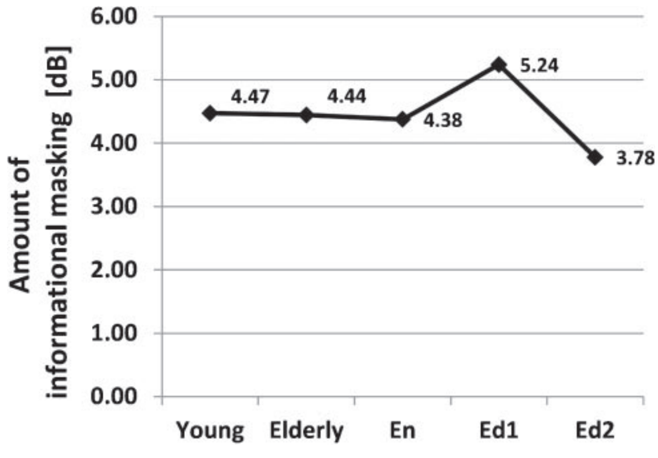

Fig. 3 Amount of informational masking (dB) for each group.

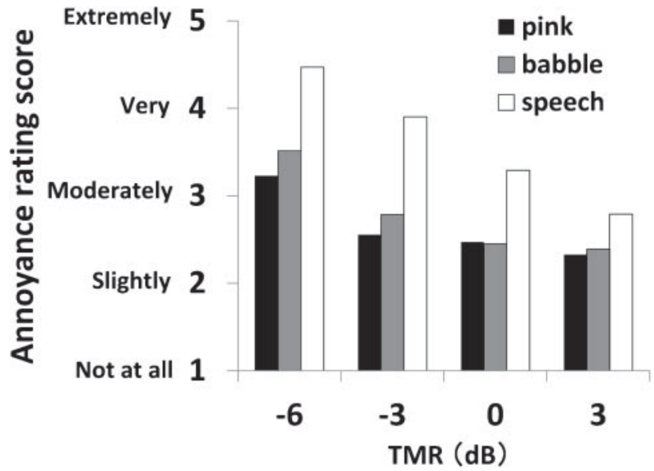

Fig. 4 Results of the annoyance assessment test for the young group.

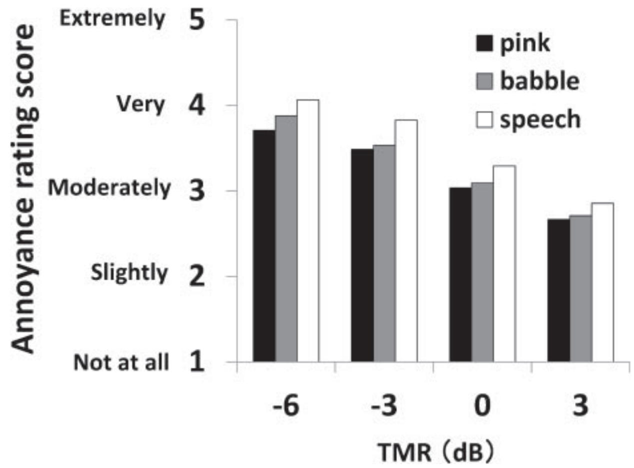

Fig. 5 Results of the annoyance assessment test for the elderly group.

was significantly different between the two age groups at -6 dB TMR, -3 dB TMR, and 0 dB TMR (-6 dB: $p < 0.001$; -3 dB: $p < 0.01$; 0 dB: $p < 0.001$). The results of the analysis confirmed that the percentage of correct answers differed between the two groups.

4.4. Discussion

In the two groups, a significant difference was found between the speech masker and pink noise and between the speech masker and babble noise at -6 dB TMR and -3 dB TMR. In addition, a significant difference was also found for the same combinations at 0 dB TMR for the elderly group but not for the young group. These findings suggest that the performance of the speech masker is effective for elderly people at 0 dB TMR.

A recent investigation [5] reported equal amounts of informational masking for a young group and an elderly group, and less was found for hearing-impaired listeners. The amount of informational masking (AIM) can be calculated as follows:

$$\text{Amount of informational masking [dB]} = \text{SRTspeech} - \text{SRTnonspeech},$$

where the speech recognition threshold (SRT) indicates the sound pressure level of the masker when the percentage of correct answers is 50%, i.e., the amount of informational masking can be calculated from the difference between the SRT for the speech masker and that for the nonspeech masker.

