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Room acoustic conditions of schools, a church, and a residential premise for hearing impaired people

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ABSTRACT

It has been known that hearing impaired people need more strict room acoustic requirements than normal hearing people for verbal communications. Therefore, several design guidelines exist, such as a maximum reverberation time of 0.4 s in classrooms, signal to noise ratios (SNR) higher than 15 dB, and ambient noise levels lower than 35 dBA. We measured noise levels and room impulse responses of 12 rooms in two schools for hearing impaired children, a dormitory apartment with 3 rooms, and a church mainly for the hearing impaired in the Republic of Korea and extracted room acoustic parameters. Subjective reverberance and quality of verbal communication and well-being are obtained through questionnaires and interviews with hearing impaired students.

Keywords: Classrooms, church, dormitory, hearing impaired people, reverberation time, speech clarity, noise

1. INTRODUCTION

Hearing impaired people have more challenges in verbal communication under noisy and bad acoustic conditions. Effects of reverberation and noise on the intelligibility of sentences have been investigated, e.g., see Ref. (1). In room acoustics, speech transmission index (STI) derived from the modulation transfer function is normally used to describe the combined effect of noise and reverberation on speech intelligibility. Using STI, it was found that for hearing-impaired subjects every 3-dB hearing loss for speech in noise (elevation of the speech-reception threshold in terms of S/N ratio relative to the speech-reception threshold for normal-hearing subjects) can be compensated for by an increase of 0.1 in STI. For classrooms, this increase can be obtained by reducing the reverberation time significantly (2). Since many hearing-impaired subjects have hearing losses for speech in noise larger than 3 dB, Plomp and Duquesnoy concluded that the hearing impaired need much lower reverberation times and lower background noise level than the normal hearing (2).

The American Speech-Language Hearing Association (ASHA) published “Guidelines for addressing acoustics in educational settings,” that called for background noise levels not to exceed 30 dBA, reverberation times not to exceed 0.4 seconds, and an overall teacher signal-to-noise ratio (SNR) of larger than 15 dB (3). Generally, these specifications were confirmed by the American National Standards Institute (ANSI) by publishing “ANSI S12.60-2010 Acoustical Performance Criteria, Design Requirements and Guidelines for Schools/Part 1: Permanent Schools” that, based on the room size, recommends that background noise level not to exceed 35 dBA, reverberation time (RT) not to exceed 0.6-0.7 seconds, and a SNR of +15 dB (4). The latest Danish Building Regulations published in 2018 (BR18) also set out a similar reverberation time limit of 0.6 s for classrooms and learning

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rooms (5). The only exceptions are rooms for singing and music, smaller than 250 m^3, for choral and acoustic music, which can have reverberation times up to 1.1 s. Several room acoustic studies also concur with the building recommendations. Bradley concluded that optimum reverberation times of 0.4 s to 0.5 s for classrooms with a uniform background noise level of 30 dBA using subjective test and theoretical prediction of U50 (6). Yang and Hodgson also found some useful speech intelligibility scores for normal hearing and hearing impaired people, in two different signal to noise (SNR) conditions, 0 and 5 dB (7).

Many studies have reported that these acoustic requirements are rarely fulfilled in reality. For example, McCroskey and Devens found that the recommended acoustical conditions had been achieved in only one classroom out of nine investigated (8), and Crandell and Smaldino reported that none of the 32 classrooms they studied met recommended criteria for noise levels (9). Only 9 rooms out of 32 satisfied for reverberation in another study (10).

We have investigated two schools, one church and one dormitory for hearing impaired people in the Republic of Korea and compared to the previously recommended acoustic conditions. We have conducted ISO 3382 measurements for objective quantification of room acoustic conditions (11). A questionnaire and individual/group interviews were supplemented to strive to search for a meaning correlation between the objective parameters and subjective responses.

2. Rooms

2.1 Two schools

Seoul National School for the Deaf (SNSD) was founded in 1913, having 95 students enrolled covering kindergarten to high school classes. Another school for hearing impaired children in Seoul, Seoul Samsung School (SS), was founded in 1957, with 109 students enrolled, covering from a kindergarten to high school. These are two large schools for hearing impaired children in Seoul, Korea. Five classrooms in SNSFD and seven classrooms in SS were measured.

2.2 Church

Youngnak chuch of the deaf is a relatively big church mainly for hearing impaired people, founded in 1946. Its dimensions are approximately 23 m, 17 m, and 4 m, ending up with a volume of 1564 m^3.

2.3 Dormitory

Nongawon dormitory (founded in 1957) is a residential facility, where 34 hearing impaired people live. Three people share an apartment, which has a living room, bathroom, kitchen, and three bedrooms. One apartment was measured.

