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The effect of room sound absorption on a teleconference system and the differences in subjective assessments between elderly and young people

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Abstract

In recent years, the rapid development of information and communication technology (ICT) and the influence of the novel coronavirus (COVID-19) have affected our lives and work in various fields such as medical and welfare, construction and manufacturing and education, etc. With this global background, teleconference systems have received attention and become a new trend. However, the acoustics of rooms using teleconference system often overlap the acoustic characteristics from multiple rooms on both the speaker and listener sides. Therefore, it can sometimes be difficult to listen to each other. A prior study suggested that the installation of sound-absorbing panels improves intelligibility and reduces the listening difficulty for young people. However, elderly people must be included in the target owing to the effects of aging. This study aimed to clarify improvements in the subjective assessments of elderly people in a room where a teleconference system is used. In addition, the differences in subjective assessments between young people and elderly people were also investigated. The results of an experiment indicate that, first, a room using a teleconference system demonstrated a greater improvement in subjective assessments after the acoustic improvements compared to the same room where face-to-face meetings. Second, the subjective assessments and improvements of them for elderly people differed greatly since older user had listening habits and experiences that varied from those of young people.

1. Introduction

In recent years, digital devices such as personal computers and tablet PCs have become indispensable in our lives. In addition, the Internet has become an important lifeline for several people. Thus, our lives are changing rapidly into a society of information and communication technology (ICT). ICT has a new relationship with human society and it will become the center of economic activity [1]. For example, various fields such as smart construction work, agriculture, factory control, medical and surgical support are using big data. There are also certain solutions that use ICT in the Sustainable Development Goals (SDGs) adopted at the 2015 United Nations Summit.

In particular, the number of people who have used a teleconference system is rapidly increasing owing to the influence of the novel coronavirus (COVID-19), which has spread worldwide in the past several months. As shown in Fig. 1, Microsoft’s Teams, a typical service used for remote collaboration, had more than 115 million daily users by October 2020. By contrast, in the middle of March, the number of users was only 44 million. Thus, a rapid increase of 240% was witnessed in just 7 months. According to the Seed Planning survey, the video conferencing market in Japan was 50.3 billion yen in 2018; this, increased by 32% compared to 38.1 billion yen in 2012 [2].

From the above, teleconference will become a common technology in our daily lives and work. Moreover, teleconference not only requires work meetings but also access to education and welfare sites. However, unlike traditional face-to-face meetings in the same room, a teleconference system requires multiple rooms to communicate video and sound. Therefore, the challenges in listening to each other often occur owing to the influence of reverberation because the acoustic characteristics in the rooms overlap.

In a previous study by Shimizu et al. [3], the goal was to architecturally enhance the sound intelligibility and reduce the listening difficulty for participants by using a teleconference system. Shimizu’s study suggested that the physical acoustic quantities of the conference rooms were improved, and the sound intelligibility and listening difficulty [4–6] were also improved, after installing sound-absorbing panels in the conference rooms.
However, the subjects of the prior study were young people around the age of 20, and they were considered to have relatively good listening capability. In addition, it has been generally confirmed that elderly people have weaker listening capability than young people.

It is necessary to mention the problem of a super-aging society (a society whose proportion of the population aged 65 and over exceeds 21%). The most developed countries around the world become super-aging societies owing to factors such as advances in medical technology and declining birth rates. According to Morizumi at al. [7], most developed countries will probably become super-aging societies by 2060. In addition, according to the United Nations, as shown in Fig. 2, the percentage of the population aged 65 and over in the world will reach 21% in the 2070 s at the earliest [8].

The present study aims to clarify improvements in the subjective assessments of elderly people by improving the sound in rooms where a teleconference system is used. Furthermore, the present study examines the difference in subjective assessments between elderly and young people in an acoustic environment when using a teleconference system.

2. Measurements of acoustic physical quantities

2.1. Acoustic physical quantities

2.1.1. STI

The speech transmission index (STI) objectively represents changes in a voice waveform owing to sound reverberation and
noise. It takes a value from 0 to 1, where 0.6 or higher is ideal. The higher the value, the less negative sound effects (such as sound reverberation and noise). Accordingly, the clarity is high. STI is calculated from the modulation transfer function (MTF) and the coefficients for each frequency, that is, the contribution rate to the intelligibility [9–11].

2.1.2. Clarity (C50)

Clarity is an index showing the intelligibility of a voice. The higher the value, the higher is the intelligibility that can be realized. It is represented by the intensity ratios of the direct sound and the individual early reflection sound that arrive after the direct sound in a logarithm. The time to separate the direct sound from the early reflection sound is 50 ms from the moment the direct sound arrives.

\[
C_{50} = 10 \log_{10} \left( \frac{\int_0^{50} p^2(\tau) d\tau}{\int_{50}^{100} p^2(\tau) d\tau} \right)
\]  

\[(1)\]

In a survey on conversations took place in a living room by Sato [12], C50 are proposed as design target values that 3.1 dB or more in listening situation and 12.6 dB or more in utterance situation.

