Noise and acoustic conditions of premises for hearing-impaired people in Korea

Jeong, Cheol-Ho; Cho, Wan-Ho; Chang, Ji-ho; Lee, Sung-Hyun; Kang, Chang Wook; Park, Jin Gyun

Published in:
Noise Control Engineering Journal

Link to article, DOI:
10.3397/1/37697

Publication date:
2021

Document Version
Peer reviewed version

Noise and acoustic conditions of premises for hearing impaired people in Korea

Cheol-Ho Jeong[a)], Wan-Ho Cho[b)], Ji-Ho Chang[c)], Sung-Hyun Lee[d)], Chang-Wook Kang[e)], Jin-Gyun Park[f)]

(Received: 3 March 2020; Revised:; Accepted:)

Hearing-impaired people need more stringent acoustic and noise requirements than normal-hearing people in terms of speech intelligibility and listening effort. Multiple guidelines recommend a maximum reverberation time of 0.4 s in classrooms, signal-to-noise ratios (SNR) greater than 15 dB, and ambient noise levels lower than 35 dBA. We measured noise levels and room acoustic parameters of 12 classrooms in two schools for hearing-impaired pupils, a dormitory apartment for the hearing impaired, and a church mainly for the hearing impaired in the Republic of Korea. Additionally, subjective speech clarity and quality of verbal communication were evaluated through questionnaires and interviews with hearing-impaired students in one school. Large differences in subjective speech perception were found between younger primary school pupils and older pupils. Subjective data from the questionnaire and interview were inconsistent; major challenges in obtaining reliable subjective speech perception and limitations of the results are discussed.

Primary subject classification: 51.1; Secondary subject classification: 56.2, 69.2

1 INTRODUCTION

Hearing impaired people, even in aided conditions, suffer more from noisy and bad acoustic conditions than normal hearing counterparts. For example, aided hearing-impaired listeners have consistently poorer speech intelligibility performance than normal-hearing listeners [1]. Combined effects of reverberation and noise on the intelligibility of sentences for the hearing impaired were investigated using speech transmission index (STI) [2], concluding that for hearing-impaired subjects, every 3 dB hearing loss for speech in noise can be compensated for by an increase of 0.1 in STI. Since many hearing-impaired subjects have hearing losses larger than 3 dB for speech in noise, Plomp and Duquesnoy concluded that the hearing impaired need much shorter reverberation times and lower background noise levels than the normal hearing [3]. To implement this conclusion in classrooms, the reverberation time would need to be reduced tremendously [3]. Yang and Hodgson also investigated speech intelligibility scores for normal-hearing and hearing-impaired people in two different signal-to-noise ratio (SNR) conditions: 0 and 5 dB. They concluded that hearing-impaired listeners were more adversely affected by reduced speech-to-noise level differences[4].

[a)] Acoustic Technology, Department of Electrical Engineering, Technical University of Denmark, Denmark
[b)] Division of Physical Metrology, Korea Research Institute of Standards and Science, Korea, chowanho@kriss.re.kr
[c)] Division of Physical Metrology, Korea Research Institute of Standards and Science, Korea,
[d)] Department of System Dynamics, Korea Institute of Machinery & Materials, Korea
[e)] Department of Special Education, Kangnam University, Korea
[f)] Oticon Korea, Seoul, Korea

Accordingly, 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 SNR of more than 15 dB [5]. Generally, these specifications were confirmed by the American National Standards Institute (ANSI), which recommended in ANSI S12.60 [6] that background noise level not exceed 35 dBA, reverberation time (RT) not exceed 0.6-0.7 seconds, and a SNR of +15 dB. Another study recommended more detailed guidelines for the hearing-impaired pupils, such as noise criteria (NC) of 20 or less, with a modified clarity ratio of $C_{\text{arrival time+20ms}}$ of 10 dB or more, and STI greater than 0.75 [7].

However, several on-site measurements have reported that these acoustic requirements are rarely fulfilled in reality. For example, Crandell and Smaldino reported that none of the 32 classrooms measured in the US met recommended criteria for noise levels and only 9 out of the 32 US classrooms showed RTs of 0.4 s or less[8-9]. No acoustic measurements have been conducted in Korean school buildings and important premises for hearing-impaired listeners, so it is still not known if these acoustic requirements are fulfilled or not.

The primary objective of this study is to investigate the objective room acoustic measures of premises mainly intended for hearing-impaired people in Korea to see whether the suggested guidelines by ASHA are fulfilled in those rooms. Moreover, it is natural and crucial to study if the users' subjective perception of acoustics is well in line with the objective acoustic parameters measured in the classrooms. We managed to collect subjective answers in seven classrooms at one school via questionnaires and individual interviews. With these data, we studied a correlation between subjective perception of acoustics and objective room acoustic measures and subjective speech clarity results for hearing aid users (HA) and cochlear implant users (CI), separately. A cochlear implant is a small electronic device that partially restores hearing through a surgical procedure for sufferers of profound hearing loss, for whom a hearing aid is of no or little benefit. Having such correlations between on-site subjective and objective data in several classrooms helps draw meaningful criteria for satisfactory acoustic conditions for the hearing impaired in terms of speech perception. This is particularly important because the objective speech parameter used in this study, C_{50}, a widely used speech clarity parameter based on the useful-to-detrimental energy ratio concept, has rarely been used in studies aimed for hearing-impaired pupils.

2 EVALUATION METHOD

This chapter describes the rooms investigated, and how the objective and subjective data were collected in this study.