(a) (b) (c)

Figure. 1. Photos of the measured rooms (a) SNSD, (b) Youngnak church, (c) Nongawon dormitory.

3. Methods

3.1 ISO 3382 measurements

Room acoustic conditions were measured according to ISO 3382 (11). Due to small volumes of the measured rooms and limited time, it was not always possible to make 12 source-receiver combinations as suggested in ISO 3382. For Youngnak church, reverberation time T_{20} and STI are of main concern. For the dormitory and classrooms, only T_{20} is presented.

3.2 Questionnaire

A questionnaire was distributed to collect the users' acoustic satisfaction regarding reverberation, speech clarity, and external/internal noise. All the questions were rated on a 5-point scale and answered in December 2018.

3.3 Interviews

Hearing impaired people usually receive a lot of questionnaires and tend not to take them very seriously. As the two schools cover a broad age range from kindergarten to high school, it was decided to interview with the pupils who use the measured classrooms as of May 2019, assuming that the results of which would make a better correlation to the objective measurement than the questionnaire results. Individual interviews are known to more precise so we tried to avoid group interviews for two reasons. First, the interview results could possibly be biased by certain strong opinions in a group interview. Second, the interviewee are hearing impaired children, who might face even bigger challenges in group conversations, e.g., lack of concentration and difficulties in conversing in a big group. However, we ended up with a group interview in one classroom (High school 3-2) at SS due to limited time allowed. The interviews were conducted only in SS in May 2019.

4. Results

4.1 Classrooms

4.1.1 Objective measures, T_{20} and noise levels

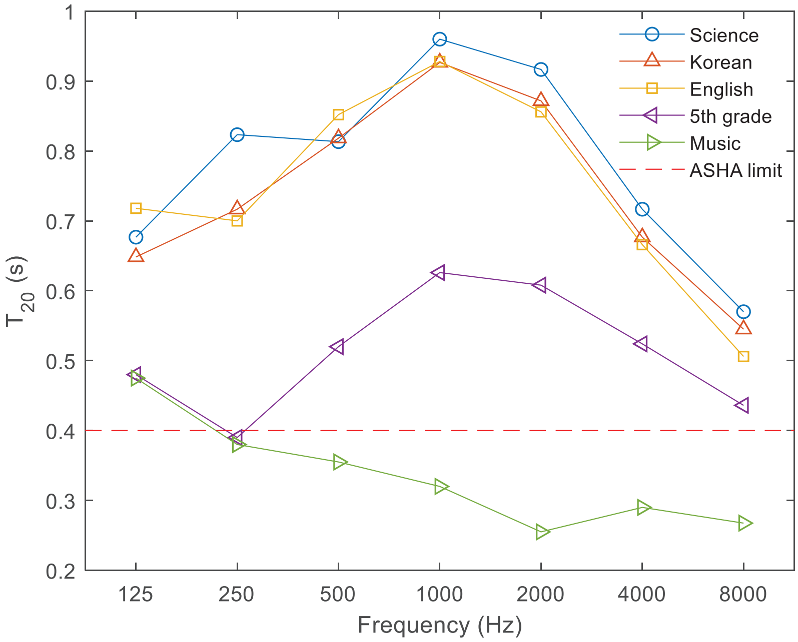
All the classrooms measured turn out not to comply with the ASHA limit of 0.4 s as shown in Fig. 2. In general, SNSD has longer reverberation times than SS. In SS, the reverberation time gradually changes from 0.45 s to 0.61 s as shown in Fig. 2 (bottom). The noise levels in **occupied** conditions vary from 31 dBA to 42 dBA.

4.1.2 Questionnaire and interview results

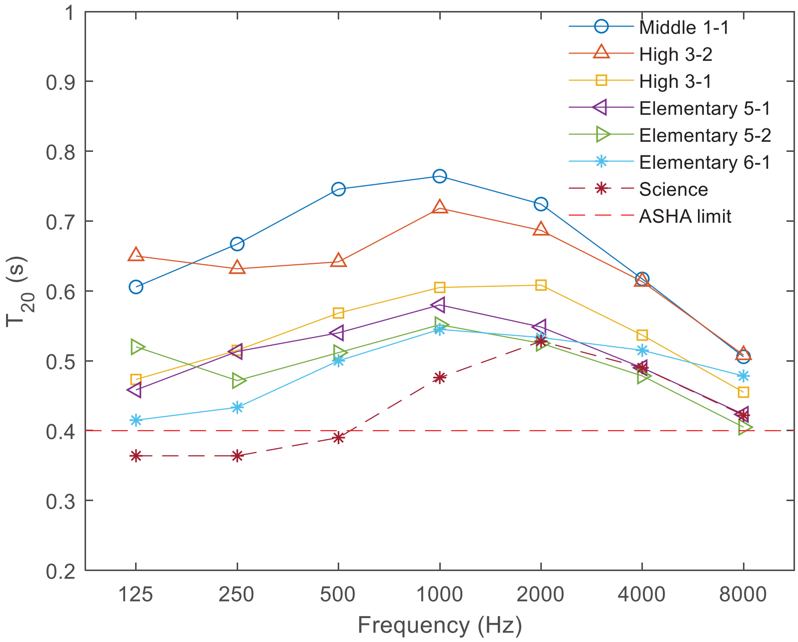
No good correlation is found between T_{20} and subjective speech clarity in Table 1 conducted in SS. Here the subjective speech clarity ratings [5, 4, 3, 2, 1] mean [Extremely good/Perfect, Good, Normal, Bad, Extremely bad]. Moreover, the subjective rating of every classroom is higher than 3, although the reverberation time of every room is longer than the ASHA limit.