2.1.3. Reverberation time (RT)

Sound reverberation is a phenomenon in which the generated sound remains in a room. It increases to a certain time and reaches a steady state. When the sound source is consequently stopped, the sound gradually weakens and becomes inaudible. The Reverberation Time (RT) is the time from when the sound source is stopped to the energy density in the room decays 60 dB from a steady value of the sound reverberation phenomenon.

RT is often calculated by the integrated impulse response method (Schroeder integration method) proposed by Schroeder [13]. The reverberation time can be obtained by finding the gradients of the reverberation energy from the reverberation decay curve equation described below [14]:

\[
E(t) = \int_0^{\infty} p^2(\tau) d\tau \\
\int_{\infty}^{50} p^2(\tau) d\tau
\]  

\[(2)\]

where \(E(t)\) is the reverberation decay curve (Schroeder’s decay curve), and \(p(\tau)\) is the instantaneous amplitude of the measured impulse response.

2.2. Methods of measurement

In a prior study, researchers used two rooms with a teleconference system (HDX 7000 manufactured by POLYCOM Co., Ltd.) to measure acoustic physical quantities. As shown in Fig. 3, two rooms (Room A and Room B) were connected to each other by the teleconference system using the Internet. A microphone of the teleconference system (HDX microphone array manufactured by POLYCOM Co., Ltd.) was located in Room A, and a loudspeaker with a liquid-crystal display (LCD: LC-40 AE7 manufactured by SHARP Co., Ltd.) in Room B. Moreover, there was a microphone with a sound level meter (NL-31 manufactured by RION Co., Ltd., microphone: UC-53A) and a loudspeaker (MSP7 manufactured by Yamaha Corporation) in each room. Needless to say, this system was able to record the sound transmitted from Room A with the microphone in Room A. In addition, it was possible to record the sound in Room A with the microphone in Room B via the Internet of the teleconference system. Therefore, the sounds recorded by the microphones in Room A and B were able to reproduce the sounds in single room face-to-face and two rooms using the teleconference system.

The acoustic physical quantities were measured in four discrete sound absorption levels from 0 to 3 by adjusting the number of sound-absorbing panels installed in both rooms as shown in Table 1. The sound-absorbing panels were paper honeycomb structures sandwiched between polyester nonwoven fabrics. The frequency characteristics of the sound absorption coefficient of the sound-absorbing panels are listed in Fig. 4; this was measured in accordance with JIS A 1409 [15]. Notably, the size of the sound-absorbing panels was \(1.08 \, m^2 (600 \times 900 \, mm \times 2 \, pieces)\), and the sound absorption coefficient exceeded 1. Table 2 lists the experimental conditions. The measuring method was the swept-sine method (time-stretched pulse method) using the sound source as the chirp signal [16–18].

Figs. 5 and 6 show the impulse responses recorded in Room A and Room B, respectively. The measurement results of STI, Clarity, and RT are shown in Figs. 7, 8, and 9, respectively. Clarity and reverberation time were measured in three octave bands from 500 Hz to 2 k Hz since they are approximate to the frequency of the human voice.

3. Methods

In intelligibility tests, the participants were presented with a test signal via headphones (SENNHEISER: HD 280 pro). The test
After taking the intelligibility test, participants were presented with a listening difficulty test in which they evaluated whether the presented test signal was difficult to hear. As shown in Table 3, the evaluation of difficulty in listening was divided into four levels: “not difficult,” “slightly difficult,” “moderately difficult,” and “Very difficult.” The listening difficulty was the percentage at which the presented test signals were evaluated as “difficult.” In other words, it was the ratio of the total of the evaluations other than “not difficult” in Table 3. Both the intelligibility and listening difficulty tests were conducted for each participant.

4. Results

4.1. Intelligibility test

Table 4 shows the results of the intelligibility test. The results for the young participants were gathered in a prior study, and the results for the elderly participants were gathered in the present test. Fig. 10 summarizes the results of the intelligibility test for both the young and elderly participants.

For the young participants, the correct answer rate was 84.6% in the same room when the acoustic physical quantity was not improved and 93.0% when the acoustic physical quantity was improved. In contrast, in the room using the teleconference system, the correct answer rate was 67.8%, but the ratio rose to 81.4% when the acoustic physical quantity was improved. In terms of the elderly participants, the correct answer rate was 69.4% in the same room when the acoustic physical quantity was not improved and 72.7% when the acoustic physical quantity was improved. In the room using the teleconference system, the correct answer rate was 36.6%, which improved to 53.0% when the acoustic physical quantity was improved.