2.1 Rooms for survey

Three different types of premises for the hearing impaired in the Republic of Korea were evaluated: one church, one dormitory apartment, and 12 classrooms of two schools, as shown in Fig. 1. Youngnak church of the deaf is a church mainly for hearing impaired people, which was built in 2006. Its dimensions are approximately 23 m, 17 m, and 4 m, ending up with a volume of 1564 m^3.

Nongawon dormitory (built in 2007) is a residential facility, where 34 hearing-impaired people live. Three people share an apartment that has a living room, bathroom, kitchen, and three bedrooms. One apartment of the dormitory was measured.

The two large schools for hearing impaired children that were measured are Seoul National School for the Deaf (SNSD) and Seoul Samsung School (SS). The main building of SNSD was built in 1988, accommodating 95 students enrolled from kindergarten to high school classes. SS was built in 1976, accommodating 109 students, from kindergarten to high school. Five classrooms in SNSD and seven classrooms in SS were measured.

2.2 ISO 3382 measurements for objective parameters

Objective quantification of room acoustic conditions was conducted according to ISO 3382-2[10]. An omnidirectional loudspeaker (B&K type 4292) was used as a sound source. Impulse responses were measured by Dirac Room Acoustics Software (B&K type 7841) using exponential sweep signals of either 0.67 s or 1.35 s to ensure a 35 dB dynamic range for properly measuring T_{20}, a reverberation time measure using a decay range of 20 dB.

For Youngnak church, reverberation time T_{20} and STI values were calculated from the impulse responses measured at 13 source–receiver (S-R) combinations. The loudspeaker was located at 3 potential locations of a priest in the chancel of the church and microphones were distributed in the nave area. The height of the source was set to 1.7 m and the height of the microphone was 1.2 m from the floor to represent a seated person. These heights were maintained in the other rooms.

For the dormitory, only T_{20} was used for a general assessment of room acoustics. We measured seven S-R combinations in the living room and the large bedroom, and four S-R combinations in the small bedroom. A smaller number of S-R combinations in the small bedroom was due to its small size to keep the distance from the microphone to the nearest reflecting surface and the sound source to 1 m and 1.5 m, respectively[10].

For the classrooms, T_{20}, STI, and speech clarity C_{50} are the main parameters used for general acoustics and speech clarity evaluation. In all classrooms, the omnidirectional loudspeaker was located at a potential teacher's position and microphones were distributed in the pupils' seating area. At least two source locations were used in all the classrooms. We aimed to sample minimum six S-R combinations in each room, but in some small rooms like the science room in SNSD it was only possible to collect four S-R combinations.

For the sake of simplicity, the measured objective parameters were spatially averaged across the S-R combinations and averaged across the octave bands centered from 125 Hz to 4 kHz, and only the mean values are presented in Section 3. All measurements were carried out in December 2018.

2.3 Questionnaire and Interviews

To collect the users' subjective responses, a paper-based questionnaire was distributed. The questionnaire concerned the users' acoustic satisfaction regarding loudness, speech clarity, and annoyance due to external and internal noise sources. The respondents could choose one answer on a five-point verbal rating scale. For example, the speech clarity question for classrooms was formulated as: "How clear do you hear the teacher's voice during class? (the quality of speech transmitted to you from the teacher)", and the rating scales were: 1=extremely bad, 2=bad, 3=fair, 4=good, 5=extremely good. The noise annoyance question for the church was: "how much are you disturbed by noise during the mass?", with rating scales: 1=extremely disturbing, 2=disturbing, 3=slightly disturbing, 4=not disturbing although noise heard, 5=no noise heard. The loudness of sermon was determined in the following question: "How loud is the sermon?", on a bipolar scale of: 1=very weak, 2=a little weak, 3=appropriate, 4=a little loud, 5=very loud.

The questions were answered in December 2018; 41 answers were collected from the church, 15 answers from the dormitory, and 60 answers collected from SS. The number of answers collected differed from classroom to classroom. The minimum number collected was six in the elementary classroom 6-1 (the first classroom of the year six students), whereas the maximum number was 10 in the science room and elementary classroom 5-2, high school 3-1, and high school 3-2.

Additional interviews were conducted in SS. Hearing-impaired people usually receive many questionnaires and tend not to answer them very seriously. The school covers a broad age range from kindergarten children to high school students; younger children may not understand as thoroughly as older students do. The hearing-impaired pupils have more difficulty in reading than in speech communication because of the limited vocabulary and lack of reading capability[11-13]. For this reason, the additional explanation in spoken and sign language is widely applied for questionnaires targeted for hearing-impaired listeners. Therefore, the interviews with the pupils who used the measured classrooms were included to complement questionnaire results. Individual interviews are known to be more precise than group interviews for two reasons. First and foremost, the interviewees 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. Second, the interview results could possibly be biased by certain strong opinions in a group interview. However, due to a time limitation, we ended up with a group interview in one classroom, High school 3-2. The interviews were conducted in the same classrooms in May 2019, meaning that the interviewees were different from the questionnaire respondents because Korean school year runs from March to February. The number of interviewees in each classroom varied from two (science room) to seven (high school 3-2).

3 RESULTS

In this section, the noise and acoustic conditions of the rooms are presented in terms of objective parameters and subjective responses from the questionnaires and interviews.