We could speculate some reasons. First, the reverberation time change is not large enough, only varying from 0.46 to 0.61 s. Second, the number of respondents is small and also varies with classrooms, from 3 to 8 people. Third, the ages of the respondents vary from 10 to 18. Particularly, younger students enrolled in the elementary school have difficulties understanding the question about the speech clarity and seems not experienced to evaluate the acoustic quality. Perhaps they do not have a decent reference/experience on good acoustic conditions with cochlea implants and hearing aids. Although many eventually answered that the speech clarity was 'Perfect', they spent a lot of time understanding the sentence of questions clearly and therefore the teachers repeated the same questions several times. We asked an additional question if they could perceive any acoustical difference in different spaces, and most of them answered negatively; 63% answered 'No' and the rest answered 'Rarely'. This potentially indicates that they might not understand the question correctly. While younger students used the high scores (4 and 5) in the speech clarity question, older students (18 years old) could use a wider score range and therefore the room High 3-2 has the lowest mean and largest spread.

Potential reasons for the good rating might be a small number of students in the class and short distance from the teacher. Many rooms have dimensions of 4.8 m (D) × 6.3 m (W) × 2.7 m (H) and the distance from the teacher was mostly within 2 m (shortest 1.3 m, longest 3.0 m).



(a)



(b)

Figure. 2. Reverberation time T_{20} (a) SNSD, (b) SS.

Table. 1. Reverberation time T_{20} and subjective speech clarity results in SS.

	Science	Ele 6-1	Ele. 5-2	Ele. 5-1	High 3-1	High 3-2	Mid. 1-1
Octave-band averaged T_{20} (s)	0.43	0.49	0.49	0.51	0.54	0.64	0.66
Questionnaire	3.9	3.3	3.5	3.7	4.4	4	3.8
Interview	4.5	4.5	5	4.6	5	3.6	5

4.2 Church

The reverberation time T_{20} in the church is shown in Fig. 3, including the 63 Hz octave band. The mean reverberation time is 0.74 s averaged across the frequency bands. This reverberation time cannot meet the ASHA limit, but compared to other worship places, the reverberation time is much shorter, and this might be a reason for a satisfactory subjective speech clarity rating.

The average of STI values in 13 source-receiver combinations was found to be 0.69 with a standard deviation of 0.03, meaning a good speech communication quality. This value corresponds to the qualification scale "C" of high speech intelligibility according to IEC 60268-16 (12). Note that the same standard states that modern churches typically have a nominal STI value of 0.58 (Category "E"). Therefore, it is concluded that this church has a better speech indelibility than other modern churches, but no data are found regarding church acoustics for hearing impaired people.

The noise level in an unoccupied condition is quite stable over the church, varying from 33 dBA to 35 dBA. With an open window, 39 dBA is measured. The unoccupied noise level satisfies the ANSI recommendation, but not the ASHA recommendation.

The church was subjectively rated as fair-to-good in terms of speech clarity (mean speech clarity rating of 3.3) and not disturbing in terms of noise annoyance (mean noise annoyance rating of 1.6). Here the subjective noise annoyance ratings [5, 4, 3, 2, 1] mean [Extremely annoying, Annoying, Slightly annoying, Not disturbing although noise heard, No noise heard]. The subjective ratings are in line with the objective room acoustic parameters.

4.3 Dormitory

The reverberation time in the dormitory Nongawon is shown in Fig. 4. The longest reverberation time was found to be 0.76 s averaged across the measurement points and frequency bands in the living room, as it the largest room volume and connected to the kitchen. The big bedroom has an averaged T_{20} of 0.49 s and the small bedroom has a T_{20} of 0.41 s.

Unoccupied noise levels are found to be 34-38 dBA, which is close to what is recommended by ANSI and ASHA, although this is not a classroom. The speech clarity was evaluated as fair-to-good (subjective score of 3.3) and noise annoyance was rated as slightly disturbing (noise score of 2.3). They commented that chair dragging noise, computers, and conversation during night were particularly annoying.