Moreover, Fig. 11 shows the correlation between the intelligibility and the acoustic physical quantities such as STI, Clarity and Reverberation time. As shown in Fig. 11 (a), the determination coefficients of intelligibility and STI were 0.961 for young participants and 0.918 for elderly participants. As shown in Fig. 11 (b), the coefficients of determination of the intelligibility and Clarity were also very high at 0.958 for young participants, and 0.941 for elderly participants.

4.2. Listening difficulty test

Fig. 12 shows the results of the listening difficulty test. (a) shows the result for young participants, which is the result of the prior study, and (b) shows the result for elderly participants, which is the result of the present test. This represents the ratio of the evaluation of the listening difficulty for sound under each experimental condition. In addition, Table 5 shows the value of the listening difficulty, that is, the ratio of the evaluation results excluding “not difficult.” Fig. 13 summarizes the results of the listening difficulty test for both the young and elderly participants.

First, there is a difference in intelligibility between the sound in the same room and the sound in the room using the teleconference.
Furthermore, more than half the young participants evaluated the sound using a teleconference system as “difficult.” Secondly, when the sound-absorbing panels are installed, the more the sound is improved, the lower the listening difficulty becomes. This applies to both young and elderly participants.

In terms of the young participants, the listening difficulty was 44% in the same room when the acoustic physical quantity was not improved and this improved to 20% at absorption level 2 and 24% at absorption level 3. By contrast, in the room using the teleconference system, the listening difficulty was 100%, and 88% when the acoustic physical quantity was improved. In terms of the elderly participants, the listening difficulty was 23% in the same room when the acoustic physical quantity was not improved and 19% when the acoustic physical quantity was improved. In contrast, in the room using the teleconference system, the listening difficulty was 43%, which improved to 30% at absorption level 2 and 32% at absorption level 3.

In addition, as shown in Fig. 12 (a), in the room using the teleconference system, the percentage of young participants who evaluated as “very difficult” or “moderately difficult” decreased with
an increase in the sound absorption level. However, as shown in Fig. 12 (b), for the elderly participants, the percentage of those who evaluated “very difficult” or “moderately difficult” were almost 10% under all conditions.

Fig. 14 shows the correlation between the listening difficulty and the three acoustic physical quantities. As shown in Fig. 14 (a), the determination coefficient between the listening difficulty and STI was 0.859 for young participants and 0.959 for elderly participants. As shown in Fig. 14 (b), the determination coefficient between the listening difficulty and Clarity was 0.902 for young participants and 0.980 for elderly participants, which was extremely high.

5. Discussions

The intelligibility results for the elderly in the room using the teleconference system were extremely low at 36.6%. However, the intelligibility of elderly people was improved by 16.4% at sound absorption levels 0 to 3 in the room using the teleconference system. When using the teleconference system, it was observed that the intelligibility of young people also improved by 13.6%. However, in the same room where the sound absorption levels were 0 to 3, the intelligibility of the elderly improved only by 3.3%, and the intelligibility of the young improved only by 8.4%. This
indicates that the intelligibility of the room using the teleconference system was highly improved by the sound-absorbing panels. The intelligibility results for the room using the teleconference system were improved by the sound-absorbing panels, but not as highly as when directly speaking to each other. The intelligibility of young people in the improved room using the teleconference system was 81.4% compared to 84.6% in the same room when the teleconference system was not used. Furthermore, the intelligibility of elderly people in the improved room using the teleconference system was 53.0% compared to 69.4% in the same room.

As shown in Fig. 11 (a) and (b), it was found that STI and Clarity have an extremely high correlation with the intelligibility of young and elderly people. Furthermore, it is generally considered that an STI of 0.75 or higher is ideal. However, even if the STI was 0.75 or more, the intelligibility of the elderly people did not reach 50% or more. Therefore, more than half of the elderly people may not understand speech even if the STI was 0.75.

Accordingly, it can be observed that the intelligibility in the room using the teleconference system can be improved by sound-absorbing panels. However, the intelligibility in the room using the teleconference system still needs to be improved. The listening difficulty in the same room improved by 20% for young people and 4% for elderly people at sound absorption levels 0 to 3. On the other hand, the listening difficulty in the room using the teleconference system improved by 12% for young people and 11% for elderly people at sound absorption levels 0 to 3. The listening difficulty in the room using the teleconference system was greatly improved by the sound-absorbing panels. However, the lis-
tening difficulty of sound absorption level 3 did not provide significant improvement over levels 1 and 2. This may be owing to the reason that the listening difficulty for improvement of the acoustic physical quantities has a certain threshold.