3.1 Church

The reverberation time T_{20} of the church hall is shown in Fig. 2. T_{20} in the 63 Hz octave band is additionally indicated as suggested by [14]. The mean reverberation time T_{20} was 0.74 s, averaged across the frequency bands from 63 Hz to 8 kHz. This reverberation time is still much shorter compared to other places of worship. The average of STI values across 13 source-receiver combinations was 0.69 with a standard deviation of 0.03, signifying a good speech communication quality. This value corresponds to the qualification scale "C" of high speech intelligibility according to IEC 60268-16 [15]. Note that the same standard states that modern churches have a nominal STI value of 0.58 (Category "E"). Therefore, it is concluded that this church has better speech intelligibility than other modern churches, but no comparable acoustic data regarding churches for hearing-impaired people were available.

The noise level in an unoccupied condition was quite stable across the church space, varying from 33 dBA to 35 dBA. With an open window, 39 dBA was measured. The unoccupied noise level satisfies the ASHA recommendation and Beranek's recommendation of 38 dBA for small churches [16].

Based on the questionnaire results, the church was subjectively rated as fair-to-good in terms of speech clarity (mean speech clarity rating of 3.2). It was also rated as 'not disturbing' in terms of noise annoyance (mean noise annoyance rating of 4.4). However, the loudness of sermon was rated as slightly weak (mean speech loudness rating of 2.5). The subjective ratings are in line with the objective room acoustic parameters measured in the church.

3.2 Dormitory

The reverberation times in the rooms of the dormitory Nongawon are shown in Fig. 3. The longest reverberation time T_{20} averaged across the measurement points and frequency bands was 0.68 s in the living room, which is ascribed to the largest room volume and coupling to an open kitchen area. The big bedroom had an averaged T_{20} of 0.46 s and the small bedroom had an averaged T_{20} of 0.39 s.

Unoccupied noise levels were 34-38 dBA, which is close to what is recommended by ASHA, 35 dBA. According to Beranek's recommendation of 38-48 dBA for bedrooms and residences for sleeping, resting, relaxing [16], the background noise level in the dormitory rooms was sufficiently low.

The subjective 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 others conversation during night were particularly annoying.

3.3 Classrooms at SNSD and SS

In Fig. 4, T_{20} of the classrooms measured is shown as a function of frequency. It did not comply with the ASHA's reverberation time limit of 0.4 s. In general, SNSD had longer reverberation times than SS. In SNSD, the octave-band averaged T_{20} changed from 0.57 s to 0.75 s from classroom to classroom as shown in Fig. 4(a). In SS, the octave-band averaged T_{20} changed from 0.43 s to 0.66 s as shown in Fig. 4 (b) and Table 1. The noise levels in occupied conditions varied from 31 dBA to 42 dBA. Unoccupied noise levels could not be measured due to a time constraint. In Fig. 5, the speech clarity C_{50} of the classrooms in SS is shown, which was used to make a correlation with subjective speech clarity scores from the questionnaire and interviews. STI scores in SS were 0.76 for the science room, 0.72 for the elementary classrooms 5-1, 5-2, and 6-1, 0.71 for high school 3-1, and 0.66 for high school 3-2 and middle school 1-1.

In Fig. 6, the subjective speech clarity scores from the questionnaire are plotted against the frequency averaged C_{50}. Note the subjective speech clarity rating scales were: 1=extremely bad, 2=bad, 3=fair, 4=good, 5=extremely good. The subjective speech clarity scores were no smaller than 3, although the reverberation times of all classrooms exceeded the ASHA limit. When the data are divided into two age groups, primary school and secondary school pupils, one can observe that the primary school classrooms had objective clarity C_{50} values higher than 4 dB, and that there was a proportional relation between the objective clarity and subjective clarity. On the other hand, the secondary school classrooms had C_{50} values smaller than 4 dB, but the subjective clarity scores were quite high, between

3 and 4. One interpretation is that older students could understand the speech better than younger students even in more adverse listening conditions. There was no significant difference found between the hearing-aid users and cochlear-implant users in terms of subjective speech clarity. Due to a lack of statistical power, statistical analyses and regression models are not presented.

In Fig. 7, the subjective speech clarity scores from the interview are plotted against the frequency averaged C_{50}. The subjective speech clarity ratings from the interview were generally much higher than those from the questionnaire, except for the high school classroom 3-2, where a group interview was conducted. Admittedly, the reason for such a low clarity score in this classroom is unknown; it could possibly be ascribed to the group interview. The subjective scores from the interviews were consistently high and do not depend on C_{50}.

We hypothesized that such high subjective scores could be partly due to the fact that the hearing-impaired students did not have a decent reference/experience of good acoustic conditions. Therefore, we asked an additional question during the interview: could they perceive any acoustical difference in different spaces, such as playground, subway station, shopping mall and so on? As a result, most of them answered negatively; 63% answered ‘Never’. In Fig. 8, the relation between their subjective evaluation of speech clarity and self-evaluation of perceptual sensitivity to changes in the acoustic conditions is shown. The more insensitive to the acoustical changes they were, the higher the subjective speech clarity scores are.

4 DISCUSSION AND LIMITATIONS

During the investigation, we found on-site evaluation of speech clarity, particularly from the hearing-impaired pupils, quite challenging for several reasons. (1) The number of collected answers was quite small. In this study, the sample size from the interview varied from 2 to 10 in each class. (2) The reliability of the answers from younger children is rather questionable, because they could have misunderstood the question about speech clarity due to lack of experience and vocabularies to describe the feeling related to the acoustic sensation. (3) Many do not have good references of good acoustics, and so they tend to overrate the speech intelligibility and clarity.

