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An investigation of speech intelligibility for second language students in classrooms

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Abstract

In this paper, speech intelligibility in 9 classrooms of a middle school and 11 classrooms of a university in Hong Kong was investigated. The subjective speech intelligibility tests were conducted with students aged from 12 to 21 in these classrooms. Besides, objective acoustical measurements were performed in each listening position and testing conditions in each classroom. The relationship between subjective speech intelligibility scores and speech transmission index (STI) was 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 STI value for all age groups. The speech intelligibility scores increase as the age increases under the same STI condition. The differences between age groups are decreased with the increase of STI values. English speech intelligibility scores in Hong Kong are always lower compared with native language researches under the same values of STI. Better STI values and better acoustical environment are needed because English is not the native language for students in Hong Kong but the official educational language.

Keywords: speech intelligibility; acoustical measurement; STI.

1. Introduction

The indoor acoustical environment is not only related to productivity, health anxiety and comfort, but also is related to acoustical quality in a space [1-4]. The education of every citizen is essential to modern societies. Most formal education takes place in the classrooms, where a high level of acoustical quality is required [5]. 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 [6]. The room acoustical factors 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) [7]. Bradley [8] first indicated that SNR was an essential factor compared with RT. Moreover, STI method was based on the assumption that the degradation of speech intelligibility in rooms was related to the reductions in the amplitude modulations of speech signals by both room acoustics and ambient noise [9-10]. The STI method is a combination of both room acoustics and signal-to-noise component into objective measure of speech intelligibility in rooms. The STI method was shown to be successful by Peng in evaluating in Chinese speech intelligibility of an elementary school [11-12].

Several studies were devoted to the study of the speech intelligibility in classrooms. Some researchers conducted a series of speech intelligibility tests in classrooms for teachers and children aged 8 to 15 years old under a variety of road traffic noise condition with RT from 0.7s to 1.5s [13]. Bradley and his co-workers [8, 14-15] investigated speech intelligibility using the English Fairbank rhyme test in occupied classrooms with RT from 0.39s to 1.20s for children aged 12 to 13 years old through a small loudspeaker with its directivity similar to human's mouth. Peng and his co-workers [16-17] have investigated acoustical parameters (e.g. RT, SPL, STI, etc.) in the elementary classrooms and discussed the relationship between Chinese speech intelligibility and the acoustical parameters. The results indicated a high correlation between Chinese speech intelligibility and these acoustical parameters.

However, in a modern and globalized world, the interaction between multilingual 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 intelligibility among languages have been noticed. Houtgast and Steeneken [9] indicated that language specification effects could be a factor causing disparity among 10 Western language tests. 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 STI in second-language classrooms through in situ measurement for young listeners has not been reported so far.

In the current study, speech intelligibility in classrooms was assessed by students in a middle school and a university. 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 this study, 9 classrooms in a middle school and 11 classrooms in a university in Hong Kong were investigated. Classrooms in the middle school were not decorated with acoustical treatment (lime walls, cement floors, etc.). 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%. The dimensions of the classrooms are shown in Table 1. Classrooms 3A, 3B, 3C and 3D refer to Grade C (aged from 14 to 16). Classrooms 2A, 2C, and 2D refer to Grade B (aged from 12 to 14). Classrooms 1C and 1D refer to Grade A (aged from 12 to 13) in the middle school.

Table 1
The dimensions of all the classrooms

School	Classroom	Length*Width/ m^2	Height/m	Volume/m^3
Middle School	3C	6.981*7.535	2.983	156.91
	3B	6.965*7.549	2.962	155.73
	3A	6.994*7.540	2.993	157.84
	3D	6.968*7.513	2.963	155.11
	2A	6.796*7.496	2.980	151.81
	2C	6.953*7.523	2.975	155.61
	2D	6.966*7.529	2.944	154.40

	1C	6.968*7.567	2.944	155.23
	1D	6.959*7.529	2.991	156.71
University	A	10.988*8.224	2.534	228.99
	B	8.906*5.846	3.087	160.72
	C	8.836*8.335	2.458	181.03
	D	8.168*5.541	2.409	109.03
	E	8.259*6.022	2.524	125.53
	F	8.868*5.245	2.502	116.37
	G	9.845*7.202	2.991	212.07
	H	8.156*5.625	2.423	111.16
	I	8.298*5.864	2.465	119.95
	J	8.956*8.265	2.564	198.06
	K	8.532*6.658	2.523	143.32