In this study, the AIM can be estimated from the difference between the SRT for pink noise and that for the speech masker. Figure 3 shows the average AIM for each group (see Table 1). The AIM does not appear to be different between the young group and elderly group. This result coincides with those of earlier studies. In contrast, our results for the different classifications of the elderly group differed from those in previous studies. Certainly, the AIM seems to be the same for the young group and En. In contrast, the AIM seems to be different between the young group and the elderly subgroups with degraded hearing: the AIM for Ed1 is higher than that for the young group, and that for Ed2 is lower than that for the young group. These findings suggest that the AIM markedly changes with the degree and kind of hearing problem. It was clearly shown in Agus's investigation [5] that the AIM was low for hearing-impaired listeners; however, this observation does not always apply in the current study. It is clear that the AIM is much smaller for those with severely degraded auditory properties than for young people with normal hearing because the former are almost deaf to sounds per se. In contrast, it can be presumed from our results that the effect of informational masking for those with a slight degree of degraded hearing is larger than for young people with normal hearing. Further investigation is needed with an increased number of samples for each type of degraded hearing.

5. Annoyance

Figure 4 shows the average annoyance rating score in the annoyance assessment test for the young group according to TMR, and Fig. 5 shows that of the elderly group. The higher the annoyance rating score, the greater the degree of annoyance.

5.1. Young group

For the young listener group, two-way repeated-measures ANOVA found that the interaction between the masker and TMR was significant ($F(6,99) = 3.119$, $p < 0.01$). A post-hoc multiple comparison test found a significant difference between the speech masker and pink noise and between the speech masker and babble noise at −6 dB TMR ($p < 0.001$) as well as at −3 dB TMR ($p < 0.001$). In addition, a significant difference was found for the same combinations at 0 dB TMR ($p < 0.05$).

5.2. Elderly group

For the elderly group, two-way repeated-measures ANOVA found that the interaction between the masker and TMR was not significant. In addition, a post-hoc multiple comparison test did not found a significant difference for all TMRs.

5.3. Young group vs. elderly group

For the two groups, the rating score was highest for the speech masker and lowest for the pink noise. That is, the degree of annoyance increased in the following order: pink noise < babble noise < speech masker. For all maskers, the elderly people tend to experience more annoyance than young people. The speech masker caused both listener groups the same degree of annoyance; however, for the pink noise and babble noise, elderly people were more annoyed than young people by these maskers at all TMRs.

One-way repeated-measures ANOVA found the main effect between the young group and elderly group. The rating score was significantly different between the two groups at −3 dB TMR and 0 dB TMR (−3 dB: $F(1,104) = 15.944$, $p < 0.001$; 0 dB: $F(1,104) = 10.939$, $p < 0.01$). In addition, the difference in the rating score between the two groups was significant for the pink noise and babble noise (pink noise: $F(4,31) = 7.243$, $p < 0.001$; babble noise: $F(4,31) = 3.782$, $p < 0.05$). In contrast, no significant difference was found for the speech masker. A post-hoc multiple comparison test found that the performance of the pink noise was significantly different between the two groups at −3 dB TMR and 0 dB TMR (−3 dB: $p < 0.001$; 0 dB: $p < 0.01$). Similarly, the babble noise was significantly different for the same TMR combinations (−3 dB: $p < 0.01$; 0 dB: $p < 0.01$). However, a significant difference was not found for the speech masker for all TMRs. The results of the analysis confirmed that the rating score was different between the two groups.

5.4. Discussion

For the young group, a significant difference was found between the speech masker and pink noise and between the speech masker and babble noise; however, the same combinations did not produce a significant difference for elderly people. The difference in annoyance between the young group and elderly group might be explained by the weighting factors in each group. It is reasonable to suppose that young people and elderly people attach importance to different aspects of maskers, such as intelligibility, loudness, noisiness, and so forth, in the evaluation of annoyance. Further investigation is needed to clarify the relationship between the annoyance rating score and aging.

6. Discussion: masking efficiency and annoyance

In a real environment, the masker should be considered in terms of its masking efficiency and annoyance. An ideal masker would have high masking efficiency and generate little annoyance. By comparing TMRs with the same percentage of correct answers for the two groups, it was found that the performance of each masker was approximately 2–3 dB higher for elderly people than for young people. That is, the masker level for elderly people can be reduced to less than that for young people. If the level of the masker can be reduced, it will be possible to create maskers that are less annoying for elderly people.

The results for elderly people indicated that the masking efficiency was highest for the speech masker. In addition, when creating effective maskers for elderly people, the speech masker may be useful since the degree of annoyance was not different from the other types of masker.

7. Conclusion

In this study, the results of applying maskers were compared between young people and elderly people from two viewpoints, masking efficiency and annoyance. For all maskers, the masking efficiency was higher for elderly people than for young people. In particular, for elderly people, the performance of the speech masker was higher than that for young people. The results for elderly people demonstrated that their level of annoyance was higher than that for young people. In addition, for elderly people, it was also found that the degree of annoyance was not affected by the type of masker. We assume that elderly people are annoyed by all types of masker to the same degree because the factors determining annoyance for elderly people differ from those for young people as a result of aging. Further investigation is needed to clarify the relationship between the age-related difference in weighting factors and the degree of annoyance caused by different types of masker.

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