Effects of acoustical parameters on speech intelligibility for second language students in classrooms

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Abstract

This study addressed the issues of enhancing teaching and learning activities in students' speech intelligibility, which was studied the relationship with acoustical parameters in 20 classrooms in Hong Kong. The speech intelligibility tests in English were conducted with Hong Kong local residential students aged from 12 to 21 in these classrooms. Besides, room acoustic measurements were performed in four listening positions under two different testing conditions in each classroom. The relationships between subjective speech intelligibility scores and acoustical parameters (such as signal-to-noise ratio (SNR), reverberation time (RT), early decay time (EDT), etc.) were discussed based on regression models. The effects of different age groups on the speech intelligibility were compared. The results show that speech intelligibility scores increase with SNR values for all age groups. The speech intelligibility scores increase as the age increases under the same SNR condition. While the differences between ages groups are decreased with the increase of SNR values. The results in this study were compared with the ones conducted in other native language speaking countries. English speech intelligibility scores in Hong Kong are always lower than those native students' speech intelligibility at the same age groups under the same values of SNR. It is mainly because English is not the native language for students in Hong Kong but the official educational language. Better SNR values and better acoustical environment are needed for enhancing teaching and learning activities in classrooms.

Keywords: speech intelligibility; acoustical measurement; acoustical parameters.

1. Introduction

The indoor acoustical environment is related to productivity, health anxiety, comfort, as well as acoustical quality in a space [1-4]. Classrooms as the most essential places in the students' education. Speech intelligibility is a measure of how comprehensible speech is in given conditions. Evidence shows that poor room acoustics, such as excessive noise and reverberation, reduce speech intelligibility in a classroom and interrupt verbal communication between teachers and students [5]. Several studies proposed noise control methods and noise attenuation designs to improve the indoor and outdoor environment acoustical environment [6-11]. Besides, the sound prediction methods in building acoustics were summarized by Mak and Wang [12]. The authors pointed out that prediction methods in room acoustics and air-borne sound, structure-borne sound, and duct-borne sound are essential for assessing the acoustical environment or applying possible noise control measures. Yang and Mak proposed an assessment model for evaluating the acoustical environment according to the noise source position [13]. The room acoustical parameters that affect speech intelligibility include reverberation time (RT or T_{30}), early decay time (EDT), early-to-late sound energy ratio (C_{80}), signal-to-noise ratios (SNRs) and speech transmission index (STI) [14]. The authors reviewed the effects of mentioned acoustical factors on children at school. Recent years, speech intelligibility and its relationship with acoustical parameters in specific linguistic conditions were studied. Peng et al. evaluated in Chinese speech intelligibility in several elementary schools [15-16]. The authors reported the relationships between speech intelligibility and acoustical parameters such as speech transmission index, signal to noise ratio and reverberation time. Astolfi et al. [17] investigated the Italian speech intelligibility scores and its relationship with acoustical parameters among the young generation. In this study, different types of noise were added to the test signals to create different listening conditions.

However, in a modern and globalized world, the interaction between multi-lingual and multicultural people in public, commercial and social spaces is gaining importance, and oral communication is at the center of this interaction [18]. The differences in speech intelligibility among languages have been noticed. Different linguistic environments and different educational modes may lead to different relationships between speech intelligibility and acoustical parameters. Kang [19] compared the differences in intelligibility between English and Mandarin under reverberation conditions and noisy conditions. Other researchers reported the impact of room acoustical conditions on the speech intelligibility of different languages [18, 20]. As for classrooms in Hong Kong, it is special with other classrooms that English as the second language among local citizens is widely used in education. The relationship between speech intelligibility scores and acoustical parameters in second-language classrooms are essential for studying the acoustical environment. Yang and Mak reported an investigation of speech intelligibility scores for second language students in Hong Kong. The authors discussed the effects of speech transmission index on the speech intelligibility [21].

In the current study, speech intelligibility scores in classrooms were assessed by students in a middle school and a university in Hong Kong. The speech intelligibility test signals recorded in the anechoic chamber were reproduced through a loudspeaker with its directivity similar to human's mouth. The aim is to investigate the speech intelligibility scores among students in Hong Kong and compare the relationship between subjective speech intelligibility scores and acoustical parameters to the native language speaking country.