Four listening positions were arranged in each classroom, a schematic drawing of classroom 3A 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 middle school and undergraduates in university. The junior students aged from 13 to 15 years old and undergraduates aged from 19 to 21 years old (adults). Referring to the previous studies, the ages of participants had a significant influence on the performance of the speech intelligibility tests [21-23]. Elliott [21] reported the performance of children aged under 15 years old performed significantly poorer than adults. In the current study, the speech intelligibility test results of junior students and undergraduates were used for discussing the differences between age groups.

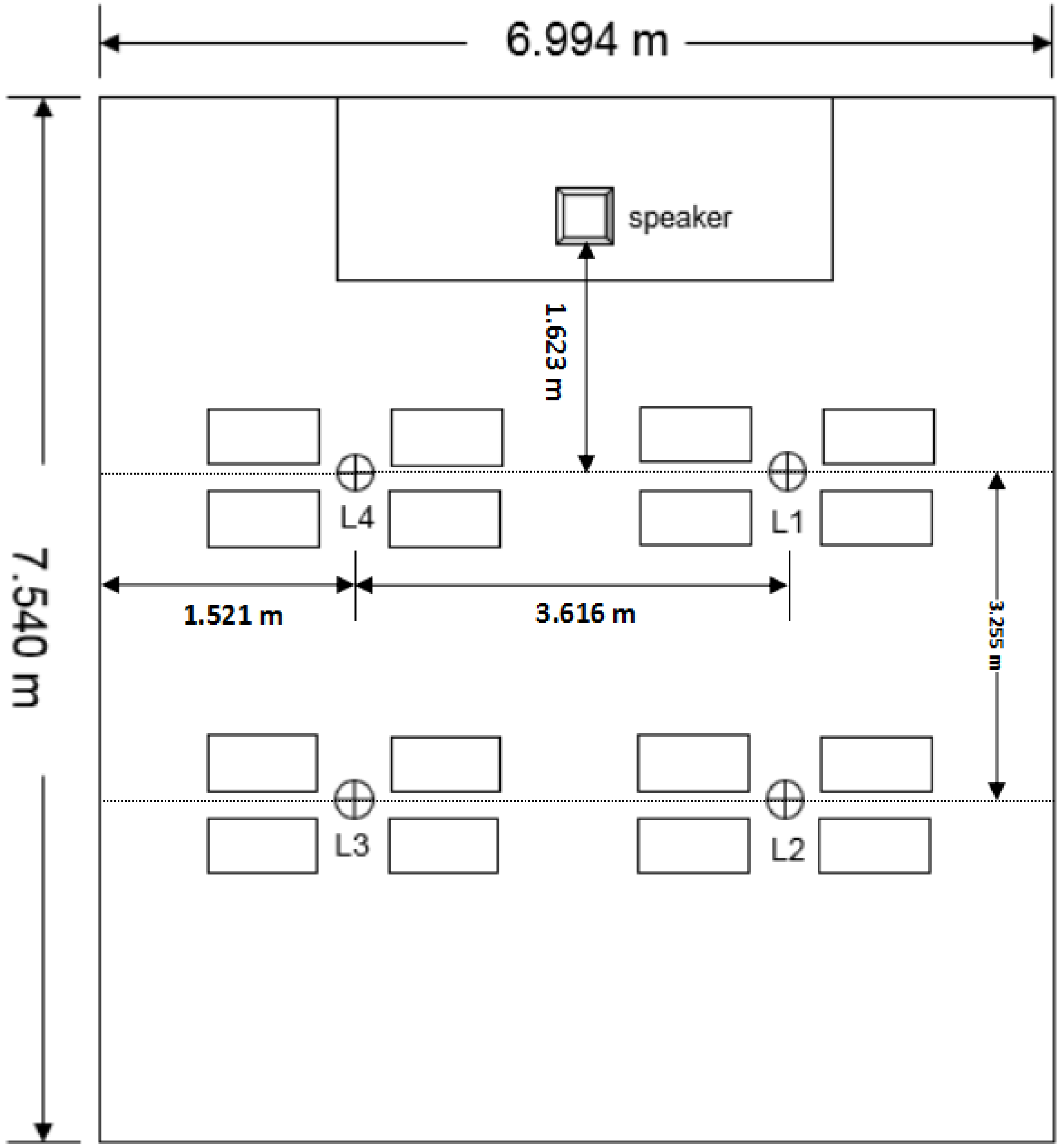

Fig. 1 schematic drawing of classroom 3A and showing of listening positions

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 row 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.

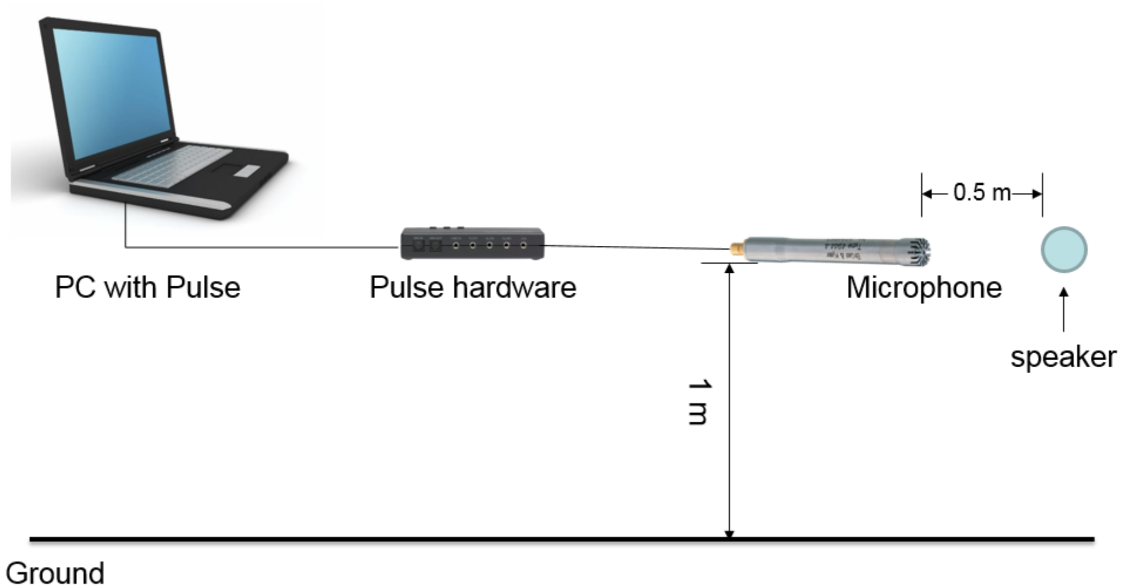

Fig. 2 schematic drawing of recording the test material

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 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. Students come from Grade A (class 1C and 1D, aged from 12 to 13), Grade B (Class 2A, 2C, and 2D, aged from 12-14), Grade C (3A, 3B, 3C, and 3D, aged from 14-16). 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 ISO/TR 4870 [25], and the averaged speech intelligibility score was obtained for each test condition. The same procedure was completed in the university classrooms.

2.4 Acoustical measurements in the classrooms

The classroom impulse responses were measured by using an e-sweep signal generated from 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. Acoustical parameters such as reverberation time (T_{30}), early decay time (EDT), speech transmission index (STI) 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 2 shows the statistics of acoustical parameters in 20 classrooms. $EDT_{(500-1000Hz)}$, $T_{30(500-1000Hz)}$ and $C_{80(500-1000Hz)}$ is the average value from 500Hz to 1000Hz octave band for each parameter.