We found two positive aspects of the Korean classrooms measured: (1) small number of students in class – normally less than six people –, (2) short distances from the teacher. Many rooms have typical dimensions of 4.8 m (D) × 6.3 m (W) × 2.7 m (H) and the distance from the teacher to the pupil is mostly within 2 m (shortest 1.3 m, longest 3.0 m). As also pointed out in the several previous studies [17, 18], in a laboratory setting with auralized sound stimuli, cochlear implant recipients are rather insensitive to the acoustic conditions, but strongly prefer shorter source-to-listener distances. In those laboratory tests, the distances vary from 1 to 15 m [17] and 1-6 m [18]. To the best of the authors’ knowledge, there are no other on-site subjective speech clarity data available for comparison.

We speculate that our interview results could be biased. Many children eventually answered that the subjective speech clarity in the class was ‘very good’, but the teachers spent a lot of time making them understand the speech clarity question, and more importantly, the teachers repeated the same question again and again until the children understood, which could be an indication that the speech clarity was not perfect. The reason for such a contradiction is not clearly understood by the authors. In addition, the expression for ‘high speech clarity/intelligibility’ in Korean can potentially be misunderstood as ‘hearing sufficiently loudly’.

5 CONCLUSIONS

The acoustic and noise conditions of several important rooms mainly used by hearing-impaired people in the Republic of Korea were characterized and compared to the ASHA guideline. Youngnak church had a reverberation time of 0.74 s averaged across the frequency bands and 13 source-receiver combinations and a mean speech transmission index of 0.69. According to IEC 60268-16, this church had higher speech intelligibility than typical modern churches, which is supported by the questionnaire answers. The unoccupied noise level satisfies the existing noise guidelines for the intended use.

Although the dormitory rooms for hearing-impaired people have no acoustic guidelines, the speech clarity was subjectively evaluated as fair-to-good. The reverberation time in the living room was 0.68 s and those in the bedrooms were shorter than 0.46 s. The unoccupied noise level in the dormitory ranged 34-38 dBA, but the residents had some complaints related to man-made noise sources, such as chair-dragging noise and conversations.

In the 12 classrooms measured in two schools, none satisfied the ASHA reverberation time requirement of 0.4 s, but no classrooms were subjectively evaluated to have bad speech clarity, which was surprising. The reverberation times in the classrooms ranged from 0.44 s to 0.75 s and STI values from 0.61 to 0.76. There was no statistically significant difference in the subjective speech clarity between HA and CI groups. The subjective speech clarity evaluation from questionnaires and interviews was inconsistent and the scores from the interviews were generally higher. We found that the older pupils in the secondary school evaluated the speech clarity highly even in more challenging acoustic conditions than those in the primary school. During the interviews, we also observed that the more insensitive to the acoustical changes, the higher the speech clarity scores. The noise level was measured only in occupied conditions, varying from 31 to 42 dBA, which seems sufficiently low, but without measurements in unoccupied conditions, it is hard to conclude the background noise and SNR condition in the school.

6 ACKNOWLEDGMENTS

The authors acknowledge all the administrators of the schools, dormitory, church, who allowed us to measure the rooms and distribute the questionnaire. The authors also thank all the participants in the questionnaires and interviews, and the audiologists who helped us during the ISO 30082 measurements, questionnaires and interviews: Ms. Hye Min Byun, Ms. Sin Sung Baek, and Mr. Youngrok Heo from Oticon Korea. The work was partially supported by KRISS project grant GP2019-0001-01 in Korea.

10. REFERENCES

1. J. Xia, B. Xu, S. Pentony, J. Xu and J. Swaminathan, "Effects of reverberation and noise on speech intelligibility in normal-hearing and aided hearing-impaired listeners", *Journal of the Acoustical Society of America*, **143**, 1523-1533, 2018.

2. A. J. Duquesnoy and R. Plomp, "Effect of reverberation and noise on the intelligibility of sentences in cases of presbyacusi", *Journal of the Acoustical Society of America*, **68**, 537-544, 1980.

3. R. Plomp and A. J. Duquesnoy, “Room acoustics for the hearing impaired”, *Journal of the Acoustical Society of America*, **S19**, 71, 1982.

4. W. Yang and M. Hodgson, “Auralzation study of optimum reverberation times for speech intelligibility for normal and hearing-impaired listeners in classrooms with diffuse sound fields”, *Journal of the Acoustical Society of America*, **120**, 801-807, 2006.

5. “Guidelines for addressing acoustics in educational settings,” American Speech-Language Hearing Association (ASHA), (2005).

6. “Acoustical performance criteria, design requirements and guidelines for schools”, American Standard ANSI S12.60, (2010).

7. D. Chin-Quee and R. Penton, “Design of a classroom for deaf/hearing impaired student educators”, *Canadian Acoustics*, **32**, 36-37, 2004.

8. C. C. Crandall and J. J. Smaldino, “Classroom acoustics for children with normal hearing and with hearing impairment”, *Language, Speech, and Hearing Services in Schools*, **31**, 362–370, 2000.

9. C. C. Crandall, “Classroom acoustics for hearing impaired children”, *Journal of the Acoustical Society of America*, **92**, 2470, 1992.

10. “Acoustics - Measurement of room acoustic parameters - Part 2: Reverberation time in ordinary rooms”, International Standard ISO 3382-2, (2008).

11. J. E. Andrew and J. M. Mason, “Strategy usage among deaf and hearing readers”, *Exceptional Children*, **57**, 536-545.

12. P. L. Mcanally, S. Rose and S. P. Quigely, *Reading Practices with Deag Learners*, 2nd edition, Austin, Texas, (2007).