2. Experimental Method

2.1 Classrooms for investigation

In the current study, totally 20 classrooms were selected in a middle school (9 classrooms) and a university (11 classrooms) in Hong Kong as the objectivities. Classrooms in the middle school were not decorated with acoustical treatment (lime walls, cement floors, etc.). By contrast, classrooms in the university were well decorated with acoustical treatment (sound absorptive panels, sound absorptive ceilings, floor isolation mat, etc.). All the classrooms were rectangular in shape and the temperature in Hong Kong during the investigation was around 27 ^{o}C, and the humidity was around 90%. In the investigation of middle school classrooms, 4 of which are Grade C students (aged from 14 to 16), 3 of which are Grade B students (aged from 12 to 14). The other 2 classrooms are Grade A students (aged from 12 to 13). The volumes of the 9 classrooms ranged from 151.81 to 157.84 m^3. While the volumes of selected 11 classrooms in the university ranged from 109.03 to 228.99 m^3. Besides the students in the university classrooms are adults whose ages are all above 18.

Four listening positions were arranged in each classroom, a schematic drawing of a classroom in the middle school was shown as an example in Fig. 1. Other desks and chairs were not shown in the classroom. Speech intelligibility tests were accomplished with junior students in the middle school and undergraduates in the university. The junior students aged from 13 to 15 years old and undergraduates aged from 19 to 21 years old (adults). In the current study, the speech intelligibility test results of junior students and undergraduates were used for discussing the differences between age groups.