Table. 2
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
	$C_{80(500-1000Hz)}$/dB	3.318	2.65	-0.56	6.86
	STI/-	0.572	0.06	0.53	0.67
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
	$C_{80(500-1000Hz)}$/dB	4.251	2.85	-0.21	9.21
	STI/-	0.645	0.07	0.59	0.75
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
	$C_{80(500-1000Hz)}$/dB	2.717	2.22	-0.68	7.21
	STI/-	0.577	0.07	0.48	0.71
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
	$C_{80(500-1000Hz)}$/dB	3.825	2.54	-0.98	8.68
	STI/-	0.617	0.08	0.51	0.75
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
	$C_{80(500-1000Hz)}$/dB	2.613	1.96	-0.18	5.88

	STI/-	0.568	0.08	0.46	0.69
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
	$C_{80(500-1000Hz)}$/dB	3.664	2.14	-0.48	7.98
	STI/-	0.634	0.09	0.51	0.79
Adults ($\mathbf{1}_{st}$condition)	$EDT_{(500-1000Hz)}$/s	0.353	0.18	0.32	0.54
	$T_{30(500-1000Hz)}$/s	0.405	0.16	0.36	0.53
	$C_{80(500-1000Hz)}$/dB	9.131	2.28	0.96	12.81
	STI/-	0.813	0.06	0.73	0.90
Adults ($\mathbf{2}_{nd}$condition)	$EDT_{(500-1000Hz)}$/s	0.327	0.15	0.28	0.52
	$T_{30(500-1000Hz)}$/s	0.365	0.18	0.29	0.55
	$C_{80(500-1000Hz)}$/dB	9.826	2.92	1.81	13.96
	STI/-	0.873	0.05	0.78	0.93

3. Results

3.1 Regression model

The relationship between speech intelligibility scores and acoustical parameters was the main focus studied by researchers. Bradley [14-15] proposed a third-order polynomial equation to simply the speech intelligibility scores with the A-weighted speech–noise level (S/N(A)) and useful-to-detrimental sound ratio (U_{80}). The normal third-order polynomial equation is:

$$\mathrm{SI} = \mathrm{a} + \mathrm{bSTI} - \mathrm{cSTI}^2 + a\mathrm{STI}^3 \quad (1)$$

A logarithmic model was used to simulate the relationship between the speech intelligibility scores and STI in investigations in Italy primary school [26].

The normal logarithmic equation is:

$$\mathrm{SI} = \mathrm{a} - \mathrm{bln}(\mathrm{STI} + \mathrm{c}) \quad (2)$$

Peng and his co-workers [11] discussed that the “S” form model was more suitable in comparison of Chinese speech intelligibility with the STI.

The normal “S” form equation is:

$$\mathrm{SI} = 100(1 - 10^{-\frac{STI}{a}})^{b} \quad (3)$$

According to Equations (1), (2), speech intelligibility score may be more than 100% with the value of STI increased to a certain value. This case would not occur in the model of “S” form fitting equation. Therefore, the “S” form model was selected to simplify the relationship between speech intelligibility score and STI in classrooms in Hong Kong.

3.2 Relationship between speech intelligibility scores and STI

Fig. 3 shows the speech intelligibility scores obtained from students in grade A in middle school (aged from 12 to 13) under two testing conditions which are plotted against the STI value from different listening positions. The first condition was carried out with the mechanical ventilation system being switched off but all the windows and doors being widely open. The second condition was conducted with all the windows and doors being closed but all mechanical equipment for ventilation being switched on. The lines shown in the figure is the result of “S” form model equation based on non-linear least square fitting method. The regression parameters, standard deviation and correlation coefficient are shown in Table 3. The value of R^2 refers to high correlation between speech intelligibility scores and STI value. The STI can explain 80.5% and 84.3% the variance of speech intelligibility scores under two testing conditions in classrooms respectively.