13. B. Strassman, “Metacognition and reading in children who are deaf: a review of the research”, *The Journal of Deaf Studies and Deaf Education*, **2**, 140-149, 1997.

14. F. Martellotta, E. Cirillo, A. Carbonari and P. Ricciardi, “Guidelines for acoustical measurements in churches”, *Applied Acoustics.*, **70**, 378-388, 2009.

15. “Sound system equipment - Part 16: Objective rating of speech intelligibility by speech transmission index”, International Standard IEC 60289-16, (2011).

16. L. Beranek and I. Ver, *Noise and Vibration Control Engineering – Principal and Application*, 2nd edition, Chap. 17, pp. 632-633, John Wiley & Sons, New Jersey, (2005).

17. B. Eurich, T. Klenzer and M. Oehler, “Impact of room acoustic parameters on speech and music perception among participants with cochlear implants”, *Hearing Research*, **377**, 122-138, 2019.

18. A. Kressner, A. Westermann and J. Buchholz, “The impact of reverberation on speech intelligibility in cochlear implant recipients”, *Journal of the Acoustical Society of America*, **144**, 1113-1122, 2018.

Table 1— T_{20}, STI, and C_{50}, 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**
Octave-band averaged C_{50} (dB)		**7.4**	**4.6**	**4.9**	**4.9**	**3.7**	**3.1**	**2.6**
STI		**0.76**	**0.72**	**0.72**	**0.72**	**0.71**	**0.66**	**0.66**
Questionnaire	Speech Clarity	**3.9**	**3.0**	**3.3**	**3.0**	**4.0**	**3.5**	**3.8**
	No. of HA/CI among Pupils	7/3	2/0	3/4	1/0	2/2	3/3	2/2
	Speech Clarity from HA	3.9	3.0	3.3	3.0	4.0	3.3	4.0
	Speech Clarity from CI	4.0	-	3.3	-	4.0	3.7	3.5
Interview	Ratio CI/HA	1/1	3/1	4/1	2/4	1/2	5/2	1/2
	Speech Clarity	**4.5**	**4.5**	**5**	**4.6**	**5**	**3.6**	**5**
	Speech Clarity from HA	**4**	**3**	**5**	**4.8**	**5**	**4**	**5**
	Speech Clarity from CI	**5**	**5**	**5**	**4.5**	**5**	**3.4**	**5**

List of Figure Captions

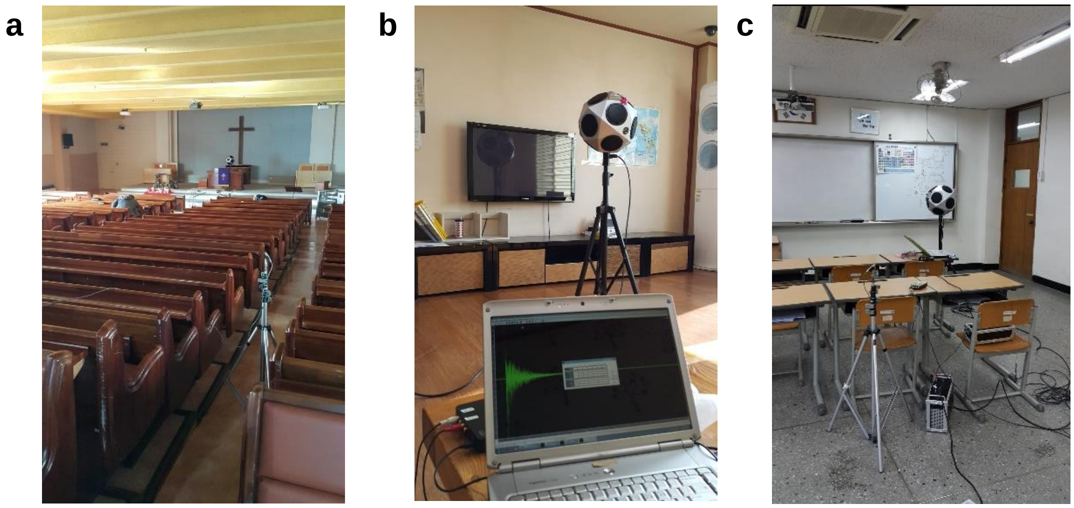

Fig. 1— Photos of the measured rooms: (a) Youngnak church, (b) Nongawon dormitory, (a) classroom of SNSD.

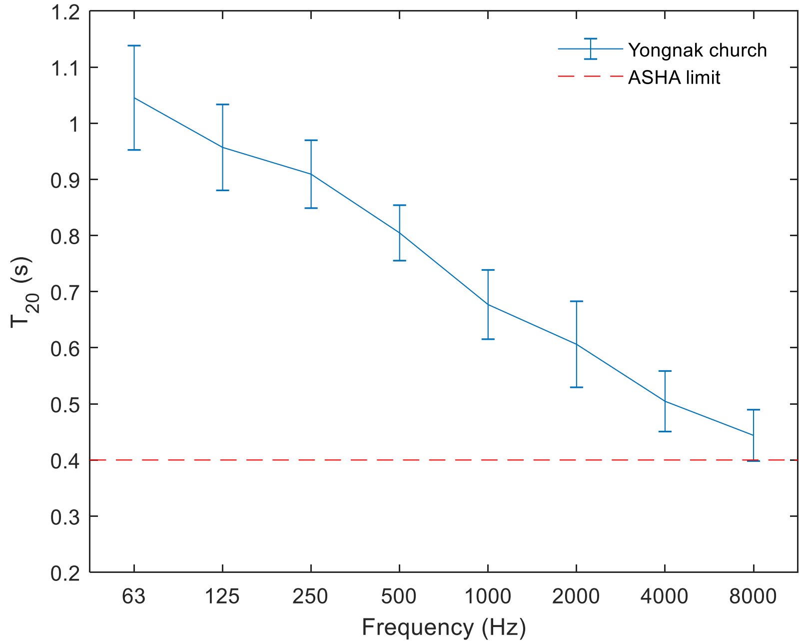

Fig. 2— Reverberation time T_{20} and its standard deviation (error bar) according to frequency in Youngnak church.