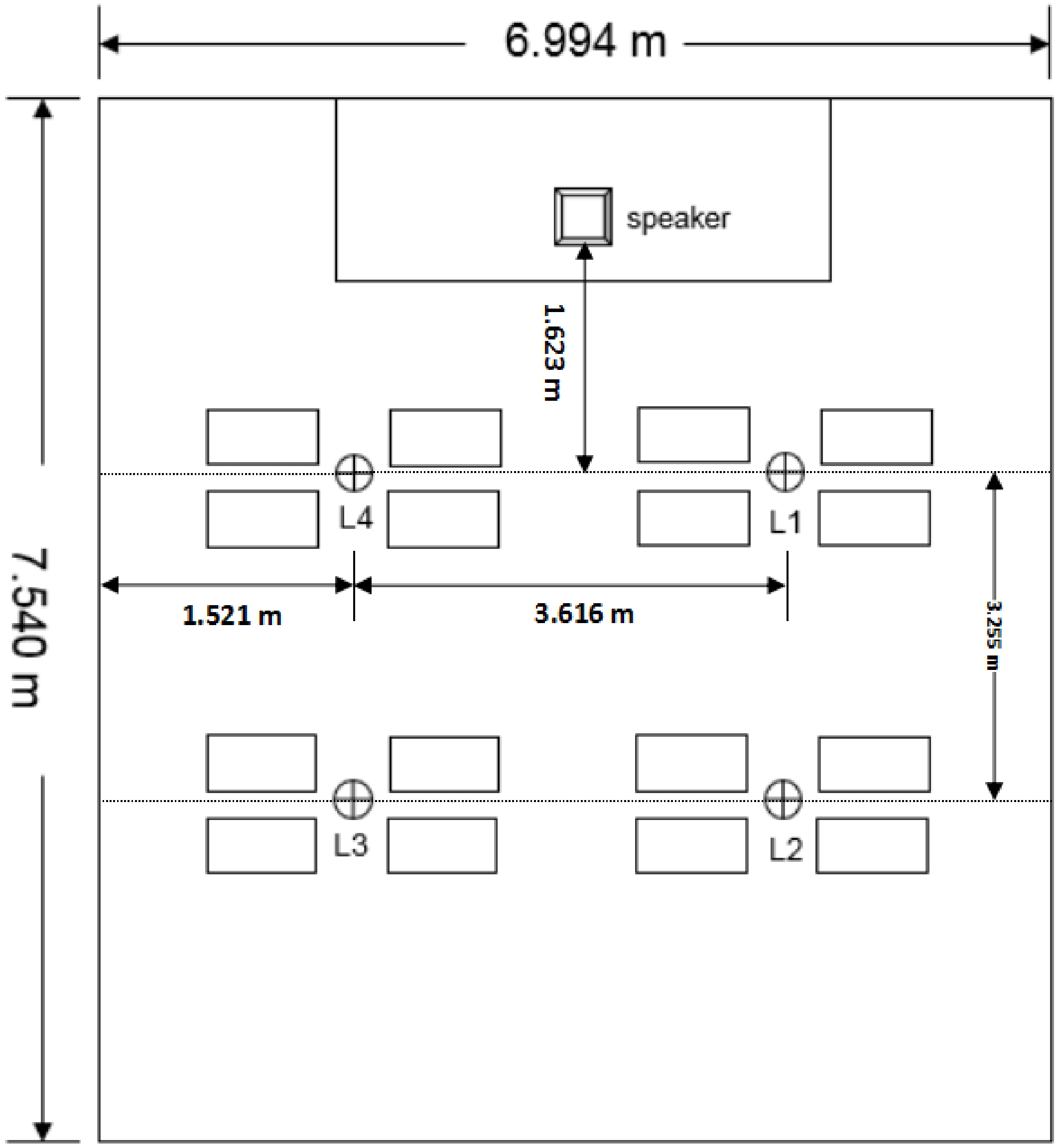

Fig. 1 schematic drawing of classroom 3A and showing of listening positions

2.2 Speech intelligibility test materials

In the current study, the speech intelligibility test word list was based on ANSI S3.2-1989 [24]. Test materials were selected directly to compare the phonetically balanced (PB) word scores. The test signal material which contained 50 six-word rows of similar-sounding English words were used. The test words in the carrier phrase are “The x row reads y,” where x and y are replaced by the number of rows and the pronunciation of the corresponding word. Readers were told to read the materials at a constant speed (4 words per second) and 65 dB sound pressure. One male and one female local residents who are English teachers in middle schools were chosen as readers in the experiment. The whole recording procedure was completed in the anechoic chamber of the Hong Kong Polytechnic University. As shown in Fig.2, a random-field microphone (B&K 4935) was placed at a distance of 0.5m from the speaker and 1.0m above the ground in the anechoic chamber, meanwhile, the speaker sat on the chair and the microphone was placed on the tripod in front of the speaker. The signal was collected from pulse hardware (B&K 3160-B-042) into the computer. All of the children were native Cantonese speakers, and no medical reports of their hearing impairment were reported from them and their parents. They represented the typical general listening audiences.