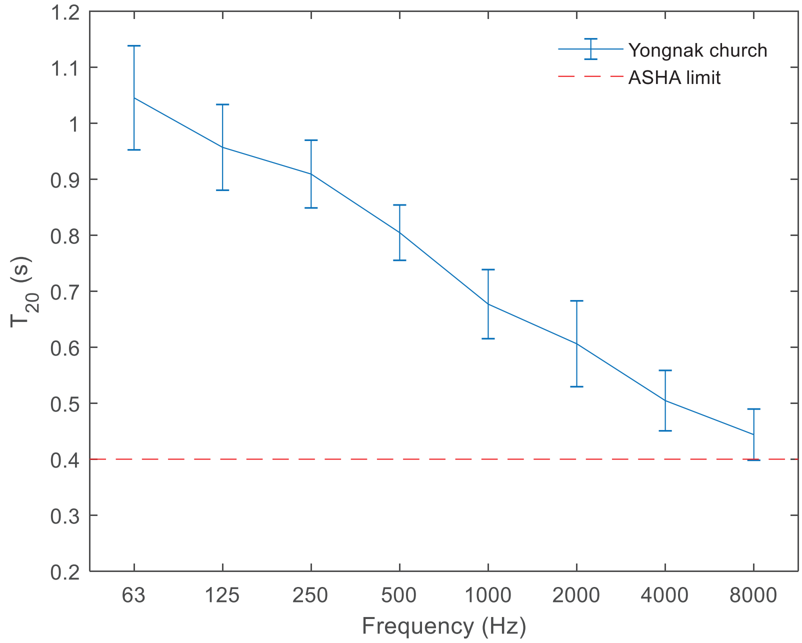


Figure. 3. Reverberation time T_{20} in Youngnak church. The error bar means the standard deviation.

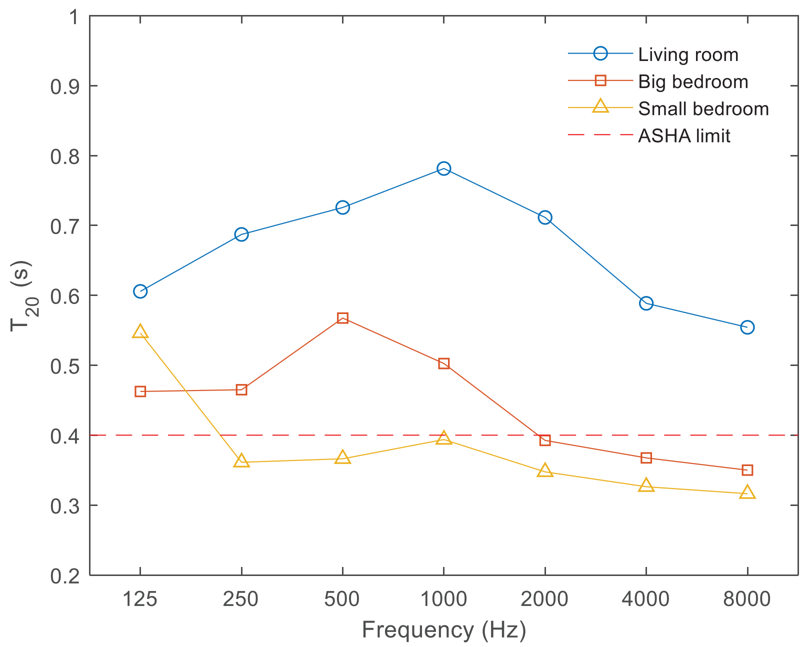


Figure. 4. Reverberation time T_{20} in Nongawon rooms.

5. CONCLUSIONS

The acoustic conditions of several rooms for hearing impaired people in the Republic of Korea are measured and presented. In the two schools measured, no classroom could satisfy the reverberation time requirement of 0.4 s. The correlation between the reverberation time and subjective speech clarity is poor, and it is difficult to obtain reliable subjective responses for several reasons. The noise level was measured to vary from 31 to 42 dBA in occupied conditions, while the recommendation was given for unoccupied conditions.

The church has a reverberation time of 0.74 s averaged across the frequency and 13 source-receiver combinations and a mean speech transmission index of 0.69. As it is a worship space, the acoustics could be much more reverberant than as it is. According to IEC 60268-16, this church has a higher speech intelligibility than typical modern churches. The unoccupied noise level seems proper for the intended use.

The dormitory has no acoustic design guideline. The reverberation time in the living room is longest as 0.67 s, and the speech clarity is evaluated as fair-to-good. The noise in the dormitory is slightly disturbing with main sources of chair dragging noise and computer noise.

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