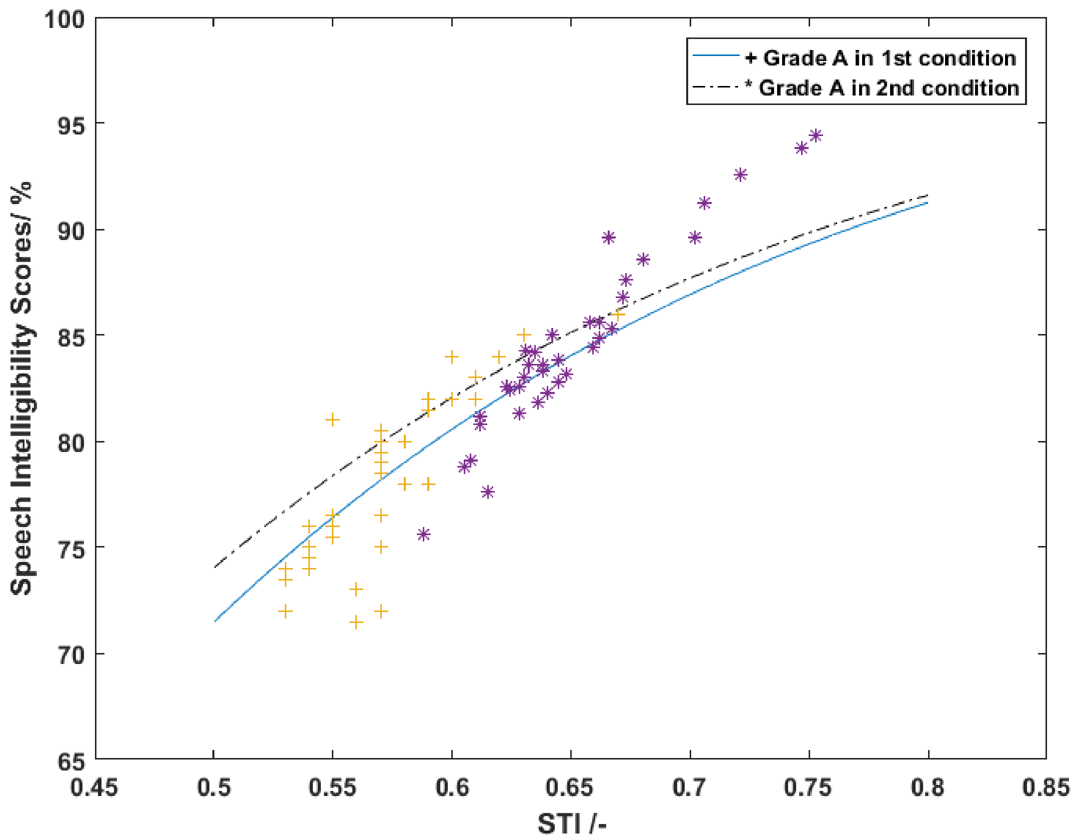

Fig. 3 The relationship between speech intelligibility scores and STI for grade A students.

Fig. 3 shows the regression results based on non-linear least square fitting method which were completed with MATLAB. The standard deviation (SD) and coefficient of determination R^2 were calculated to account for independent variables.

Table 3 shows that the values of variables, standard deviation (SD) and coefficient of determination R^2. The value of R^2 refers to the independent variables in the regression analysis.

Table 3

Results of each variable in the regression models.

Variables	*a*	*b*	*R*	*SD*	R^2
Values in 1st condition	0.5515	2.5354	0.897	6.02	0.805
Values in 2nd condition	0.5861	1.9892	0.918	6.52	0.843

4. Discussion

4.1 Comparison with results under two testing conditions

Referring to the two testing conditions mentioned, the first condition was the most usual operation condition of the classrooms in autumn or winter in Hong Kong. The second condition was the most usual operation condition of the classrooms in spring or summer in Hong Kong. However, these two conditions have different influences on speech intelligibility in classroom education. Fig. 3 shows the best-fit curves between speech intelligibility scores and STI value for Grade A students under both two testing conditions. Both the best-fit curves were used "S" form-fitting model curves. The speech intelligibility scores increase as the STI increases under each testing condition. Moreover, under the same STI value, speech intelligibility scores in the second test condition are always higher than those in the first test condition based on the fitted curves. Besides, the second test condition i.e. closing all windows and switching on ventilation systems can achieve higher STI values and the corresponding speech intelligibility scores in classrooms. This means that mechanical ventilation system may have lower influence on speech intelligibility than road traffic noise. This may be an explanation of the fact that most schools in Hong Kong have been badly affected by noise from road traffic. A school insulation programme to redress the noise problem for a quieter learning environment for students was implemented by the Hong Kong Environment Protection Department (EPD) in 1999 [29]. The programme proposed several stages to insulate road traffic noise. To et al [4] investigated road traffic noise levels compared with the Acceptable Noise Levels (ANLs) in the whole day in Hong Kong. They proposed that most daytime hourly outdoor noise levels and all the nighttime hourly outdoor noise levels were at or above ANLs. Therefore, closing windows is an effective mode for insulating heavy road traffic noise in Hong Kong.