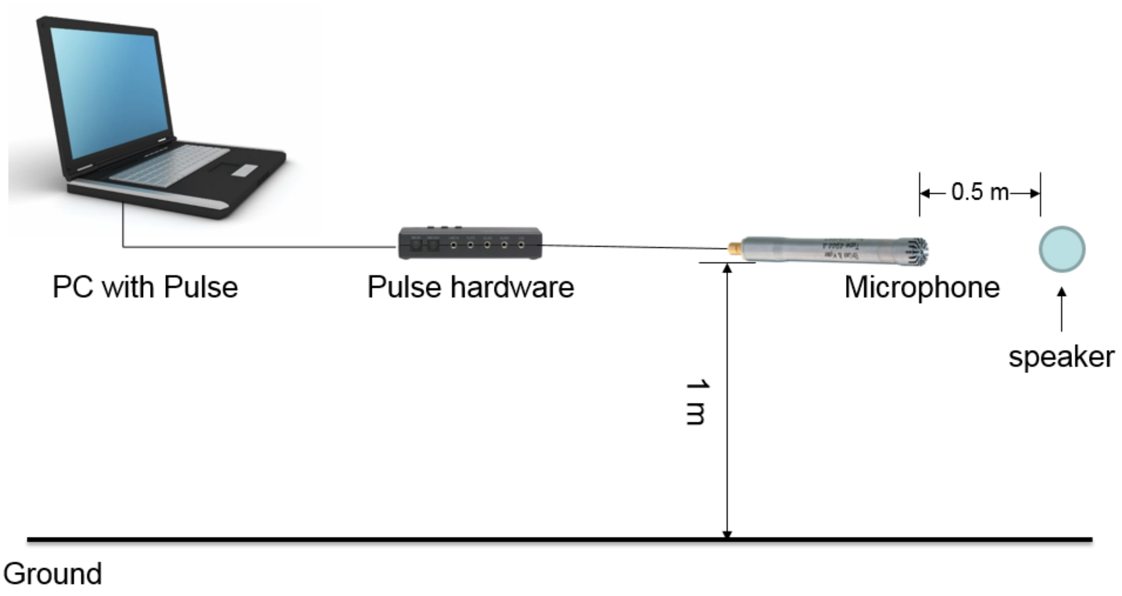

Fig. 2 schematic drawing of recording the test material

2.3 Speech intelligibility tests in the classrooms

The speech intelligibility test signals recorded in the anechoic chamber were reproduced by a loudspeaker which is similar to the human mouth. The loudspeaker was located at the center of the platform where a teacher frequently stands and orients toward the students (location of the loudspeaker see Fig.1). It was set 1.5m above the floor and 0.5m from the blackboard on the front wall. The speech level at 1m directly in front of the loudspeaker was set at 65 dBA by adjusting the volume of the loudspeaker when the subjects seated around the listening positions. Two testing conditions were investigated in the experiment. The first condition was carried out with the mechanical ventilation system being switched off but all the windows and doors being widely open. This case was the most usual operation condition of the classroom in autumn or winter in Hong Kong. The second condition was conducted with all the windows and doors being closed but all mechanical equipment for ventilation being switched on. This was the most usual operation condition of the classroom in spring or summer in Hong Kong. During the test period in middle school, 9 classrooms nearly 300 students participated in the survey. The gender of all children was not taken into account, and the difference in the number of boys and girls was nearly negligible. Besides, approximately 200 undergraduates participants aged from 19 to 21 were conducted in 11 classrooms. As shown in Fig. 1, four listening positions were arranged in each classroom, and four subjects were arranged to seat around each listening position. Therefore, a total of 16 subjects participated in the test in each classroom. For each testing condition, two test word lists (one with a male speaker, the other with a female speaker) were used. All the subjects received a few minutes of instruction prior to the test and were told that they should not communicate with each other while completing the word tests. The subjects were asked to mark the words they heard. The four subjects' English intelligibility scores at each listening position across all eight lists (4 children×2 talkers=8 lists) were calibrated according to ISO/TR 4870 [25], and the averaged speech intelligibility score was obtained for each test condition. The same procedure was completed in university classrooms.

2.4 Acoustical measurements in the classrooms

The classroom impulse responses were measured by using an e-sweep signal generated from the internal DIRAC e-sweep source at the four listening positions with subjects in classrooms after the subjective questionnaire investigation. The e-sweep signal was generated from the same loudspeaker which was placed at the same location as the subjective questionnaire tests. In order to reproduce the signal which is similar to human's mouth, the selected loudspeaker was Echo Speech Sound Source (B&K Type 4720). Acoustical parameters such as reverberation time (T_{30}), early decay time (EDT), and early-to-late sound energy ratio (C_{80}). At the meantime, the background noise level was measured by B&K 2270 sound analyzer for each listening position. Table 1 shows the statistics of acoustical parameters in 20 classrooms. $EDT_{(500-1000Hz)}$,$T30_{(500-1000Hz)}$ and $SNR_{(500-1000Hz)}$ are the average value from 500Hz to 1000Hz octave band for each parameter.

Table. 1

Statistics of acoustical parameters in 20 classrooms

Grade	Parameters	Mean	SD	Min	Max
Grade A ($\mathbf{1}_{st}$condition)	$EDT_{(500-1000Hz)}$/s	1.022	0.29	0.39	1.41
	$T_{30(500-1000Hz)}$/s	0.996	0.27	0.46	1.38
	$SNR_{(500-1000Hz)}$/dBA	18	4.65	12	22
Grade A ($\mathbf{2}_{nd}$condition)	$EDT_{(500-1000Hz)}$/s	0.833	0.28	0.41	1.35
	$T_{30(500-1000Hz)}$/s	0.852	0.26	0.45	1.38
	$SNR_{(500-1000Hz)}$/dBA	15	6.23	6	29
Grade B ($\mathbf{1}_{st}$condition)	$EDT_{(500-1000Hz)}$/s	1.138	0.26	0.36	1.39
	$T_{30(500-1000Hz)}$/s	1.167	0.24	0.42	1.40
	$SNR_{(500-1000Hz)}$/dBA	22	3.28	18	31
Grade B ($\mathbf{2}_{nd}$condition)	$EDT_{(500-1000Hz)}$/s	0.926	0.31	0.45	1.28
	$T_{30(500-1000Hz)}$/s	0.945	0.25	0.42	1.22
	$SNR_{(500-1000Hz)}$/dBA	19	6.08	8	32
Grade C ($\mathbf{1}_{st}$condition)	$EDT_{(500-1000Hz)}$/s	1.187	0.29	0.44	1.35
	$T_{30(500-1000Hz)}$/s	1.196	0.29	0.46	1.36
	$SNR_{(500-1000Hz)}$/dBA	20	4.69	11	29
Grade C ($\mathbf{2}_{nd}$condition)	$EDT_{(500-1000Hz)}$/s	0.956	0.31	0.42	1.38
	$T_{30(500-1000Hz)}$/s	0.979	0.28	0.46	1.32