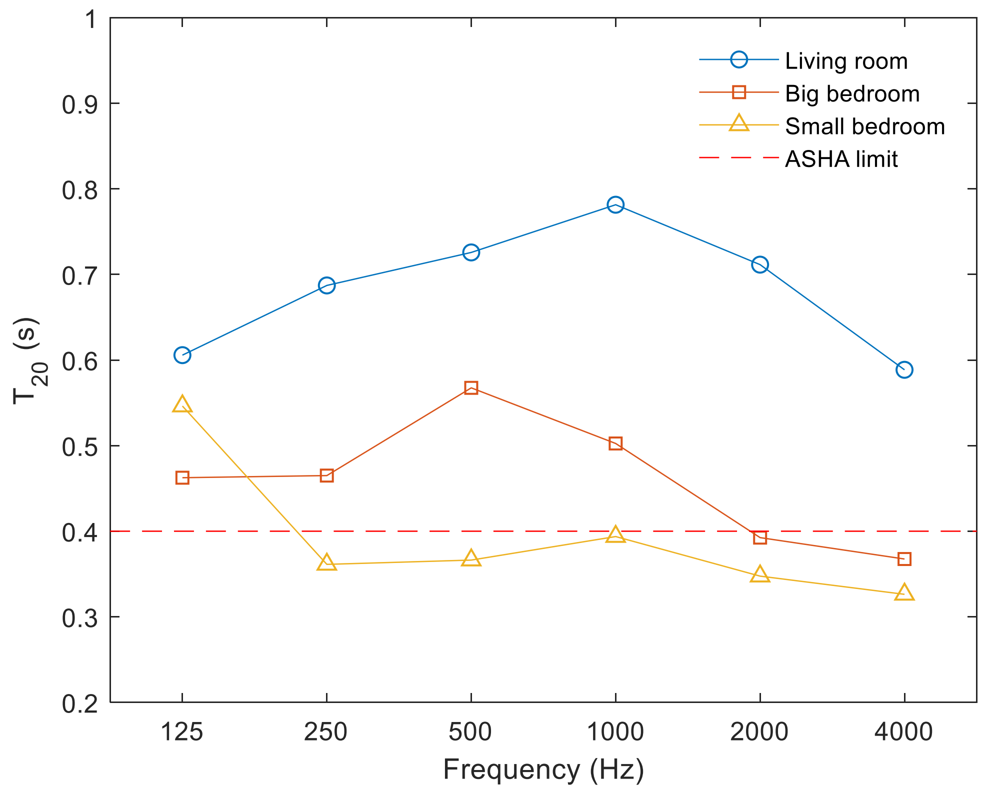

Fig. 3 — Reverberation time T_{20} according to frequency in the rooms of Nongawon domitory.