In Fig. 14 (a) and (b), it was found that STI and Clarity have an extremely high correlation with the listening difficulty of young and elderly people. Furthermore, even if the STI is 0.75 or higher, the listening difficulty of young people is not improved to less than 50%. Therefore, more than half the young people found it difficult to listen when the STI was 0.75. However, it is known that participants tend to judge on a scale for the entire experiment in the case of subjective assessments such as the listening difficulty. Therefore, it is possible that the narrow range of STI used in this study result in higher the listening difficulty than the wide range of STI containing less than 0.7. In addition, as mentioned above, according to Sato et al., it is suggested that the listener will not be irked if the Clarity is 3.1 dB or higher in the living room [12]. According to the experimental results, even if the Clarity was 3.1 dB (which was the designated target value) or higher, the listening difficulty of young people did not improve to less than 50%. It can be said that more than half the young people do not evaluate as “difficult to listen” when the Clarity is ≥9.4 dB.

A difference was found in the evaluation of the listening difficulty between elderly people and young people. Young people found it more difficult to listen than elderly people. The listening difficulty of elderly people in the same room were 0 to 22% lower than that of young people. Furthermore, it is interesting that the listening difficulty of elderly people in the room using the teleconference system were 51 to 58% lower than that of young people. According to a study by Uchida et al. [20], elderly people tend to underestimate the listening difficulty compared to young people if their hearing thresholds are comparable. It is speculated that elderly people do not find themselves difficult to listen. More specifically, elderly people may mistakenly think that they can lis-
ten accurately regardless of whether they can understand what they heard, so they will not pay attention to listening. Additionally, the effect was stronger in the room using the teleconference system than in the same room. Therefore, elderly people should be more careful when listening, and the acoustics of rooms using teleconference system still need to be improved.

Table 5
Results of listening difficulty test.

| Experimental condition | Listening difficulty |
|------------------------|----------------------|
|                        | Young    | Elderly |
| A0-A0                  | 44%      | 23%     |
| A1-A1                  | 44%      | 22%     |
| A2-A2                  | 20%      | 20%     |
| A3-A3                  | 24%      | 19%     |
| A0-B0                  | 100%     | 43%     |
| A1-B1                  | 88%      | 37%     |
| A2-B2                  | 88%      | 30%     |
| A3-B3                  | 88%      | 32%     |

Fig. 12. Answer results of listening difficulty test.

Fig. 13. Results of listening difficulty test.
6. Conclusions

In this study, we investigated the effects of acoustics in the same room and the room using a teleconference system on subjective assessments such as intelligibility and listening difficulty. In addition, the influence of the improvement of the acoustic physical quantities using the sound-absorbing panels on the subjective assessments was also investigated. This research aims to clarify the difference in the subjectivity between young people and elderly people, including the viewpoint of the aging society, which has become a challenge in developed countries in recent years. Moreover, we examined the improvement of the subjective assessments of young and elderly people by improving the acoustics of the room using the teleconference system.

An analysis of the data obtained from this research led to the following findings. Firstly, it was found that the improvements in acoustic quantities by the sound-absorbing panels increased the subjective assessments of both young and elderly people in the same room and the room using the teleconference system. In particular, the acoustic improvement by the sound-absorbing panels in the room using the teleconference system greatly affected the subjective assessment of the listener. Furthermore, it is possible to satisfy the design target value of the acoustic physical quantities even with a small number of sound-absorbing panels. However, the acoustics of a room using a teleconference system may not always be applicable to the existing design target values. Even if the acoustic physical quantities are improved to the design target value, this does not imply that the listener can understand what is being transmitted.

Second, elderly people have different listening abilities than young people, and thus the strength of the effect on intelligibility also differs. It is considered that elderly people tend not to admit to having listening difficulties. It is important to note that elderly people may unknowingly overlook or mishear certain sounds. Therefore, it is necessary to assume users of various ages when organizing a conference or meeting, or when designing a room using a teleconference system. This is because use of teleconference systems will become commonplace among the general public, and there will definitely be more opportunities for the elderly as well as the young to use these systems.

In this study, the sound field of a relatively small and easy-to-hear room was used for the experiment. It is also necessary to cover the sound fields of larger conference rooms and venues because not only meetings and lectures for small groups but also performances, classes, and lectures for large numbers of people will need to be accommodated.
CRediT authorship contribution statement

Rikiya Hara: Conceptualization, Formal analysis, Data curation, Writing - original draft. Takafumi Shimizu: Conceptualization, Methodology, Investigation, Writing - review & editing, Resources, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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