	$\mathrm{SNR}_{(500-1000Hz)}$/dBA	17	5.66	11	31
Adults ($\mathbf{1}_{st}$condition)	$\mathrm{EDT}_{(500-1000\mathrm{Hz})}$/s	0.353	0.18	0.32	0.54
	$\mathrm{T}_{30(500-1000\mathrm{Hz})}$/s	0.405	0.16	0.36	0.53
	$\mathrm{SNR}_{(500-1000Hz)}$/dBA	28	2.02	26	30
Adults ($\mathbf{2}_{nd}$condition)	$\mathrm{EDT}_{(500-1000\mathrm{Hz})}$/s	0.327	0.15	0.28	0.52
	$\mathrm{T}_{30(500-1000\mathrm{Hz})}$/s	0.365	0.18	0.29	0.55
	$\mathrm{SNR}_{(500-1000Hz)}$/dBA	26	2.88	18	32

3. Results

3.1 Regression model

The relationship between speech intelligibility scores and acoustical parameters was the main focus studied by researchers. Bradley [26-27] proposed a third-order polynomial equation to simply the speech intelligibility scores with the A-weighted speech–noise level (S/N(A)) and the useful-to-detrimental sound ratio (U_{80}). The authors presented a regression equation that expressed (Equation 1) the speech intelligibility as functions of the A-weighted SNR and RT.

$$SI = 95.0 + 2.26SNR - 0.0888SNR^2 - 13.9RT \qquad (1)$$

Yang and Mak [21] presented an "S" form model described the relationship between speech intelligibility and speech transmission index which expressed as Equation 2.

$$SI = 100(1 - 10^{-\frac{STI}{0.5515}})^{2.5354} \qquad (2)$$

In the current study, the “S” form model was selected to simplify the relationship between speech intelligibility score and SNR in classrooms in Hong Kong. The normal “S” form equation is:

$$SI = 100(1 - 10^{-\frac{SNR}{a}})^b$$

3.2 Relationship between speech intelligibility scores and SNR

Fig.3 shows the speech intelligibility scores obtained from students in grade A in middle school (aged from 12 to 13) are plotted against the SNR values from different listening positions. The line shown in the figure is the result of the “S” form model equation based on the non-linear least square fitting method. The regression parameters, standard deviation and correlation coefficient are shown in Table 2. The value of R^2 refers to the high correlation between speech intelligibility scores and SNR value.