4.2 The effects of different age groups

Referring to previous researches, younger children always have greater difficulty in understanding speech and require less noisy acoustical conditions [21]. To compare speech intelligibility scores under the same STI value for different age groups. Fig. 4 shows the best-fit curves between speech intelligibility scores and STI 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 STI condition. With the increase of the STI 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 acoustical environment. In most cases shown in Table 2, the reverberation is longer in a lower STI 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].

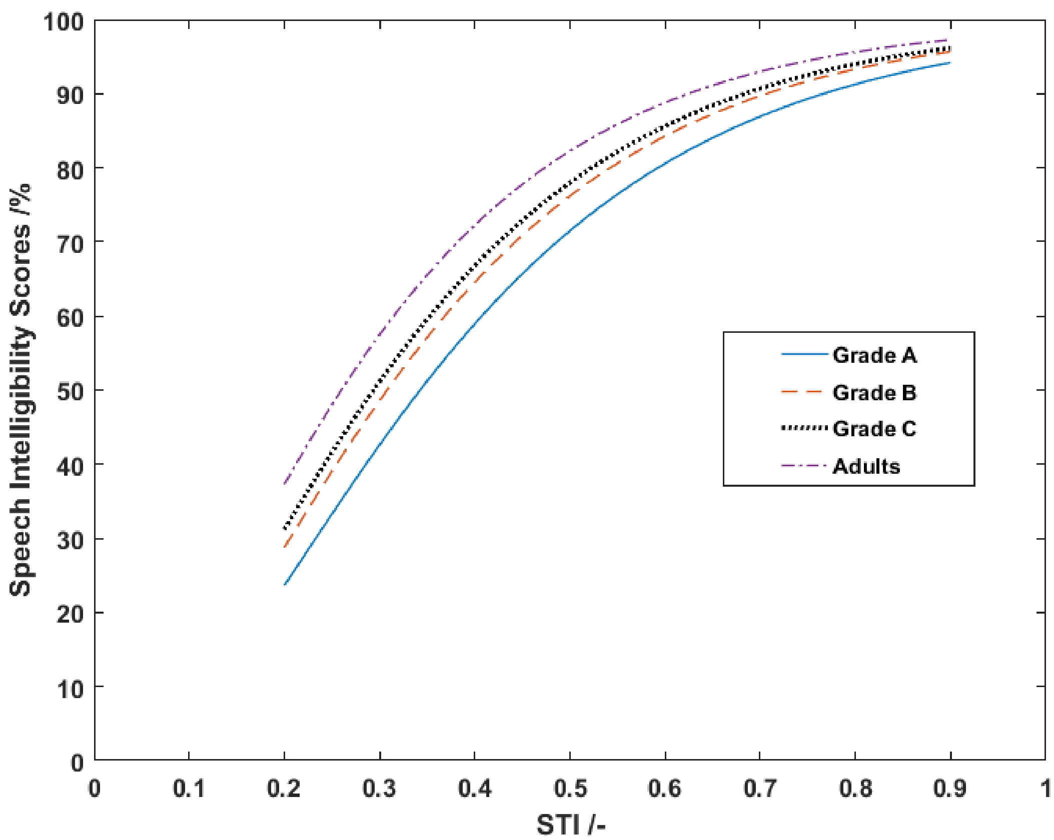

Fig.4 Relationships between speech intelligibility and STI for different age groups under the first condition.

4.3 Comparison with other studies

Speech intelligibility scores for students were investigated to relate to S/N(A), sound pressure level (SPL), speech intelligibility metric U_{50} in previous researches[8, 16, 28]. The relationships between these parameters and speech intelligibility scores cannot directly compared because STI and other indices are different acoustical objective parameters to evaluate speech intelligibility in rooms. Therefore, different relationships between speech intelligibility scores and STI under different language condition were compared. As shown in Fig. 5, the fitting curves between two indices obtained by Astolfi et al and Peng et al were compared [26, 17]. Astolfi et al. [26] used a diagnostic rhyme test to investigate the Italian speech intelligibility scores and different types of noise were added to the test signals to create different listening conditions. The best-fit curve between two indices for grade 3-5 elementary students was described by a logarithmic curve.