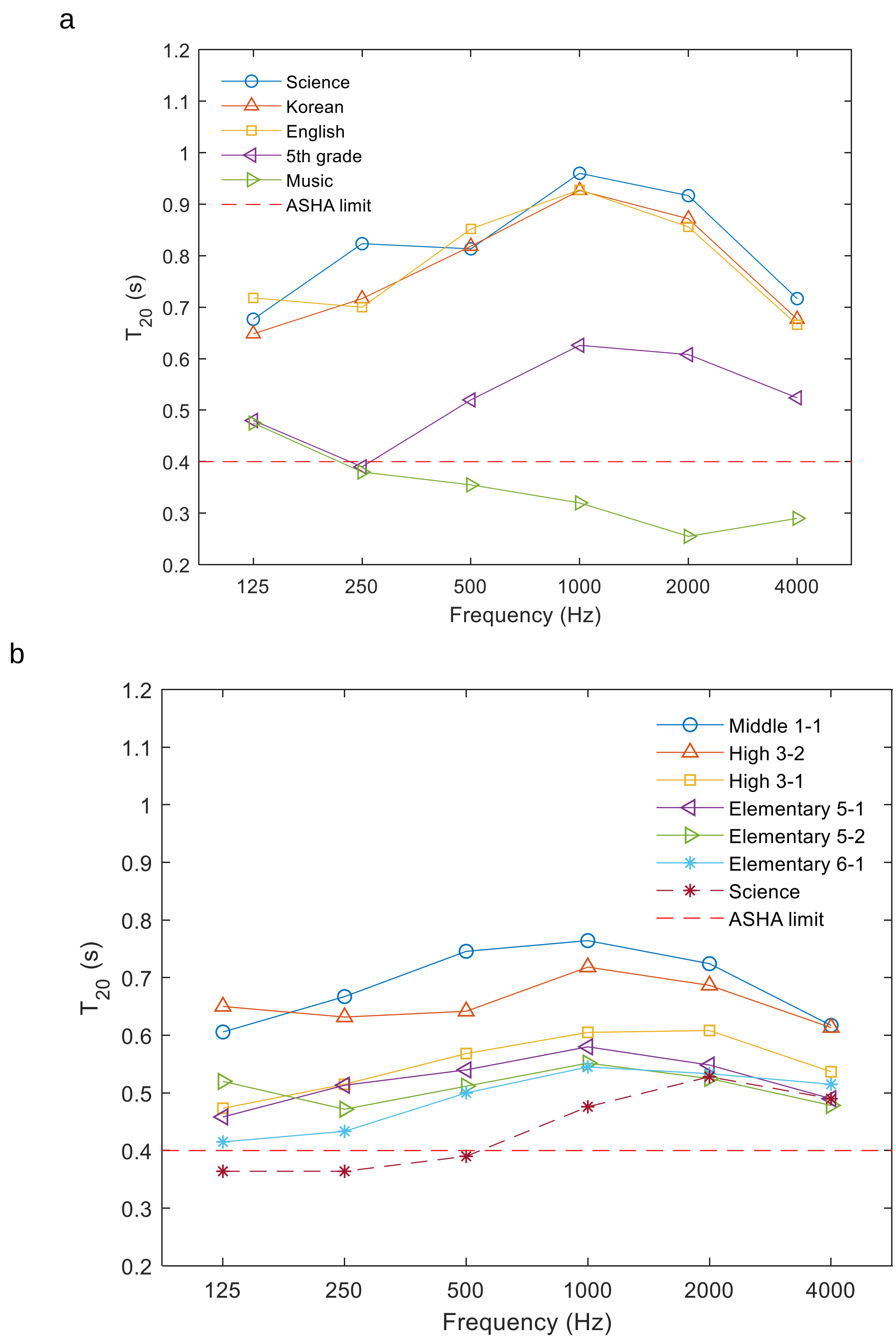

Fig. 4— Reverberation time T_{20} according to frequency: (a) SNSD, (b) SS.

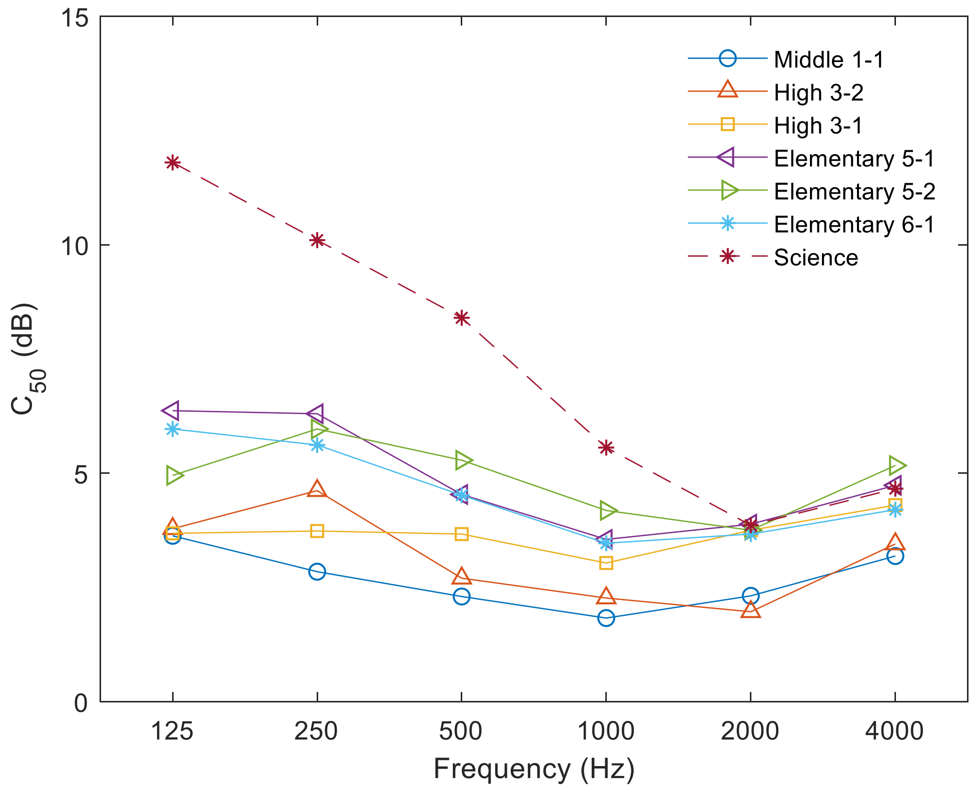

Fig. 5 — Clarity C_{50} according to frequency in SS.