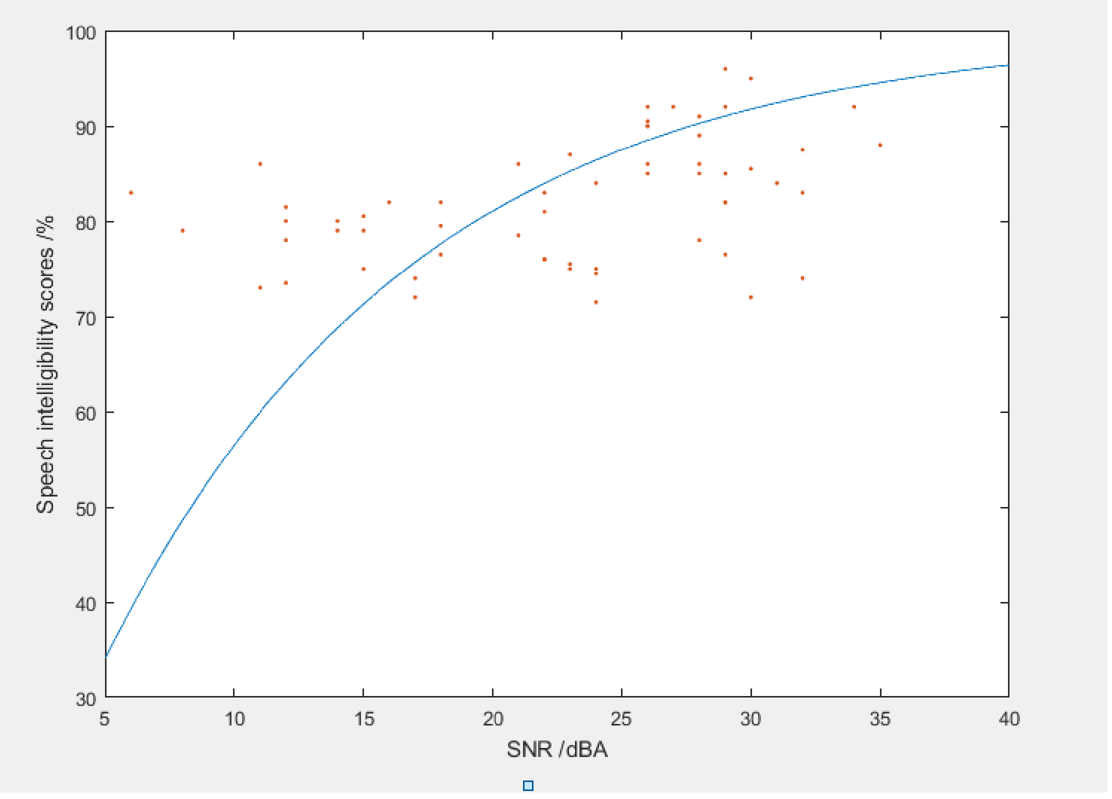

Fig. 3 The relationship between speech intelligibility scores and SNR values for grade A students.

Table. 2 Results of each variable in the regression models.

Variables	$\boldsymbol{a}$	$\boldsymbol{b}$	$\boldsymbol{R}$	$\boldsymbol{SD}$	$\boldsymbol{R^2}$
Values	22.6	0.82	0.862	7.05	0.743

As shown in Figure 3, the speech intelligibility scores increase with an increase in SNR. The relationship of the speech intelligibility scores and SNR values were analysed the effect of RT in classrooms. The SNR values were the major determinant of intelligibility scores, RT had a significant effect because the intelligibility scores were shown to increase with a reduction in RT. To investigate the combined effects of SNR and RT on intelligibility scores, multiple nonlinear regression ('S' form curve for SNR) analyses were performed with SNR and RT being the independent variables. The regression equation is shown as follows:

$$SI = 113.6(1 - 10^{-\frac{SNR}{22.6}})^{0.82} - 12.2RT$$

4. Discussion

4.1 The effects of different age groups

Younger children were proved to have greater difficulty in understanding speech and require less noisy acoustical conditions [22]. To compare speech intelligibility scores under the same SNR value for different age groups. Fig. 4 shows the best-fit curves between speech intelligibility scores and SNR value for different age groups under the first testing condition. Grade A, B, and C are three different grades in the middle school investigated in the study. Students from grade A, B and C aged normally 13, 14 and 15 respectively. The undergraduates' curves represent the participants from university aged from 19 to 21 (adults). All the best-fit curves were used “S” form-fitting model curves. The speech intelligibility scores increase as the age increases under the same SNR condition. With the increase of the SNR value, the gap between each curve narrowed, which indicates the differences between age groups decreased. This finding indicates that students have greater difficulty in understanding speech in noisy acoustical conditions. The differences between grade A and B are greater than that in grade B and C curves. This finding indicates that the younger students were more affected by the acoustical environment. In most cases shown in Table 1, the reverberation is longer in a lower SNR condition. Masking by reverberation reduces the amount of acoustical information available to students. Children are less flexible in their auditory sensitivity and their ability to separate sounds even under quite complex listening condition [27].