Peng et al. [17] 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 STI 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 other two studies. Both two testing conditions were not mentioned in these two studies, the first condition was assumed to choose for comparison with other studies.

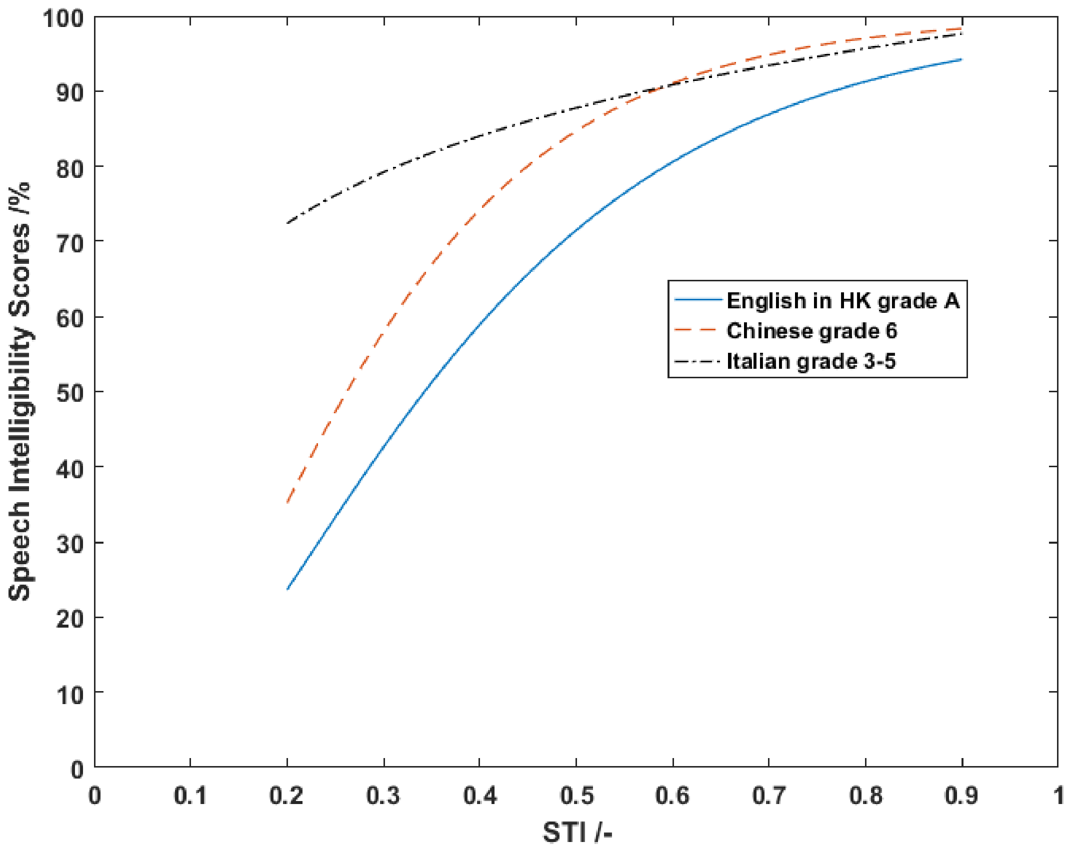

Figure. 5 Comparison of the regression curves between speech intelligibility scores and STI values with other studies

It can be seen in Fig. 5 that all these three curves indicate speech intelligibility scores increase with STI value. As for English curve in Hong Kong, it can be seen in Fig. 5 that English speech intelligibility scores in Hong Kong are always lower than another two cases under the same values of STI. This means that better STI 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. 2) was almost higher than that in Chinese and Italian 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 STI 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 STI value for all the age groups. The speech intelligibility scores increase as age increases under the same STI condition. The differences between age groups are decreased with the increase of STI values. Speech intelligibility scores in Hong Kong are always lower than another two cases, in Italy and China, under the same values of STI. Better STI 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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