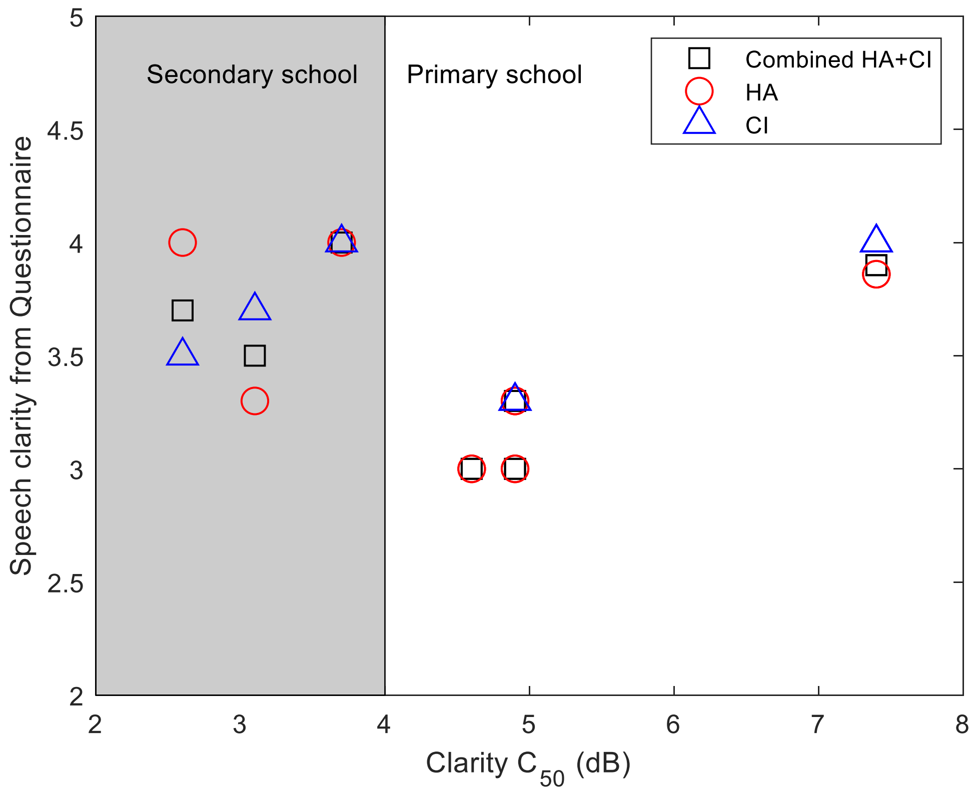

Fig. 6— Subjective speech clarity scores in the classrooms from the questionnaire as a function of C_{50} (HA: Hearing aids, CI: Cochlear implant).

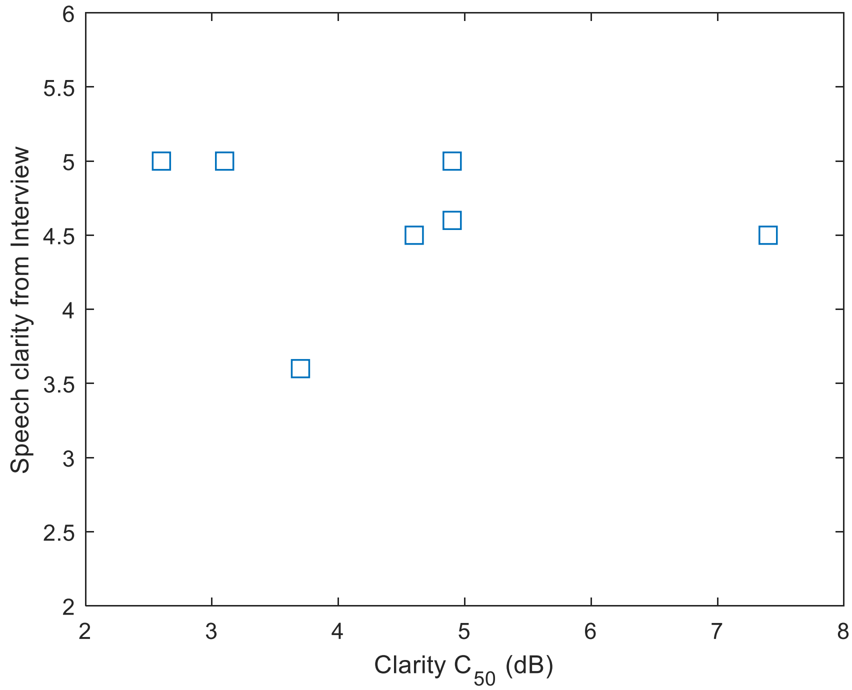

Fig. 7— Subjective speech clarity scores in the classrooms from the interview as a function of C_{50}.

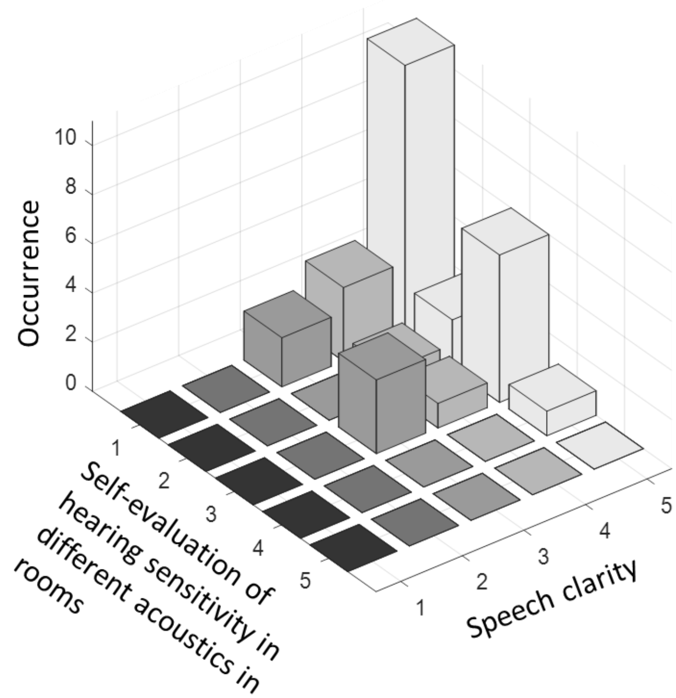

Fig. 8— Counts of subjective speech clarity responses plotted against the self-evaluated sensitivity to acoustic changes and subjective clarity. The self-evaluation scale [5, 4, 3, 2, 1] corresponds to the extent to which an interviewee notices a difference between reverberant and almost anechoic conditions [Always, Frequently, Occasionally, Rarely, Never]).