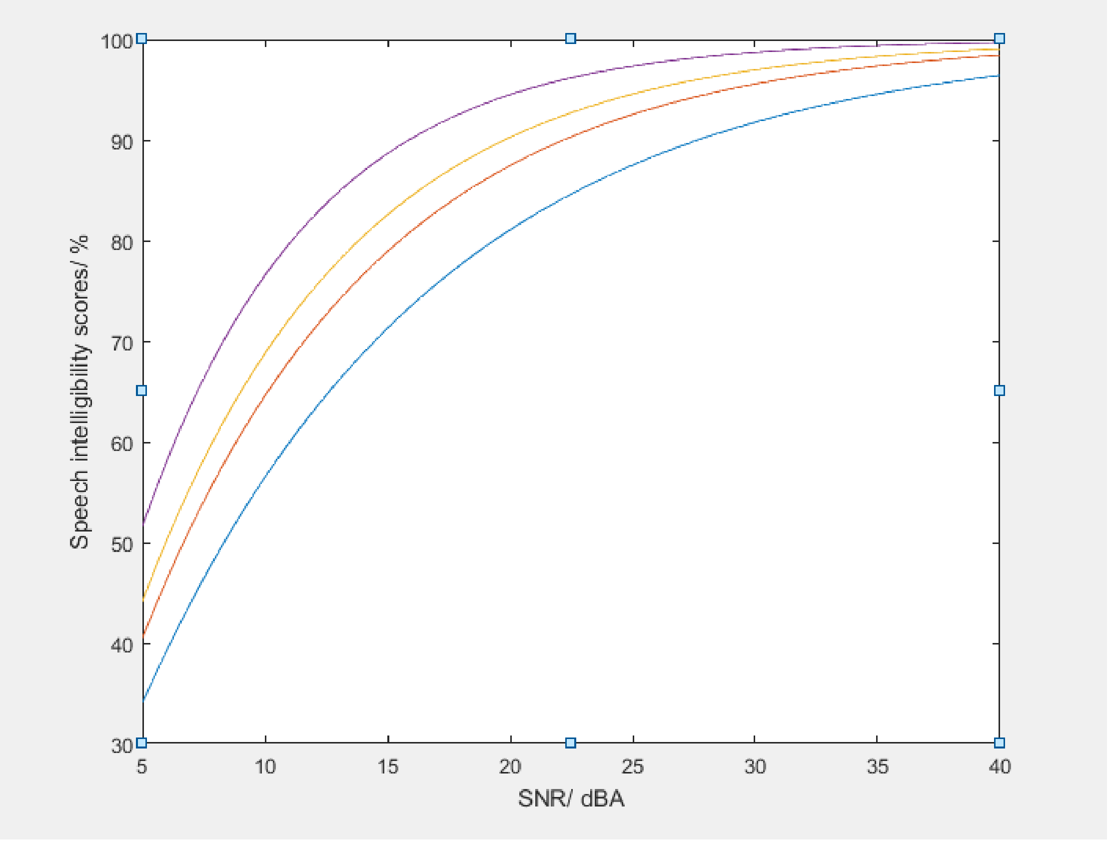

Fig.4 Relationships between speech intelligibility and SNR values for different age groups.

4.2 Comparison with other studies

The relationships between acoustical parameters and speech intelligibility scores cannot be directly compared because different acoustical objective parameters to evaluate speech intelligibility in rooms. Therefore, different relationships between speech intelligibility scores and SNR values under different language conditions were compared. As shown in Fig. 5, the fitting curves between two indices obtained by Peng et al were compared. Peng et al. [16] used Chinese rhyme test word lists which is similar to the modified rhyme test of English to obtain the relationship between the two indices.

9 primary schools and 27 classrooms were investigated. The best-fit curve between speech intelligibility scores and SNR for grade 6 was simulated by an “S” form curve.

In order to avoid the influence of age groups, students from grade A (aged 12-13) were selected to compare with the other study. Both two testing conditions were not mentioned in these two studies, the first condition was assumed to choose for comparison with other studies.

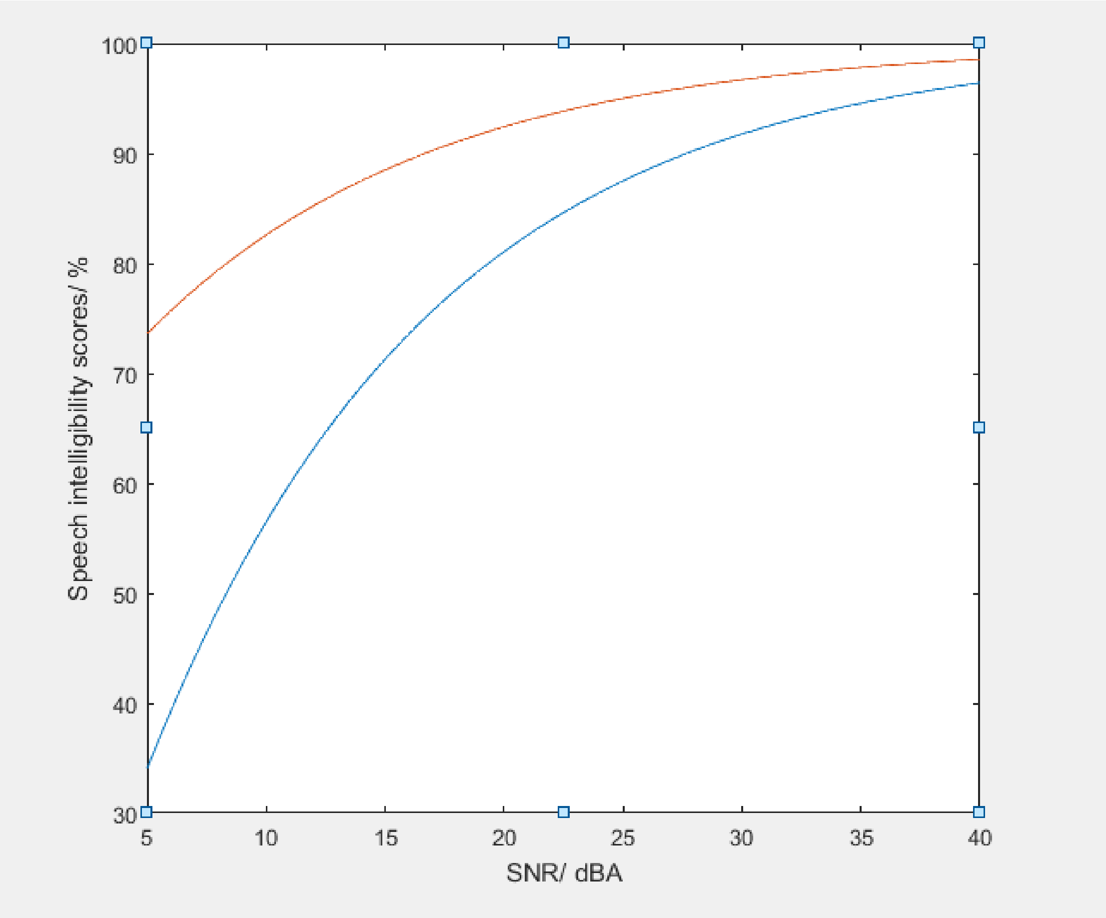

Figure. 5 Comparison of the regression curves between speech intelligibility scores and SNR values with other studies

It can be seen in Fig. 5 that all these three curves indicate speech intelligibility scores increase with SNR values. As for English curve in Hong Kong, it can be seen in Fig. 3 that English speech intelligibility scores in Hong Kong are always lower than the other case under the same values of SNR. This means that better SNR values and better acoustical environment are needed in Hong Kong to obtain high speech intelligibility scores. This may be an explanation of the fact that English is not the native language for students in Hong Kong but the official educational language. In addition, the reverberation time measured from middle school classrooms (shown in Table. 1) was almost higher than that in Chinese classrooms. All these factors will influence the lower English speech intelligibility scores obtained in Hong Kong classrooms.

5. Conclusion

This study investigated speech intelligibility in middle school and university classrooms. Speech intelligibility tests were conducted in 9 middle school and 11 university classrooms and the acoustical measurements were performed in these classrooms. Subjective speech intelligibility tests were obtained from PB word lists and SNR values were conducted in different listening positions and testing conditions in each classroom. The regression model was fitted based on non-linear least square fitting method. The effects of different age groups on the speech intelligibility and findings from different studies were also discussed.

Speech intelligibility scores increase with the increase of SNR value for all the age groups. The speech intelligibility scores increase as age increases under the same SNR condition. The differences between age groups are decreased with the increase of SNR values. Speech intelligibility scores in Hong Kong are always lower than those in China, under the same values of SNR. Better SNR values and better acoustical environment are needed because English is not the native language for students in Hong Kong but the official educational language.

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